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FRANKFORD ARSENAL

REPORT NO. R-915

ACCEPTANCE TESTS

BY

R. J. Emrich, Lehigh University

PROJECT TA1-5002

PITMAN-DUNN LABORATORIES GROUP
FRANKFORD ARSENAL
Philadelphia, Pa.

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REPORT R-915

ACCEPTANCE TESTS

Project TA1-5002

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FOREWORD

Chapter 15 is one of fifteen that comprise the literature survey on armor-piercing steel projectiles. Under the general editorship of C. W. Curtis, the survey has been prepared in part by personnel of the Lehigh University Institute of Research and in part by personnel of Frankford Arsenal. This chapter was written by personnel of Lehigh University and revised by personnel of Frankford Arsenal.

Chapters published are as follows.

Chapter 1, Frankford Arsenal Report R-901, Feb 1951 (Secret) "The Problem of Armor Piercing Projectile Design: Its Principal Divisions and Important Phases," by C. W. Curtis

Chapter 2, Frankford Arsenal Report R-902, Feb 1951 (Secret) "Mechanism of Armor Penetration," by R. B. Sawyer

Chapter 3, Frankford Arsenal Report R-903, Feb 1951 (Secret) "Perforation Limits for Nondeforming Projectiles," by C. W. Curtis

Chapter 7, Frankford Arsenal Report R-907, May 1952 (Secret) "Mechanism of Cap," by R. J. Emrich and F. E. Myers

Chapter 11, Frankford Arsenal Report R-911, Aug 1952 (Confidential) "Control of Metallurgical Properties," by J. H. Gross

Chapter 15 - Acceptance Tests

Chapter 15. Acceptance Tests

Before armor plates and projectiles are accepted for service use, samples are customarily subjected to tests designed either to measure ballistic quality or to assure that this quality exceeds minimum requirements. In addition to specifications of ballistic quality there also may be requirements on weldability, machineability, formability, magnetic properties, banding, marking, packing, etc. The present chapter is not concerned with these latter requirements, however, but deals only with tests related to ballistic performance.

Ideally, tests for quality would be carried out by machines which separate satisfactory from unsatisfactory pieces at various stages of manufacture.[1] At present, however, automatic inspection represents a goal rather than an achievement. Although there has been considerable progress in the development of nonballistic tests and such tests are often used for special purposes or to obtain supplementary information, the direct ballistic test as the basic method of acceptance has not been replaced.

The obvious advantage of the ballistic test, and the reason it has been retained as the basic method of assessment, is that it closely simulates service conditions. To be weighed against this feature are many disadvantages,[2,3] such as the following.

(a) Comparatively speaking, ballistic testing is a cumbersome process. It requires special equipment and usually must be carried out at a proving ground under the supervision of a trained staff. The resulting cost is high.

(b) Because materials must be shipped to the proving ground, a time lag between the completion of production and the completion of the test may hold up further fabrication or immediate shipment to combat areas.

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(1) For one type of small arms projectile, such a machine has actually been built and used. (However, this represents an isolated case rather than general practice.) See report by W. N. Hindley, "Quality Control of SAAP Bullet Cores," Armament Research Department (British) MET 9/45 (Feb 1945).

(2) H. H. Zornig, N. A. Matthews, and C. Zener, "Armor Plate Ballistic Testing," Watertown Arsenal Report WAL 710/685 (Aug 1944).

(3) "Investigation into the Possibility of Replacing Plate Proofs of Shot by Laboratory Tests," British Ordnance Board Proceedings 19,063 (Aug 1942).

(c) The result is available only after all stages of manufacture are completed; earlier knowledge of trouble might allow correction of faults or at least save work on unsatisfactory material.

(d) It is often difficult to determine from a ballistic test what changes should be made in fabrication to improve the product.

(e) The test is destructive. It is therefore wasteful of material and can be carried out only on samples. The inadequacy of sampling procedures is borne out by many examples.

To avoid these difficulties numerous investigations have been undertaken to develop nonballistic tests that are cheap, fast, nondestructive and usable in the manufacturing plant. Nonballistic tests should also show good correlation with ballistic performance. Even though such tests have not replaced the ballistic test, they often serve useful purposes: (a) in sorting out distinctly inferior material before further processing, (b) in informing the manufacturer of trouble before large quantities of defective product have been produced, (c) in providing a clue to the causes of failure in a ballistic test and (d) in helping to control uniformity of the product to add to the reliability of ballistic tests on samples.[4]

[4] The last point is particularly emphasized in the following excerpt from footnote 2: "Ballistic acceptance tests must necessarily be augmented by indirect tests because of the impossibility of controlling uniformity by ballistic tests alone."

Section 15.1

Choice of Tests and Test Conditions

Section 15.1

Choice of Tests and Test Conditions

There are a variety of factors that may influence the choice of test conditions to be used in acceptance. The choice may depend on how well the factors controlling performance are known, on the degree to which service conditions can be defined, on the extent to which capabilities of the product have been determined in development work, or on the importance of simplicity and reproducibility compared to complete assessment.

by R. J. Emrich

Sec. 15.1 - Choice of Tests and Test Conditions

In general, tests on armor and projectiles are conducted for one of three purposes, as follows:

(a) Experimental or development tests are conducted to determine ballistic characteristics of new steels, experimental heat treatments and similar variables or, in the case of ballistic tests, to find the best characteristics for various types of attack. Firings are also conducted to obtain information upon which design improvements or alterations are based.

(b) Qualification tests are conducted for the purpose of qualifying a manufacturer's process. Such tests may be of comparative complexity and when employed are designed to establish the ability of a manufacturer to produce a satisfactory product. After qualification, indirect tests may play a considerable part in controlling uniformity of the product.

(c) Acceptance tests are conducted on samples or test pieces, representing distinct lots, which are presented by the manufacturer.

Although the subsequent review is primarily concerned with the problem of acceptance testing, the tests considered may well be used for any of the above three purposes. In fact, even in practice, the results of acceptance tests are often employed for purposes of development, making it difficult to distinguish between the two types.

Considering acceptance tests, the choice of type and conditions of test may depend, in a particular case, on any one or a combination of several factors. It may depend on how well the factors controlling performance are known, on the degree to which service conditions can be defined, on the extent to which capabilities of the product have been determined in development work, or on the importance of simplicity and reproducibility compared to complete assessment.

Factors Controlling Performance

When the ballistic quality of the product can be defined in terms of definite, measurable characteristics, these form a useful basis for assessment. Thus the quality of homogeneous armor is said to depend on its resistance to penetration, its resistance to spalling, and its resistance to cracking.(1) The quality of an armor

(1) In the case of face-hardened and very hard homogeneous armor, quality will also depend on the ability of the armor to deform the projectile.

piercing projectile is a function of its ability to resist deformation and shatter. In addition, an APHE projectile must remain in an effective bursting condition.(2) One of the criteria for the suitability of a test is whether or not it is properly designed to measure the physical characteristics controlling these properties. In fact, it is only on such a basis that nonballistic tests have any significance.

Difficulties sometimes arise in applying this criterion, however, mainly because of vagueness in physical concepts. For example, the order of merit of a set of plates tested for resistance to penetration by determination of ballistic limit may be quite different when the test projectiles are small than when they are large.(3) Although the reasons for this are known in a general way, it appears impossible in this and other cases to predict from limited test results what the performance of the product will be under all possible conditions of use.

Service Conditions

Lacking a fundamental basis that is entirely unambiguous, a second criterion in the case of a ballistic test is the closeness to which conditions approach expected service use. The usefullness of this criterion will depend on whether or not the intended use is restricted to a few types of impact and on the likelihood that service conditions will be altered by changes in the tactical situation.(4)

At best, there is some uncertainty in predicting actual use since, to a certain extent, this is within the control of the enemy. This situation is in contrast to that existing in the case of a gun tube, a structural element of a vehicle, or a gun mount wherein the material can be proof tested under such conditions that assurance is obtained that the stresses in service will not exceed those in test.(5)

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(2) "Ballistic Testing of Armor, Rev A," Naval Proving Ground Report 21-43 (Apr 1944).

(3) H. H. Zornig, N. A. Matthews, and C. Zener, "Armor Plate Ballistic Testing," Watertown Arsenal Report WAL 710/685 (Aug 1944).

(4) At the beginning of World War II, the 90 mm projectile was planned for low angle attack of face-hardened plate, but later, due to a change in the tactical situation, its greatest use was against homogeneous armor set at a high angle. See report by H. F. Brown, "The History of 90 mm Armor Piercing Projectile (Steel) Development," Office, Chief of Ordnance (Aug 1945).

(5) "Bibliography on Armor, Armor Piercing Projectiles and the Welding of Armor - Vol I," Watertown Arsenal Report WAL 900/97 (Apr 1945).

Product Performance

Two types of acceptance tests have been used in practice. In one type, the test provides a numerical measure of quality, such as a ballistic limit; in the other, the product merely passes or fails a given requirement, e. g., that a plate withstand attack by a given projectile at a stated velocity and obliquity. The choice of the level set for acceptance in the first case and of test conditions in the second case is based on expected performance as determined in previous development or acceptance tests.

The severity of the test will obviously depend on qualities that can be obtained in mass production and not on those achieved under ideal laboratory conditions. Particularly in time of war, with new manufacturers in the field, expediency may require acceptance of pieces below some arbitrary, predetermined standard. It may then be an advantage to have a test which will tell not only whether, but how much, the product is below or above a given level. Such a test will also give a better idea of improvements that are being made; its disadvantage in most cases is greater complexity.

Simplicity and Reproducibility

The practical need for simplicity and reproducibility is evident without elaboration. This provides a fourth criterion for the suitability of a given test or test condition.

A review of specifications for armor and projectiles, as well as the literature on acceptance testing, reveals no simple, infallible set of rules for choosing a test or test conditions in particular cases. As illustrations of acceptance practice in the United States near and at the end of World War II, examples of specifications are given in Appendix A. Specifications are, of course, continually subject to revision.

To indicate some of the practical difficulties involved in setting up satisfactory acceptance tests, modified selected quotations are given in the following sections which cover the history of two developments. Although both examples are from British sources, the troubles encountered are typical of those of other countries.

15.11 - Acceptance Tests (British) on Homogeneous Hard Armor up to 14 mm Thickness.[6]

The specification, approved in 1936, and in use at the outbreak of the war, stipulated that the plates were to be subjected to an "immunity firing test." The composition of steel and the method of manufacture were left to the manufacturer and no definite hardness range was specified. Plates were rejected if under visual examination they showed signs of cracks or laminations or other defects, and if under firing tests with caliber .303 ammunition (at stated velocity and obliquity) they were perforated or showed signs of spalling. The firing trials were carried out at ranges on the manufacturer's premises, the normal proving procedure being as follows: 10 per cent of all plates produced were subjected to the immunity firing test so long as no failures occurred; upon the failure of any plate, all plates were tested until 100 consecutive passes, when the 10 per cent test was resumed. All firing was carried out with special rifles and ammunition supplied by Woolwich Arsenal, supposedly to assure the achievement of the stated striking velocity; velocity of each round was not measured and it was later shown that striking velocities considerably outside the ±40 f/s stated tolerance were occurring.

Early in 1940, certain manufacturers were experiencing difficulty in passing the immunity firing test and, in consequence, were continuously on 100 per cent test. In April 1940, the severity of the test was reduced by increasing the obliquity. In July 1940, the test was further changed and inspecting officers were asked to compare the results of the new and the old tests. At the end of a six months' concession period no satisfactory conclusions had been reached and the concession was further extended for another three months. This arrangement worked satisfactorily and no further ammendments were formulated until 1942.

By agreement all manufacturers began to work toward a Brinell hardness of 444 to 477, in which range very little trouble was experienced in passing the immunity test.

(6) W. L. J. Pomfret, "The History of Specification I.T. 70 for the Manufacture and Testing of Rolled Homogeneous Hard (Non-machineable) Armor up to 14-mm Nominal Thickness," British Ministry of Supply Permanent Records of Research and Development 5.003 (Aug 1947).

Meanwhile, during 1941, experimental trials at arsenal ranges provided the first means of making comparative trials of the ballistic properties of different types of IT 70 armor plates. These showed that the specification immunity test failed to discriminate among plates which might possess greatly differing ballistic qualities and gave little indication of the behavior of plates under an overmatching attack. A number of failures meant an increase in the number of plates fired at, and the return of plates for retreatment, but this retarding effect did not prevent plates essentially similar to those rejected from going into vehicles, nor was any pressure, other than the inconvenience and delay, put upon the manufacturer to improve his quality.

In November 1942 a new draft specification evolved. Immunity firing tests were included with more attention to detail and, in addition, a ballistic limit was to be obtained with the same caliber .303 ammunition within a velocity bracket of 100 f/s. An overmatching test was introduced, and it was stipulated that plates should be within the Brinell hardness range 444 to 477. Ballistic tests, except the immunity tests, were conducted at proving grounds on samples shipped there.

In October 1943, immunity tests at the firm's ranges ceased. Up to 1944 the results of the proving ground tests did not require any action regarding acceptance or rejection of production plates. Plates were accepted provided they were in the agreed hardness range.

During the trial period in which hardness alone was used as a basis for acceptance, 426 plates from five firms were subjected to ballistic test at the proving ground, and the results showed considerable variation in the properties of plates of different makers. During this period some firing had been done at various obliquities, and the proving grounds impressed upon the Ministry of Aircraft Production the unreliability of results obtained in angle shooting. It was agreed that plates should be proved at normal, as well as at angle, during the trial period.

In April 1944 a new draft specification called for the subjection of tank and aircraft plates to the ballistic tests. Perforation limits were measured and overmatching projectiles were fired against samples. Some of the overmatching tests, viz., those which had not been performed during the trial period, were ignored in giving verdicts on plates which failed and such plates were subjected to the old immunity test. Acceptance was carried out under this specification, with minor changes in detailed perforation limit requirements up to the time of the writing of the history which has been summarized.

15.12 - Acceptance Tests of Heavy Naval Projectiles(7)

During the early years of World War II, the British Ordnance Board came to the conclusion that the system of proof, whereby if one shell chosen from a lot of 400 shell failed, the lot would be accepted if a second shell succeeded under the same conditions, was not an adequate safeguard against inferior shell getting into the shellrooms of the ships.

After a review, the Board recommended in November 1943 that

(a) Two shells are to be proved from each lot of 400;

(b) If either fails, three more are to be proved;

(c) If one of the five is a failure, an investigation into the back history is to be made and five of that maker's next lot are to be proved;

(d) If more than one shell out of the five fails, the lot is to be rejected and a drastic investigation carried out, and no further lots are to be accepted from that maker until there is concrete evidence that the trouble has been located and eliminated;

(e) Until a firm has shown that it is reliable, two shells from each lot should be sectioned for a complete metallurgical examination; and

(f) The firm should keep complete records of the manufacture of all shell; these are to be available to the proof organization.

Certain objections to these proposals were raised by the firms and in January 1944 the Board stated that the fundamental objection (that long delays in manufacture and supply would necessarily result) did not appear to be correct unless a large proportion of the shell brought forward for proof was incapable of passing the specification tests.

The Board's idea was that the Heavy Shell Sub-committee would learn how to make good shells and that a specification with which a good shell could comply would be determined. They recommended that,

(7) "Report of the President of the Ordnance Board (Great Britain) 1941-1945," pp 297-301.

when that had been done, approval of the proof organization must be given for the composition of the steel, the processes of manufacture, the hardness gradients, and the design of the shell. Complete history sheets of each shell and cap should be available, hardness tests should be taken over the whole of the shell from tip to base, and of each cap, and two shells per 400 should be sectioned and tested for hardness over the area of the sections.

It was next proposed that acceptance of heavy shell should be based entirely on tests of

(a) Chemical analysis of heats of steel;

(b) External hardness (VDH) on every shell;

(c) Internal hardness gradient of 1/2 per cent of the shell by sectioning;

(d) Magnetic crack detection on all shells; and

(e) Identical tests on caps.

Methods of manufacture were to be open to inspection and to be fully recorded for each shell. As a check on the above specification requirements, 1/2 per cent of the shell would be held for firing trials to provide information on whether the expected performance was, in fact, being realized. In the event of failures, an investigation into methods of manufacture could be made. But, complete control of manufacturing methods was not regarded with favor.

This policy was approved by the Board since the Admiralty was in a much better position to specify methods of manufacture than it had been in 1939; the Armament Design Department and the Armament Research Department were now well qualified to give technical advice on AP shell problems, the Heavy Shell Sub-committee was actively investigating the qualities of the best possible piercing shell, and the Royal Ordnance Factory had been shown capable of setting an excellent standard in the manufacture of 15-inch shell.

In September 1945, the firms had agreed to cooperate in working out the new procedure for acceptance of heavy projectiles. The firms suggested that each manufacturer should produce shell according to approved samples. It was pointed out by the proving organization that the principle of the proposed new procedure was based on sufficient knowledge to specify the optimum characteristics of all shell for a given performance. If the characteristics were obtained by different methods and the results achieved differed, it was the intention that the methods of manufacture should be brought into line rather than have the specification altered to suit existing methods of manufacture.

Section 15.1 - Choice of Tests and Test Conditions

Basic Material

1. W. L. J. Pomfret, "The History of Specification I.T. 70 for the Manufacture and Testing of Rolled Homogeneous Hard (Non-Machineable) Armor up to 14-mm Nominal Thickness," MOS; Permanent Records of Research and Development 5.003 (Aug 1947).

2. "Report of the President of the Ordnance Board (Great Britain) 1941-1945," pp 271-272, 297-301.

3. "Report of the President of the Ordnance Board (Great Britain) 1946," pp 74, 77.

4. "Results of the Homogeneous Aircraft Armor Development Program," Naval Proving Ground Report 11-43 (Jun 1943).

5. "Ballistic Testing of Armor, Rev A," Naval Proving Ground Report 21-43 (Apr 1944).

6. H. H. Zornig, N. A. Matthews, and C. Zener, "Armor Plate Ballistic Testing," Watertown Arsenal Report WAL 710/685 (Aug 1944).

7. A. Hurlich, "Development of Non-ballistic Tests of Armor at Watertown Arsenal 1940-1945," Watertown Arsenal Report WAL 710/793 (May 1946).

Related Material

1. W. N. Hindley, "Quality Control of SAAP Bullet Cores," Armament Research Department/MET 9/45 (Feb 1945).

2. A. J. Herzig, "Report of Investigations Conducted at the Laboratory of the Climax Molybdenum Company in Connection with Heat Treatment of Armor Piercing Shot," Reports L147-L149 (1942).

3. "Investigation Into the Possibility of Replacing Plate Proof of Shot by Laboratory Tests," British Ordnance Board Proceedings 19,063 (Aug 1942).

Related Material (Cont'd)

4. H. F. Brown, "The History of 90 mm Armor Piercing Projectiles (Steel) Development," Office, Chief of Ordnance (Aug 1945).

5. "Bibliography on Armor, Armor Piercing Projectiles and the Welding of Armor - Vol 1," Watertown Arsenal Report WAL 900/97 (Apr 1945).

Section 15.2

Proof Firing for Acceptance of Armor

Section 15.2

Proof Firing for Acceptance of Armor

To determine the ability of a plate to resist (a) penetration, (b) spalling, and (c) cracking, three types of ballistic tests are used. In the first type, a determination is made of the ballistic limit of the plate; in the second, projectiles are fired at velocities above the limit to determine whether an excessive amount of armor is thrown from the back face; and in the third, a large projectile or slug is used to provide shock and thus test the plate's resistance to cracking. Each of these types is discussed.

by R. J. Emrich

Sec. 15.2 - Proof Firing for Acceptance of Armor

Four criteria for the choice of an acceptance test or test conditions were discussed in the previous section. Since it is usually impossible to satisfy all four criteria simultaneously, an essential part of the problem in setting up a test is to decide on the relative importance of the various factors. Since this may vary from one acceptance problem to the next, it is difficult to establish a general basis for acceptance which will apply to all cases. A discussion of such a basis can be useful, however, even though exceptions are advisable in practice.

Except where noted, the present section reviews a system proposed by Watertown Arsenal[1] for the acceptance of armor for aircraft, tanks, and other armored vehicles. The significant part of the proposal is the stress laid on measurements which distinguish among different modes of failure and which emphasize characteristics inherent in the armor and controllable in manufacture. The spirit of the proposal is expressed in the introduction of the subject report: "Considerable progress has been made during World War II in an improvement in armor quality and also in an understanding of the mechanics of how armor functions. It is believed that still further improvement in armor quality may be obtained if this understanding of the mechanics of armor is utilized in establishing a rational basis for the ballistic specifications of armor. An attempt is made to establish such a basis."

15.21 - Basis for Armor Testing

It is generally accepted that good armor must possess three characteristics:

(a) Resistance to penetration. The primary function of armor is the protection of men and material behind it and it must first of all prevent, as far as possible, the perforation by enemy missiles.

(b) Resistance to spalling. There should be no pieces thrown from the plate into the protected area.

(c) Resistance to cracking. The plate should not crack or break up. Even when the crack is not severe, the plate will be unable to sustain further attack; if the plate is an integral part of any framework, the structure will be weakened.

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[1] H. H. Zornig, N. A. Matthews, and C. Zener, "Armor Plate Ballistic Testing," Watertown Arsenal Report WAL 710/685 (Aug 1944).

These are useful designations, not only because they correspond to different types of damage, but also because they represent different modes of failure which can be related to controllable physical characteristics of the armor.

Thus, the first requirement stipulated for a ballistic test is that it be able to measure one of these qualities and that it be sensitive to the factors controlling the corresponding mode of failure. The second requirement, taken to be of equal importance with that of the first, is simplicity and reproducibility. Approximation to service conditions is relegated to a secondary role, while the requirement that the armor be tested near its limit of performance is automatically taken care of by the suggestion that the resistance to penetration be measured by the determination of a limit velocity.

The first requirement will be considered later. For the requirement of reproducibility it is recommended that tests be carried out under controlled conditions at a proving ground, that the projectile be non-yawing, and that, except in tests for cracking, a nondeforming, monobloc projectile be used whenever feasible.[2] A cap is considered an undesirable feature since it "introduces a variable factor over which the test range has no control."

For simplicity, as well as reproducibility, it would be desireable to have all tests conducted with impacts at normal incidence. The reasons for this are that small variations from the specified angle of incidence affect results to a much greater extent at obliquities than at normal, that the effects of random yaw are more pronounced at obliquities, and that the likelihood of projectile deformation and fracture is less at normal. With respect to simplicity, it is also noted that normal impact firing is somewhat easier with regard to mounting of the plates and the interpretation of ballistic impacts. These advantages are undoubtedly

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(2) There are many cases in which a monobloc projectile is not used in practice. It would certainly not be feasible to use such a projectile against face-hardened plate since it would invariably shatter and, consequently, produce very erratic results. Jacketed caliber .30 and .50 projectiles are used at normal obliquity in testing light armor.
In cases where nondeforming projectiles cannot be used, a specially prepared batch of projectiles is often maintained at the proving ground. These projectiles are prepared under especially well controlled conditions, are tested for uniformity by pertinent nonballistic tests, and are subject, through large samples, to a more thorough ballistic test than is feasible in regular projectile acceptance testing.

real; they are often obtained, however, at the expense of the requirement that the test should approximate service conditions. The reasoning behind the suggestion is that qualities which are responsible for poor behavior at obliquities can be tested at normal without the necessity of obliquity firing. This is an important point, but one which needs further investigation. At present, many acceptance tests are carried out at oblique impact.(3)

15.22 - Resistance to Penetration

Aside from the function of face hardened plate to deform the projectile and thereby dissipate its energy,(4) and the function of any plate to deform or deflect the projectile upon high obliquity impact, the chief property of armor in resisting penetration is absorption of energy through its own plastic deformation.(5) The characteristics of the plate material which affect its capacity to absorb energy through plastic deformation are customarily described as:

(a) Resistance to plastic deformation,

(b) Resistance to instability of homogeneous deformation,

(c) Freedom from laminations, and

(d) Ductility.

The general nature of the plastic deformation, and therefore the resistance to penetration, depends upon whether and at what stage of the penetration homogeneous deformation becomes unstable. Once such instability has set in, a plug is formed, thereby allowing the projectile to pass through more freely; the penetration resistance is lowered (Figures 2.1-12, 2.1-13, 2.1-14, 2.1-15, 2.1-16).(5) Since not all the factors affecting the instability of homogeneous deformation are understood, an adequate nonballistic test cannot be made for this quality.

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(3)See Parts I and II of Appendix A.

(4)To assure that face-hardened armor can perform this function, it is required that the nose of a standard test projectile be deformed by a specified amount.

(5)A more complete discussion of the mechanism of perforation is given in Chapter 2, Frankford Arsenal Report R-902, "Mechanism of Armor Penetration," by R. B. Sawyer, Feb 1951. Figures listed here are found in this report.

The presence of laminations and the absence of ductility, since they lead to spalls and cracks, lower the resistance to penetration by permitting the plate material to make room for the projectile without undergoing the normal amount of plastic deformation (Figures 2.1-8, 2.1-9, 2.1-11).[5] These two qualities are examined in special tests (spalling and cracking tests, respectively).

The Watertown Arsenal report[1] remarks that "the concept of resistance to penetration is not without ambiguity, and therefore any test which is devised to measure it is somewhat arbitrary. The ambiguity in the concept of resistance to penetration arises from the wide variety of conditions of attack to which armor is subjected. That combination of qualities which enables armor best to resist penetration under one type of attack is not necessarily the same combination which enables it best to resist penetration under another set of conditions. The most that can be expected of a single method of testing for resistance to penetration is that the test be sufficiently sensitive to all four resistance qualities so that any gross failings in any one quality will be reflected in the test.[6] Since the qualities (c) and (d) (freedom from laminations, and ductility) have special ballistic tests, it is desirable that the resistance to penetration test be especially sensitive to the first two qualities."

Type of Test

It is suggested that for firings at normal impact the "Navy" ballistic limit is preferable to that of the "Army" as a measure of resistance to penetration.[7] The "Navy" limit is the minimum striking velocity required for the projectile or major portion thereof to pass entirely through the plate, while the "Army" limit requires only that the tip of the projectile be seen from the back side when the projectile remains in the plate or that a pinhole of light be seen when the projectile has been ejected. The reason for favoring the "Navy" limit is that it is considered

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(1) Loc cit

(5) Loc cit

(6) The assumption is that service use is never restricted to a definite type of attack. The extent to which this is true will vary with the intended use of the plate.

(7) A description of the different types of ballistic limit, methods of measurement, and means of averaging statistical fluctuations in results is contained in an Appendix to Chapter 3, Frankford Arsenal Report R-903. See also "Definitions of Terms Used in Ballistic Testing of Armor - Rev B," Naval Proving Ground Report 10-46 (Jun 1946).

to be more sensitive to changes in the plate qualities under test, since these changes greatly affect the behavior of material near the back face.

"(i) The resistance to plastic deformation of the material near the back of the plate affects the 'Navy' ballistic limit much more than the 'Army' ballistic limit.

"(ii) The tendency for instability of homogeneous deformation does not appreciably affect the 'Army' ballistic limit while it greatly modifies the 'Navy' limit.

"(iii) An increase in hardness lowers the ductility of the back fibers of the plate, thereby lowering the bulging at the back of the surface before light is transmitted or the nose of the projectile appears, and therefore such an increase in hardness has a greater effect upon the 'Navy' than upon the 'Army' limit."

This disadvantage of the "Army" limit, that it is less sensitive to the qualities under test, would also apply to the "immunity" type test in which it is merely required that the plate not be perforated by a given projectile fired at a specified velocity and obliquity.

Although a review of specifications reveals that an immunity test is commonly used in practice, this is undoubtedly because of its greater simplicity, which is particularly important in the case of heavy armor. It is interesting to note, in this respect, that there is available a method for calculating a "Navy" limit for normal impact with data obtained from a single shot.[8] This

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[8] It is believed that this method was first suggested by the U. S. Navy. It was later used and developed by other organizations as well. A few references to this method are the following:

"Definitions of Terms Used in Ballistic Testing of Armor - Rev B," Naval Proving Ground Report 10-46 (Jun 1946).

G. R. Irwin, "Ninth Partial Report on Light Armor," Naval Research Laboratory Report O-1778 (Sep 1941).

"The Ballistic Properties of Mild Steel, Including Preliminary Tests of Armor Steel and Dural," Office of Scientific Research and Development Report 1027, NDRC A-111 (Nov 1942).

C. H. Fletcher, H. Davis, and C. W. Curtis, "Measurement of Projectile Velocities by Double Spark Shadowgraphs," Office of Scientific Research and Development Report 4829e, OTB-8e (Mar 1945).

method consists of firing one or more rounds at velocities estimated to be a little above the perforation limit velocity, and measuring the residual velocity of the projectile. The perforation limit velocity is then obtained by reference to experimentally established relationships between the perforation limit velocity and residual velocity. This method would reduce the number of shots required in obtaining a limit over the number needed in the "bracketing" method, but would make the measurements on each shot more complicated.

Conditions of Test

The choice of normal incidence as the obliquity for test and its advantages of reproducibility and simplicity have already been discussed. There remains a choice of projectile caliber.

That the rating of a set of plates may depend on the size of the test projectile is evident from Figure 15.2-1. (Compare results obtained with the caliber .30 and caliber .50 projectiles in the Brinell hardness range above 350.) In this figure limit velocities are given as a function of plate hardness for plates of the same metallurgical quality. Differences in hardness were obtained by differences in time and temperature of the temper. The optimum hardness increases with decrease in caliber; for the caliber .30 projectile it is supposedly at a higher value than shown in the graph. A deterioration in metallurgical quality would be reflected mainly in a shift of the optimum hardness to lower values.[9]

The method recommended for choosing the projectile caliber to be used in an acceptance test assumes that the best range of hardness and possible plate quality have been decided upon by

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[9] Optimum hardness is discussed more completely in Section 3.2 of Chapter 3, Frankford Arsenal Report R-903, "Perforation Limits for Nondeforming Projectiles," by C. W. Curtis (Feb 1951). For pertinent references, see:

"Results of the Homogeneous Aircraft Armor Development Program," Naval Proving Ground Report 11-42 (Jun 1943).

"The Penetration of Homogeneous Light Armor by Jacketed Projectiles at Normal Obliquity," Naval Proving Ground Report 14-43 (Jul 1943).

B. R. Queneau and F. C. Albers, "Metallurgical Aspects of Optimum Ballistic Properties in Homogeneous Light Armor," Naval Proving Ground Exp Memo 1040-44 (Jun 1944).

D. G. Sopwith, "The Optimum Hardness of Homogeneous Armor for Resistance to Perforation at Normal Attack by Projectiles of Different Sizes," Armor Piercing Projectiles Sub-committee Paper 80 (Sep 1944).

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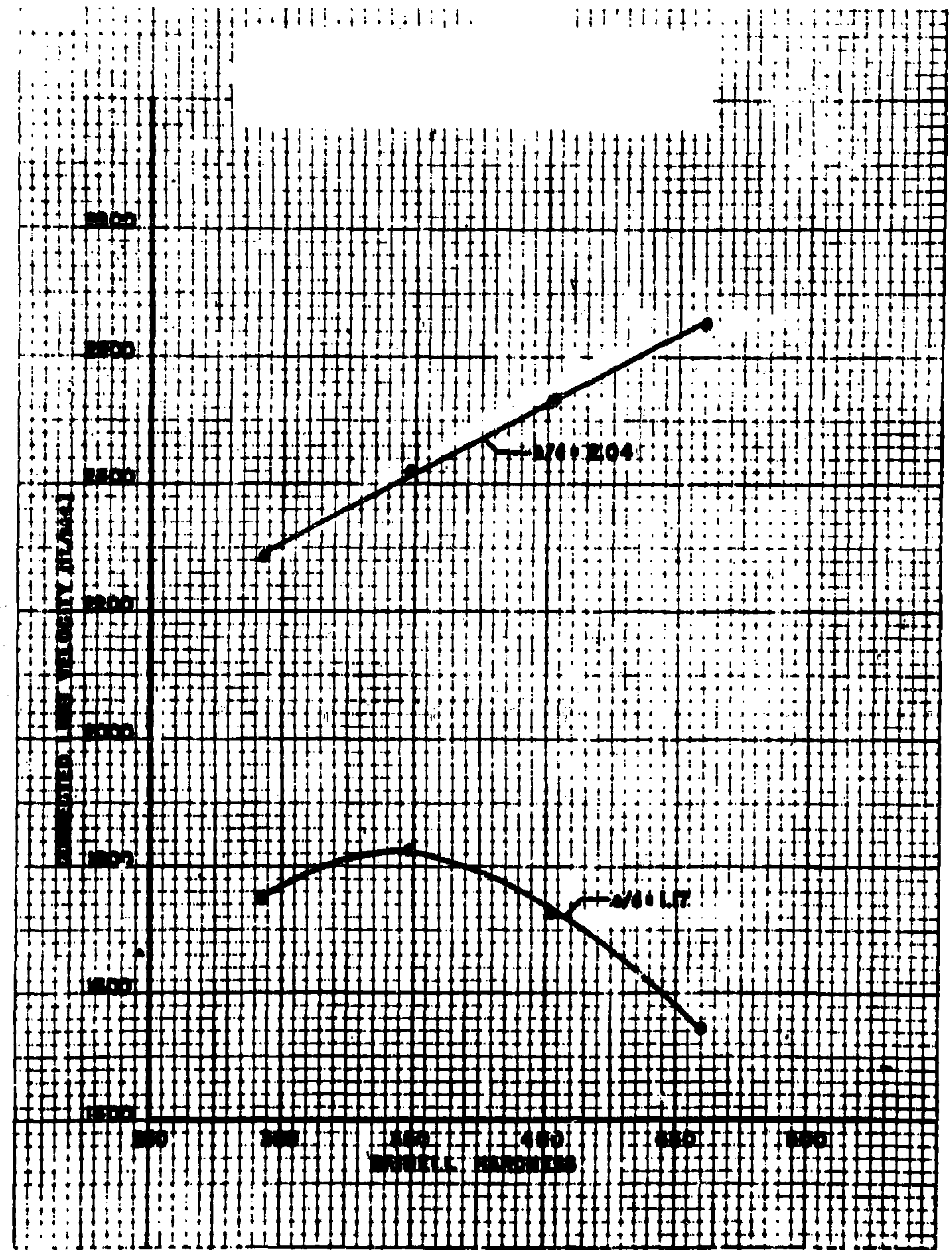

Figure 15.2-1. Variation of optimum hardness with e/d for 1/2 in. homogeneous light armor vs caliber .50 and caliber .30 AP M2 bullets at 0° obliquity
(Taken from Naval Proving Ground Experimental Memo 1040-44)

development tests, with due regard to expected service conditions. For plates of acceptable quality it would then be possible, by adjusting the ratio of plate thickness to projectile diameter, to test either in a region below optimum hardness, where ductile perforations are expected, or above optimum hardness, where nonductile perforations should occur. It is suggested that tests be conducted in the region below optimum hardness. Essentially, the test would then control the minimum hardness level; it might also show excessively poor quality due to lack of ductility and the occurrence of laminations, but would be relatively insensitive to these factors. Control of the upper limit of hardness and indication of poor ductility and flaws is then left mainly to spalling and cracking tests.

Projectiles chosen on the above basis would usually have a diameter less than the thickness of the plate and must therefore have a relatively high striking velocity for perforation. A sharp nose would be required to avoid projectile deformation.

Reduction of Data

It is often convenient to be able to reduce actual limit velocities to values corresponding to standard thicknesses of plate or to interpolate between values for two thicknesses. Perforation formulas for correlating limit velocities with plate thicknesses are discussed in Section 3.5 (Frankford Arsenal Report R-903). Of the many formulas that have been proposed, the simplest for interpolation is a linear dependence which may be used with fair success provided the range in plate thickness is small.[10] Nearly as simple, if a graphical means of interpolation is employed, is to consider the logarithm of the perforation limit velocity a linear function of the logarithm of plate thickness and to make a plot on log-log graph paper.[1]

15.23 - Resistance to Spalling

Different types of plate fragments may come off the back of a plate during impact. One type of fragment (referred to in 15.22) is caused by the localization of shear deformation about certain internal surfaces. Such a localization is caused by the instability

(1) Loc cit

(10) A. V. Hershey, "Ballistic Summary - Part I. The Dependence of Limit Velocity on Plate Thickness and Obliquity at Low Obliquity," Naval Proving Ground Report 2-46 (Mar 1946).

of homogeneous shear deformation which arises after a slight deformation. The mechanism of this type of failure (discussed in Section 2.1 of Chapter 2)[5] gives rise to the formation of plugs (Figures 2.1-12, 2.1-14, and 2.1-15),[5] and to the wiping off of petals (Figures 2.1-1 to 2.1-7 and 2.1-10),[5] both on the front and back faces.

A second common type of plate fragment is associated with a lack of cohesion across planes parallel to the plate surface. The resulting fragment usually takes the form of a thin disc somewhat larger than the diameter of the projectile. In Naval parlance this is called a "button."[11] The occurrence of such fragments was the most usual cause for rejection of rolled armor during World War II.

Another type is mentioned by the U. S. Naval Proving Ground and is, in fact, the only type to which the word "spall" is applied. This is a circular cone of metal with a base several times that of the projectile (Figures 2.1-8, 2.1-9, 2.1-11 and 2.1-16).[5] The depth of the cone usually extends through the entire thickness of the plate and the sides have a rough flaky crystalline appearance. The cause of failure is not explained.

Type of Test

The spalling characteristics of a plate are tested ballistically in the projectile-through-plate (PTP) test. In this test a projectile is fired at normal incidence with a velocity considerably above the perforation limit velocity. If a spall exceeding a certain diameter is ejected from the back of the plate, the plate fails the test.

Conditions of Test

Several factors influence the tendency of a plate to spall. The greater the velocity of the projectile, the greater are the inertial forces tending to separate the spall from the back of the plate (see Section 2.1, Frankford Arsenal Report R-902, for a discussion of the mechanism of spall formation). Spalls are also favored by a blunt

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(5) Loc cit

(11) "Definitions of Terms Used in Ballistic Testing of Armor - Rev B," Naval Proving Ground Report 10-46 (Jun 1946).

ogive and by an increase in the size of the projectile. Figures 15.2-2 and 15.2-3 illustrate how the tendency to spall increases with increase in velocity and with increase in bluntness of ogive. These pictures show only the formation of "buttons," but it is known that the tendency to plug also increases with increase in bluntness of ogive.

Certain projectiles which have in the past been used for the projectile-through-plate test are especially unsuitable, in particular the caliber .30 AP and caliber .50 AP jacketed core bullets. On the one hand, the unusually long pointed ogives of their cores require a high striking velocity in order to subject the plate to a severe back spalling test. On the other hand, their jacket produces a type of punching at high velocities which may disqualify the plate on the criterion of exit diameter, but which is in no way an indication of surfaces of weak cohesion in the plate. No other caliber .30 or caliber .50 ammunition is produced in quantity; Watertown Arsenal suggests the use of special test projectiles with cores of blunter ogive. These would then need to be shot at only a comparatively low velocity in order to differentiate between plates which are good and bad with respect to spalling characteristics; at the low velocity the jackets would be less likely to form their type of punching. Another suggested solution is to provide special test projectiles which are unjacketed and have a blunt ogive.[12] The use of a projectile, such as the 20 mm M75, which yaws excessively and does not remain undeformed is not recommended.

15.24 - Resistance to Cracking

As a rule, good quality armor cracks extensively only under unusual conditions of impact. It is particularly likely to do so if the plate is attacked by an overmatching projectile at high obliquity. The plate then resists penetration by deflecting the projectile so that, roughly speaking, the plate reaction is independent of the initial tangential component of the projectile velocity (Figure 15.2-4). The plate reacts essentially as if it were struck normally by a projectile with 90 degree yaw and a lower striking velocity; bending occurs with the back face subjected to tension. Fracture is likely.

A ballistic shock test should simulate these conditions, namely, it should apply, over an extended area of the face, an impulsive force of sufficient magnitude to produce bending;

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(12) J. F. Sullivan, "Considerations Preliminary to the Development of Improved PTP Test Projectiles," Watertown Arsenal Report WAL 762/320 (Jun 1945).

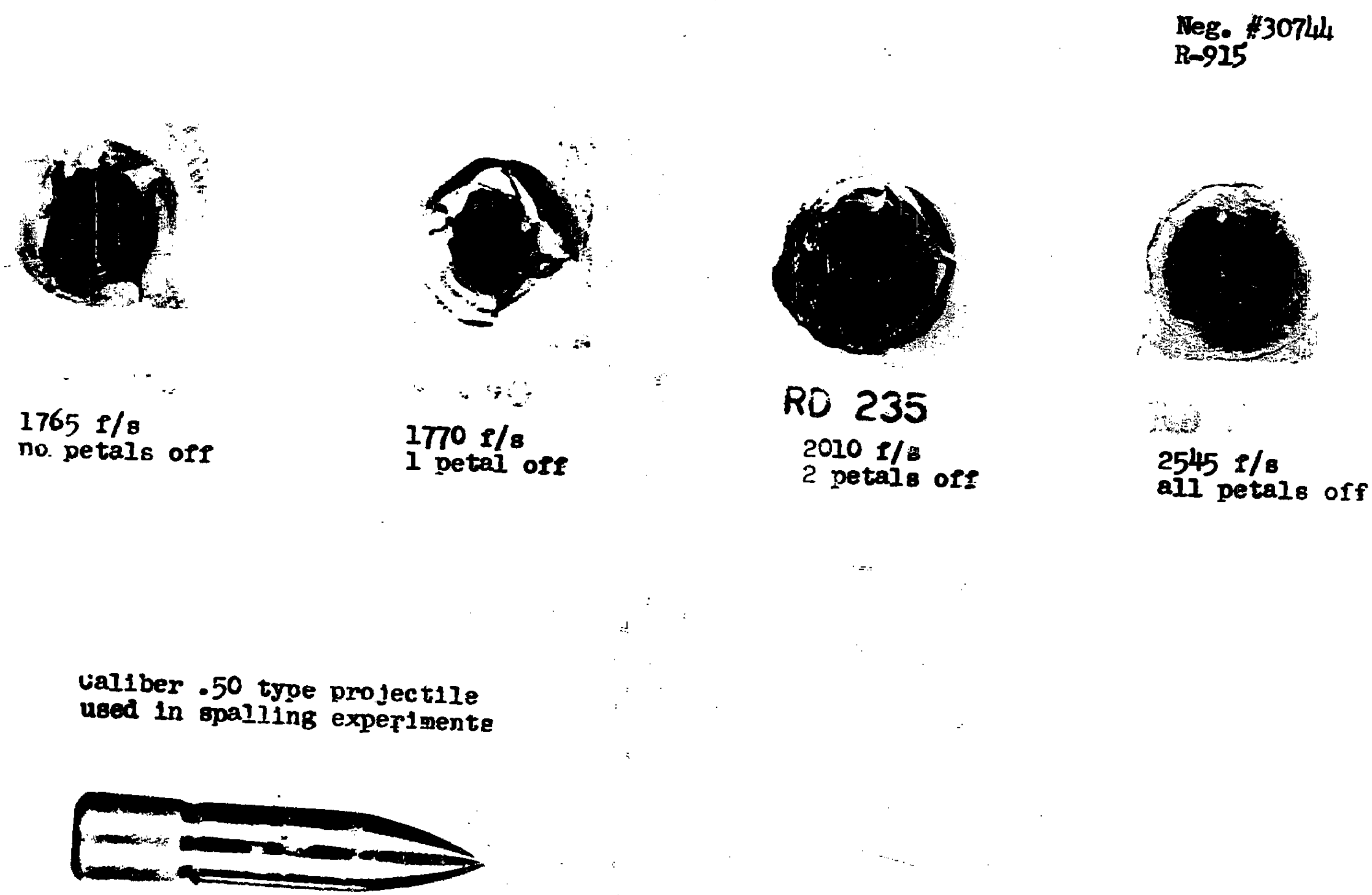

Figure 15.2-2. Effect of velocity upon spalling - caliber .50 type ogive
(Taken from Watertown Arsenal Report WAL 710/685)

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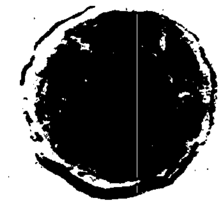
RD 243

1345 f/s
incomplete penetration

RD 244

1370 f/s
complete penetration
no petals off



RD 233

1375 f/s
complete penetration
all petals off

Blunt type projectile
used in spall experiments

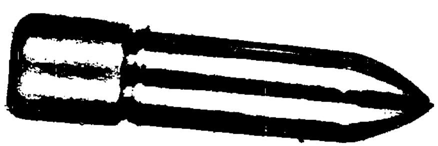


Figure 15.2-3. Effect of velocity upon spalling - major caliber type ogive
(Taken from Watertown Arsenal Report WAL 710/685)

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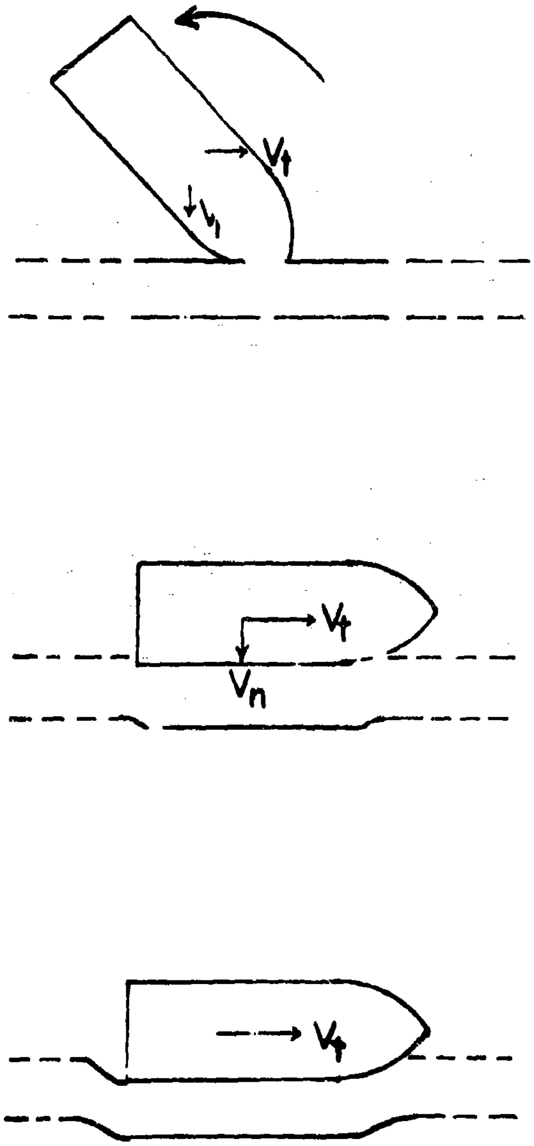

a. THE INITIAL REACTION FORCE EXERTS A COUPLE WHICH TURNS THE PROJECTILE SO AS TO LIE PARALLEL TO PLATE.

b. THE PROJECTILE PRESSES SIDEWISE AGAINST THE PLATE.

c. ALL THE ENERGY ASSOCIATED WITH THE VELOCITY COMPONENT NORMAL TO THE PLATE IS ABSORBED AS PLASTIC DEFORMATION.

Figure 15.2-4. Illustration of approximate manner in which undermatching plate resists penetration at high obliquities (Taken from Watertown Arsenal Report WAL 710/685)

Types of Test

At one time or another four different types of tests have been used to evaluate resistance to shock:(13)

(a) Repeated Fire. Light armor has been subjected to a 5- to 15-round machine gun burst. The reviewer has seen no report discussing this test. If it has physical significance, which seems doubtful, it is extremely difficult to see how it can be made reproducible.

(b) Explosion. The armor is impacted with fuzed, high explosive shell. It would appear that an explosion would subject the armor to the required bending. Personnel at Watertown Arsenal feel that such a test is not reliable, however, because of the extreme sensitivity of such shocks to the time of initiation of explosion. Furthermore, a German laboratory reports that the resistance of armor plate to a contact explosion did not correlate with resistance to cracking.(14,15)

(c) Yaw and high obliquity impact. Although the presence of yaw may increase the tendency toward cracking, yaw is hard to control in routine firing. The same effect may be produced more simply by other methods.

One such method is to use a relatively large, inert projectile fired at a high obliquity (usually 50 to 70 degrees to plate normal). This type of test is used by the U. S. Navy for testing medium and heavy armor. It has the advantage that the armor is tested under the same conditions that are likely to lead to failure by cracking in service.

(d) Slug. Watertown Arsenal favors the use of soft, blunt slugs fired at normal incidence. Ball ammunition has been used for the same purpose. A further discussion of this method follows.

(13) "Ballistic Testing of Armor, Rev A," Naval Proving Ground Report 21-43 (Apr 1944).

(14) A. Krisch, "The Formation of Plates and Plugs" (German Translation), British Intelligence Objectives Sub-committee/Gr 2/HEC/4521/5489/301 (1943).

(15) Dean and Sneddon, "The Problem of Discing of Armour Plates," Armament Research Department/THE Report 36/44 (Aug 1944).

Conditions for test with soft slug

It is suggested by Watertown Arsenal that the force on the face of the plate must not be so localized that its associated energy is used to form partial or complete holes, as are produced by armor piercing projectiles. The pressure must be distributed over an area having a diameter at least equal to the plate thickness. In order that such a pressure distribution be obtained at normal incidence it is desirable that the testing projectile have a flat nose or truncated ogive. However, the use of a flat nose projectile introduces the possibility of a new type of plate reaction, namely, the formation of a plug. This, however, can be avoided if the projectile is sufficiently soft to mushroom and is fired at a velocity which is carefully chosen. A projectile with low resistance to its own deformation will exert a nearly constant force for an appreciable time, and during this time the bending moment applied to the plate will steadily rise, while the shearing stress in the plate, which would produce a plug, remains constant.

It was felt that the physical picture of shock testing by this method was sufficiently complete to allow the proposal of a formula relating the parameters involved. The fundamental principle of this formula is that the test projectile should be fired just under the velocity which will give rise to a plug. The force exerted by the soft projectile will be roughly proportional to

$$\left[(T.S.)_{proj} + \rho V^2\right] \pi d^2$$

where $(T.S.)_{proj}$ is the numerical value for the tensile strength of the projectile material; ρ is the density of the projectile material; V is the striking velocity, and d is the projectile diameter. This force is to be just insufficient to cause a shear failure of the plate material, and in the critical case (the shear strength being about one-half the tensile strength) the forces may be equated. Whence,

$$(T.S.)_{proj} + \rho V^2 = \beta \, (T.S.)_{pl} \, \left(\frac{t}{d}\right)$$

where t is plate thickness, and β a numerical constant with a value of approximately 4, which is determined by experimental firing.

The test consists in firing the slug at the appropriate striking velocity, and inspecting the plate to see that no cracks appear with a length greater than a stated amount. This test[16] is being used for the acceptance of welded plate.

[16] Specification MIL-A-11356B, "Armor, Steel, Cast, Homogeneous; Combat-Vehicle-Type (1/4 to 12 inches, Inclusive)," 2 Jan 1953. (See Part II, Appendix A.)

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8. Specification JAN-A-434 for Armor, Steel; Plate, Rolled; Non-magnetic (5/32 to 1 1/16 in., Incl) Aircraft-type (31 Dec 1946).

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12. Specification MIL-A-11356B for Armor, Steel, Cast, Homogeneous; Combat-vehicle-type (1/4 to 12 in., Incl)(2 Jan 1953). Supersedes MIL-A-11356A.

13. Specification MIL-A-12560 for Armor, Steel; Plate, Wrought, Homogeneous; Combat-vehicle-type (1/4 to 12 in., Incl) (9 Mar 1953). Supersedes 57-115-11 and 57-115-18.

14. Specification MIL-A-13812 for Armor Plate, Light, for Testing Small Arms Armor-piercing Bullets, (30 Nov 1954).

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2. J. F. Sullivan, "Considerations Preliminary to the Development of Improved PTP Test Projectiles," Watertown Arsenal Report WAL 762/320 (Jun 1945).

3. A. Krisch, "The Formation of Plates and Plugs (German Translation)," British Intelligence Objectives Sub-committee/ Gr 2/HEC/4521/5489/301 (1943).

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8. "The Penetration of Homogeneous Light Armor by Jacketed Projectiles at Normal Obliquity," Naval Proving Ground Report 14-43 (Jul 1943).

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Section 15.3

Nonballistic Tests of Armor

Section 15.3

Nonballistic Tests of Armor

High hardness does not insure a high ballistic limit. Fiber fracture, Charpy, and reduction in area tests, as well as other measures of mechanical properties, have been suggested as means of revealing the tendency of armor to spall or crack. These and additional tests, such as radiographic and sonic methods of examination, are described.

by R. J. Emrich

Sec. 15.3 - Nonballistic Tests of Armor

One of the important changes in attitude during World War II was that taken toward the nonballistic testing of armor. At the beginning, nonballistic tests were regarded with almost complete lack of confidence; toward the end of the war they were sometimes used in the evaluation and interpretation of ballistic results. As previously stated, however, they are still by no means regarded as infallible. The present situation is summed up in a report[1] reviewing developments at Watertown Arsenal from 1940 to 1945: "An increasing tendency to rely upon the results of nonballistic tests to evaluate the ballistic characteristics of armor has been established during the last years of World War II. It is hoped that further research will result in the development of more precise, quantitative, and informative nonballistic tests for armor materials."

Nonballistic tests are of two general types: (a) those mechanical tests which subject the armor to a deformation somewhat similar to the deformation caused by projectile impact, and (b) tests of factors such as composition, treatment, and homogeneity of material, which have been found to affect ballistic behavior. The latter type of test is employed chiefly to insure, as far as possible, that all plates of a lot have uniform characteristics and ballistic properties at least equivalent to the samples chosen for ballistic testing. The former type of test has been investigated in the hope that ballistic quality could be assessed without having to resort to firing tests.[2] This section will be concerned mainly with the former type of test and will consider, in order, tests which correlate with (a) resistance to penetration, (b) resistance to spalling, and (c) resistance to cracking.

15.31 - Resistance to Penetration

Undoubtedly the most widely used nonballistic tests of armor are hardness by indentation (usually Brinell), resistance to impact (V-notch Charpy), and ultimate tensile strength. It hardly

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(1) A. Hurlich, "Development of Nonballistic Tests of Armor at Watertown Arsenal 1940-1945," Watertown Arsenal Report WAL 710/793 (May 1946). This is a companion report to the one on ballistic testing reviewed in the last section. These two reports form the basis for the present section.

(2) R. B. Sawyer, "Mechanism of Armor Penetration," Frankford Arsenal Report R-902 (Feb 1951). (See discussion of static punching tests, Section 2.2.)

needs repeating that these tests of resistance to plastic deformation though useful, do not correlate exactly with resistance to penetration by a projectile. Reference is again made to Figure 15.2-1. An optimum hardness, with drop in resistance to penetration beyond this value, occurs because of change in the mode of plate failure. For a particular projectile and plate, the position of the optimum depends on the number and size of the imperfections present, on the ductility, and on the tendency of the material to fail by inhomogeneous shear. None of these is measured by hardness alone. At a constant hardness near the optimum value, resistance to penetration is known to depend on chemical composition and probably metallographic structure.[3]

Although hardness and impact resistance (toughness) are not infallible measures of resistance to penetration, they indicate one of the most important factors involved. When the composition of steel, its metallographic structure, and its soundness are held within narrow limits, these tests can provide a good indication of performance. A hardness test is particularly useful since it is nondestructive and can be employed for testing all plates produced.

15.32 - Resistance to Spalling

It has been known for several years that laminations and segregations of nonmetallic inclusions are the primary cause of backspalling in rolled armor.[4] Excessive laminations of nonmetallic inclusions in armor are also responsible for base metal cracking during

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(3) For ballistic data on the effect of carbon content of steel on the perforation limit at a constant hardness level, see:
G. R. Irwin, "Ninth Partial Report on Light Armor," Naval Research Laboratory Report O-1778 (Sep 1941).
"The Penetration of Homogeneous Light Armor by Jacketed Projectiles at Normal Obliquity," Naval Proving Ground Report 14-43 (Jul 1943).
B. R. Queneau and F. C. Albers, "Metallurgical Aspects of Optimum Ballistic Properties in Homogeneous Light Armor," Naval Proving Ground Exp Memo 1040-44 (Jun 1944).
The indications are that the deviations from direct correlation with hardness are small so long as the type of plate failure remains ductile.

(4) E. L. Reed, "Correlation of Microstructure and Ballistic Properties of Armor Plate," Watertown Arsenal Report WAL 710/261 (Jul 1938).

the welding and flame cutting of armor. In the United States, the practice of certain firms in correlating ballistic performance of their plates with the appearance of fractures induced in notched bend specimens cut from the armor after heat treatment was studied by the laboratory at Watertown Arsenal, and, after comparison with other types of test, led to the development of the "fracture test for steel soundness." This test is required in the current Army specification[5] for acceptance of wrought homogeneous steel armor for thicknesses of 1/4 to 12 inches, inclusive.

The fracture test is very simply conducted. Specimens are flame cut from heat treated slabs of armor, notched by flame cutting in from the middle of the two longer sides, and broken under a press. The purpose of the notches is to localize the fracture in the plane of the notches. The fractured surface is then examined and rated as belonging to one of five classifications, either by comparison with a set of standard photographs or according to a description. A slow break is somewhat preferable to a fracture produced by impact because the laminations generally split open more definitely during the slow break. Fracture ratings which accurately reflect steel quality result only when the armor is heat treated so as to break in a completely dectile manner. When laminations of nonmetallic inclusions exist in steel, the path of the fracture will preferentially follow the laminations because the stress required to rupture the weak bond between the steel and the nonmetallics is much less than that required to rupture the homogeneous metal. The laminations will thus open up and be revealed as splits or shelves on the fractured surface. With brittle fractures, on the other hand, no preference is shown for the fracture to follow laminations.

Various other tests, including hot acid macroetching, magnafluxing, and microscopic examination, were applied at Watertown Arsenal in comparison with the fracture test for steel soundness. Correlations were established between these tests and, where possible, with projectile-through-plate tests, but the fracture test was considered the most readily applicable as a quality inspection tool. The hot acid macroetch test requires considerable experience for accurate rating, the magnaflux test was found to be too sensitive, and microscopic examination suffers from the drawback that only a relatively minute area is examined and the chance of having non-representative areas is great.

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[5] Specification MIL-A-12560, "Armor, Steel; Plate, Wrought, Homogeneous; Combat-Vehicle-Type (1/4 to 12 inches, Incl), (9 Mar 1953). See Appendix A, Part I.

Gensamer and co-workers,[6] at the Carnegie Institute of Technology, undertook to find a correlation between transverse tensile properties of the plate and its spalling tendencies. Investigation of a series of accepted and rejected plates showed marked deficiencies in tensile strength, elongation, and reduction in area in the transverse direction of spalled plates. Tests showed all plates having a reduction of area in the thickness direction in excess of 30 per cent passed the ballistic test, and all but one of the plates having less than 10 per cent reduction of area in the thickness direction failed the ballistic test by back spalling.

This work was continued at Watertown Arsenal in a more extensive program, including notched bar tensile impact tests across the thickness, static tensile tests across the thickness, longitudinal and transverse tensile tests, and fracture tests. The results showed that the reduction of area in the static tensile test across the gage (thickness) of rolled armor, in general, correlates well with the back spalling tendency of the armor. The notched bar tensile impact test across the gage likewise correlated well with the back spalling characteristics of the armor. The notched bar tensile impact tests taken in the longitudinal and transverse directions showed no definite correlation with back spalling tendencies. Similarly, static tensile tests in the longitudinal and transverse directions did not correlate with the ballistic properties. The results of the fracture test for steel soundness correlated well with the back spalling characteristics of the armor, and it was concluded that the fracture test is by far the most satisfactory indicator of the backspalling tendencies of armor and the test most applicable as a quality control test for the following reasons:

(a) Physical tests require the machining of relatively expensive test specimens. The fracture test specimen can be prepared very quickly and inexpensively.

(b) Tensile tests across the thickness of armor are limited to plates no less than approximately 1 1/2 inches thick and are not readily applicable to very thick armor. The fracture test, on the other hand, can be applied to all thicknesses of armor.

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(6) M. Gensamer et al, "Final Report on Nonballistic Test for Armor Plates," Office of Scientific Research and Development Report 2041, M-87 (Nov 1943).

(c) Since the tensile test is limited to a relatively small cross-sectional area, the results of the test may be misleading since the chance of having a nonrepresentative area included in the test specimen is high. The fracture test in macroscopic in nature in that a large cross-sectional area of the armor is exposed for examination.

15.33 - Resistance to Cracking

Cracking is associated with the perplexing phenomenon of brittle fracture in metals.(7) The concept of failure by brittle, rather than by ductile, process has been introduced by Ludwig. The flow stress is the stress necessary to make the material flow plastically. It depends both upon the transverse components of stress and upon the previous strain in the material. The fracture stress is defined as the stress at which the material would fracture if no plastic deformation were to occur.(8) The fracture stress appears not to depend upon the transverse components of stress, but like the flow stress, it is, in general, a function of the previous strain. As the load is increased, the material will flow plastically if the flow stress is below the fracture stress; it will fracture if the reverse is the case.

The flow stress of steels, all of the same hardness, seems to depend little on metallurgical structure, while the fracture stress is markedly affected by metallurgical structure.(9) Zornig, Matthews, and Zener described this by considering the two extreme cases of a pearlitic and of a tempered martensitic steel.(10) In the former steel, the initial fracture stress is only slightly higher (from 10 per cent to 20 per cent) than the initial flow stress for the case of uniaxial tension. In the latter steel, the fracture stress is

(7)A review of theoretical and experimental work in this field is contained in the Transaction of ASM, Vol 40A (1948).

(8)This definition of fracture stress is a useful one only if it is possible to suppress plastic deformation by introducing an embrittling parameter, such as a lowering of temperature or the addition of a transverse biaxial tension, without changing the resistance to fracture. Evidence that this possibility does not exist has been summarized by C. Zener in Transactions of ASM, Vol 40A (1948).

(9)This does not mean, however, that the flow stress is not sensitive to metallurgical structure, but rather that the hardness correlates well with the flow stress.

(10)H. H. Zornig, N. A. Matthews, and C. Zener, "Armor Plate Ballistic Testing," Watertown Arsenal Report WAL 710/685 (Aug 1944).

essentially independent of strain. In the example given, the pearlitic and the tempered martensitic steels have identical properties as measured in the conventional tensile test or by the conventional hardness machines. They no longer behave identically when a transverse constraint is imposed which prevents any change in dimensions along one transverse direction, as is the case when an overmatching projectile strikes a plate normally with 90 degrees yaw (as is essentially the situation when it is incident without yaw at high obliquity - see Sec. 15.24 and Figure 15.2-4). Such a restraint raises the flow stress. According to von Mises (or the octahedral shear stress theory), the rise will be 16 per cent. The fracture stress remains essentially unaltered by this restraint. Reference to Figure 15.3-1 shows that this 16 per cent rise in flow stress, which has only a minor effect upon the strain-to-fracture of the tempered martensitic steel, has, on the other hand, a drastic effect upon the strain-to-fracture of the pearlitic steel. In the latter steel, the flow stress is raised above or nearly to the fracture stress at zero strain, depending upon the precise conditions, such as strain rate and temperature. If the strain rate is sufficiently high or the temperature sufficiently low, the transverse restraint will raise the flow stress of the pearlitic steel above the fracture stress at zero strain, so the steel will fracture brittlely with no plastic deformation.

This example illustrates what has been verified by a thorough correlation study of ballistic and metallurgical characteristics of armor: armor can successfully withstand severe shock conditions only if it contains no pearlite.[11] The effect of the presence of intermediate structures, such as bainite, is complicated and is not well understood.

For a given composition, both the flow stress and the fracture stress curve of a tempered martensitic steel rise with an increase in hardness. The flow stress curve rises faster than the fracture stress curve, however, so the strain to fracture diminishes with an increase in hardness. The harder a steel plate is, the less able it is to withstand shock conditions.

In addition to the metallurgical structure and hardness level, the casting and forging practice also may affect the fracture stress.

[11] M. Bolotsky, "Historical Review of the Correlation of Ballistic and Metallurgical Characteristics of Domestic Armor at Watertown Arsenal," Watertown Arsenal Report WAL 710/795 (Dec 1945).

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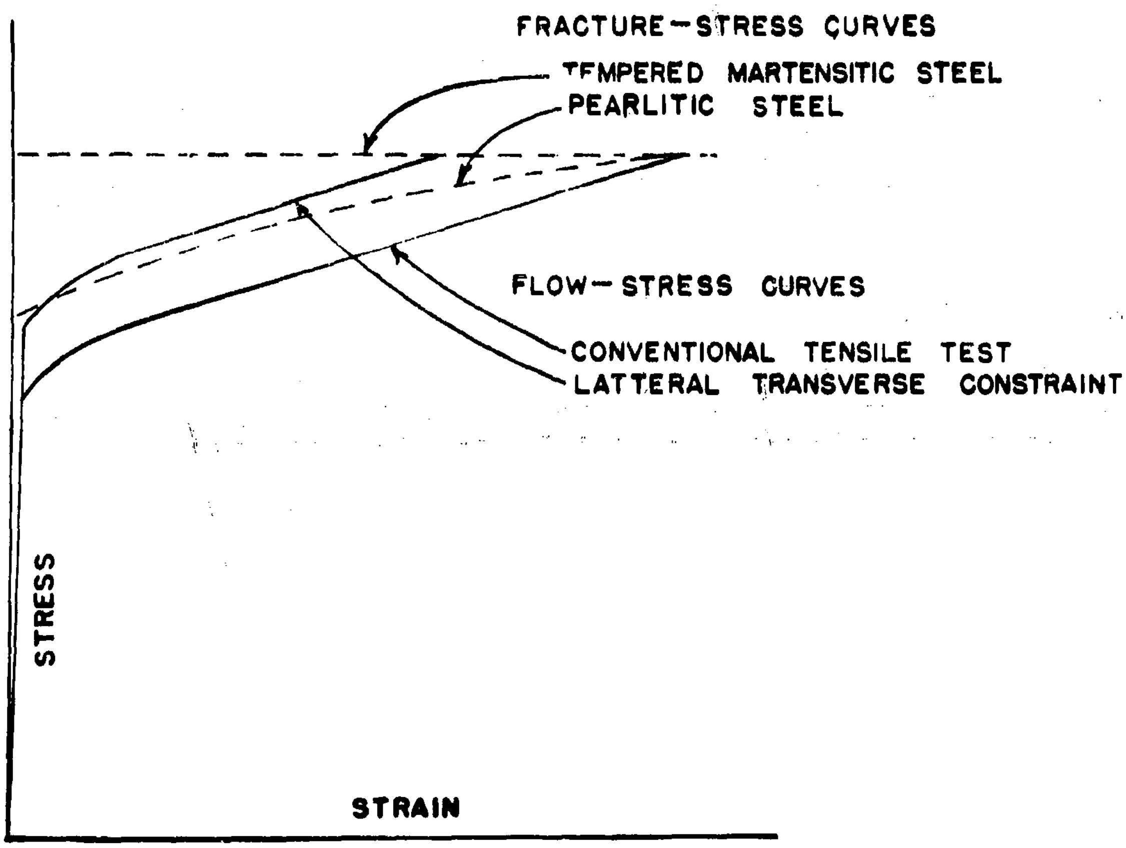

Figure 15.3-1. Inter-relation of difference between behavior of tempered martensitic and pearlitic steels under shock conditions (Taken from Watertown Arsenal Report WAL 710/685)

Thus, nonmetallic inclusions in a rolled plate always lower the fracture stress along an axis transverse to the principal direction of rolling.

The shock resistance of armor, or its ability to deform plastically at high rates of strain, may be greatly affected by temperature of test, dependent upon its metallographic structure. Satisfactory ballistic test behavior at normal temperatures does not provide assurance that the armor will resist brittle failure at low temperatures.[11,12]

A. Hurlich, Watertown Arsenal, has developed a "fibre fracture test" as a measure of the properties of steel armor to withstand shock, and this test has been correlated with the results of ballistic shock tests. It is sufficiently simple so that it may be applied in the production shop on an adequate number of samples to effectively control the quality of the armor produced. Ordinarily, the detection of the presence of high temperature transformation products (pearlite and bainite) in sufficient quantities to have a deleterious effect upon the ballistic properties involves laboratory techniques, such as microscopic examination of prepared surfaces.

The fibre fracture test merely determines whether or not a sample bar, sawed or flame cut out of armor and notched by a saw or cutting torch, fractures in a brittle or ductile manner upon being struck with a falling weight or a forging hammer. The fracture is examined visually and is characteristically one of the following.

(a) Fibrous. Characterized by a nonreflecting dark gray, rough, and pitted surface. The sides of the fracture show the necking-in associated with ductile behavior.

(b) Crystalline. Characterized by a bright silvery sheen caused by reflections from facets. The surface of the fracture tends to be flat and the sides undeformed. The fracture appears brittle in nature.

(c) Mixed. Part of the surface is typically fibrous, with clearly demarked areas typically crystalline.

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(11) Loc cit

(12) P. V. Riffin, "Armor Plate - Correlation of Metallurgical Properties with the Low Temperature Ballistic Shock Characteristics of 1" to 2" Low Alloy Cast Armor Tested at Camp Shilo," Watertown Arsenal Report WAL 710/534 (Aug 1943).

These characteristic appearances of notched and fractured steel samples are noticeable as well in Charpy test specimens cut from armor plate, and the type of fracture is well correlated with the energy absorbed in the Charpy test.

The correlation of the fibre fracture test results with the ballistic shock test results at low temperature is illustrated by the following data.

Table 15.3-1. Results of Ballistic Tests for Resistance to Shock

Fracture Rating	No. Tested	No. Failed	% Failures
	Cast Armor		
Fibrous	15	0	0
Predominately fibrous	4	1	25
Mixed, fibrous and crystalline	10	8	80
Predominately crystalline	22	17	78
Crystalline	23	19	83
	Rolled Armor		
Fibrous	17	0	0
Predominately fibrous	5	1	20
Mixed, fibrous and crystalline	11	2	18
Predominately crystalline	7	5	71
Crystalline	-	-	-

As may be seen from this table, the requirement that the fracture be completely fibrous will probably assure good ballistic shock resistance, even under cold weather conditions. However, the requirement is more critical with respect to the inherent ability of the material to deform plastically than are ballistic shock tests. The fibre fracture test is most useful as a control test during production in evaluating the characteristics which determine the resistance of the armor to shock.

The Charpy V-notch impact test has been suggested as a means of evaluating the shock resistant properties of armor,[6] and its correlation with ballistic shock tests has been demonstrated both

[6] Loc cit

at the Carnegie Institute of Technology and at Watertown Arsenal.[6,11] The notched bar impact properties at -40° F are considered a better index of shock resistance of armor than room temperature values. The correlation between the fibre fracture test and the Charpy test is better, however, than the correlation of either with ballistic shock tests.

An investigation of another distinctive type of fracture, designated "conchoidal," was made at Watertown Arsenal. The conchoidal fracture is characterized by large facets and smooth, bright, curved surfaces dispersed in varying amounts throughout an otherwise normal appearing fracture matrix. The fracture was found to be associated with a precipitate at the prior austenite grain boundaries which causes preferential fracture at dendrite grain boundaries. Very poor shock resistance is always associated with the conchoidal fracture. The Battelle Memorial Institute conducted a very extensive investigation of the phenomenon and found that the conchoidal fracture is caused by precipitation of aluminum nitrides at primary austenite grain boundaries. Faulty deoxidation and poor steelmaking practice are largely responsible for conchoidal fractures in production armor. This particular defect was, however, quite rare, being largely confined to the output of only one or two companies.

The experience of German armor makers during the second world war has apparently led to the same conclusions on nonballistic methods of testing shock strength. Paraphrasing a translation of a paper presented at a conference held in Berlin:[13] "The visual inspection of the fracture on statically broken samples of heavy armor plates often allows a better prediction of the behavior under fire than does the numerical value of the standard notch impact test. The subtle differences in the appearance of the fracture are scarcely noticeable on a photograph, so I shall not present them here."

15.34 - Control of Uniformity; Sampling Procedure

In the preceding sections, nonballistic tests which correlate directly with ballistic performance have been discussed. It has been mentioned that none of these correlates well enough with ballistic results, but that each is useful in (a) sorting out distinctly inferior

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(6) Loc cit

(11) Loc cit

(13) E. Houdremont, "The Strain on and the Properties of Armor Plate Steels" (German Translation), British Intelligence Objectives Sub-committee report /Gr 2/HEC/4521/5489/9.

material before further processing, (b) informing the manufacturer of trouble before large quantities of defective product have been produced, and (c) helping to control uniformity of the product to add to the confidence in ballistic tests on samples. In addition to the mechanical nonballistic tests, other information is recorded during the manufacture of armor to help assure that the finished batch will have uniform ballistic properties. The effects which variations in these factors have on the ballistic performance is not well understood, and the following is a list of the factors which have been seen in specifications or which have been proposed.

(a) Chemical analysis of steel.

(b) Heat number of steel, pouring temperature, ladle additions, etc.

(c) Ingot number, position in ingot, and rolling procedure or casting procedure.

(d) Heat treatment.

(e) Visual inspection to reject plates showing cracks, laminations, inclusions, or ruptures (particularly, machined or ground edges are so inspected).

(f) Radiographic inspection for inclusions and voids (chiefly castings).

(g) Sonic testing. The Naval Proving Ground has made some tests with the Sperry Supersonic Reflectoscope, which detects inhomogeneities in steel by noting the time taken for a sonic pulse to be reflected from points below the surface of the material.[14] Good agreement between laminations (revealed as large by the reflectoscope) and those leading to degradation of ballistic quality was obtained on about 70 impacts. If future results substantiate this agreement, it may be that those variations in ballistic performance which are caused by internal defects or nonuniformities can be rather accurately predicted before ballistic testing by careful ultrasonic examination. The instrument used was rather complicated and delicate, and its continual use might be difficult under conditions necessary for the testing of large plates. The instrument cannot be effectively used on plates less than 2 inches thick.

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[14] "A Study of Nonuniformity in 3.0 and 4.0 inch Homogeneous Armor," Naval Proving Ground Report 11-46 (Jul 1946).

How closely each or any of these factors needs to be controlled to provide uniform ballistic properties is a matter of judgement. Reference to specifications issued by the Ordnance Department and the Bureau of Ordnance will indicate the limits that have been set in specific cases. Examples of current specifications are included in the appendix to this chapter.

The realization that manufacturing conditions play an uncontrollable part in determining the ballistic quality of armor has led, both in the United States and in Great Britain, to the procedure of "qualifying" a manufacturer before he undertakes the manufacture of large quantities of armor. This procedure consists in having the manufacturer produce a group of plates, all of one thickness and size, and all as homogeneous in quality as possible. All the plates are then subjected to both ballistic and nonballistic tests of comparative complexity to establish the ability of the manufacturer to produce a satisfactory and uniform product. A manufacturer must "qualify" for each type and each thickness of armor he intends to produce.

Acceptance of armor, after qualification, is then based on nonballistic tests performed on some or all of the plates of a lot and ballistic tests on samples chosen from the lot. In general, a lot consists of a limited weight of plates, all from one heat of steel, all of the same thickness, which have had the same heat treatment and which are submitted at one time. Samples are selected from the lot at the manufacturing plant by a government inspector. Sometimes complicated sections, such as castings, are not themselves sampled but, rather, a ballistic test sample of convenient size and shape is produced under the same conditions. The percentage of the lot sampled varies, but is usually larger than one plate out of 100.

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Section 15.4

Proof Firing of AP Projectiles

Section 15.4

Proof Firing of AP Projectiles

Firing trials are performed mainly for three purposes: (a) to determine the projectiles' perforating ability, (b) to test cap and band security, and (c) in the case of APHE projectiles, to insure that the projectiles remain in an effective bursting condition after passing through the plate.

by R. J. Emrich

Sec 15.4 - Proof Firing of AP Projectiles

Except for a few general remarks, the only literature on ballistic acceptance tests for projectiles consists of specifications for the procurement of standard designs.[1] Although such specifications state quite explicitly what the requirements are for certain projectile types, it is not their purpose to justify the particular test conditions stipulated. No report giving reasons or a general basis for choosing test conditions has come to the attention of the reviewer.

It is clear from the specifications, however, that the tests for projectiles are of a slightly different nature from those for armor. Whereas the tests used for accepting armor correlate closely with definite qualities of the plate, acceptance tests for projectiles are concerned primarily with end results. The armor test for resistance to penetration correlates with the ability of the plate to resist general and localized plastic deformation; the test for spalling correlates with imperfections; the shock test correlates with the ability to resist cracking, e. g., plate brittleness. Projectile tests, on the other hand, require that the projectile perforate a given plate (or set of plates) under certain specified conditions of attack and, in the case of an AP high explosive (APHE) projectile, that it remain in an effective bursting condition. Neither of these tests correlates directly with a definite physical property of the projectile.

The general philosphy of projectile testing is reflected by the following quotation from a report of the President of the Ordnance Board:[2]

"1. In the Development of A.P. shot the Board obtains a supply of shot made by the best known methods and from the best available materials by the most reliable producer.

"When the development trials are complete, and a design approved, these best quality shot are used by the Board for determining proof conditions.

(1) For examples of specifications, See Appendix A, Parts III and IV.

(2) Report of the President of the Ordnance Board (Great Britain), 1941-1945.

"This trial is usually carried out against the thickest plate that the shot will defeat at fighting ranges and a critical striking velocity obtained at which it is considered that with such shot there is an even probability of success.

"The result is applicable only to the particular plate and shot used.

"In order to quote a striking velocity that will give some indication of the range at which this performance may be expected to be achieved by good shot of other makers against average plates, a margin of about 100 ft/sec is added for all calibers.

"Thus the recommended proof conditions specify the plate thickness and angle and include a nominal striking velocity.

"2. It is intended that proof should be carried out on the following broad lines:

"(i) In each calibre a supply of the best obtainable shot should be available. These are known as "standard" shot.

"(ii) The proof plate should be calibrated by means of standard shot[3] and a velocity obtained between success and failure (within bracket of less than 50 ft/sec). This is the calibration velocity.

"(iii) The shot under proof should succeed (in perforating) when fired at the calibrated plate at a proof velocity equal to the calibration velocity plus an agreed margin."

With the exception that the "calibration" of the target armor with "standard shot" is not universally performed,[4] the British procedure indicated above seems to be followed, at least in major outline.

It will be noted that these tests are somewhat analogous to the "immunity tests" used in armor acceptance, in that the projectile perforates under specified conditions or it fails. While

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(3) The British obtain armor for projectile acceptance testing under a special specification (See Reference 2).

(4) Ordnance Proof Manual 7-17, "Manual of Test Methods of Small Arms Ammunition," Ordnance Department, US Army, ORD-M 608-PM, Vol III (Jan 1945). However, see also Specification MIL-A-13812, "Armor Plate, Light, for Testing Small Arms Armor-piercing Bullets," (30 Nov 1954).

these are essentially yes or no tests in that they provide no numerical measure of the relative superiority of one projectile over another, gradations in quality are apparent to a skilled observer simply from observation of the recovered projectiles and the type of hole left in the plate.

To repeat, good correlations of projectile failures with physical properties (similar to those noted for armor) are still lacking, as are means of assigning numerical values to factors governing quality. Methods of developing these correlations and numerical assessments are still in the suggestion stage. It has been proposed that a "shatter velocity" be used as a numerical measure of the projectile's ability to resist nose failure,[2,5] and that a "breaking velocity" be used as a definite index of the projectile's ability to resist body failure.[6] The term "shatter velocity" will be discussed in Sec 4.2 and Sec 5.1 (Frankford Arsenal Reports R-904 and R-905), so it requires no elaboration here. In addition to providing a desired numerical performance rating for a lot of projectiles, it should correlate with localized and general plastic deformation in shear. Both of these factors are related to hardness. "Breaking velocity," in the sense used here, refers to the critical velocity at which a body failure first occurs. It presumably correlates with the ability of the projectile body to resist failure in tension, and this factor is related to bend strength.

It must be emphasized that these ideas have not been developed to the point necessary for immediate practical application as acceptance tests and, in fact, practical difficulties may even prevent such development. Even if these specific critical velocities and the presumably related physical properties are not suitable for the purpose at hand, some tests showing the desired characteristics should be sought.

Lest the above discussion be misleading, further reference should be made to the information available from observations of the condition of the projectile after perforation, which was barely mentioned above. Causes of failure can frequently be inferred by a skilled observer, and under some circumstances projectiles can probably be graded, at least roughly, as to quality. Definite

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(2) Loc cit

(5) H. W. Euker and T. A. Read, "The Shatter of Caliber .60 AP Bullets," Frankford Arsenal Report R-553 (Oct 1944).

(6) C. W. Curtis, "Terminal Ballistics of Tungsten Carbide Projectiles - Body Failures," Office of Scientific Research and Development Report 6640 (Apr 1946).

numerical ratings and good correlations are, however, missing. A comprehensive description of the types of deformation occurring during projectile impact and definitions of standard terms are contained in Appendix B.[7]

Unrelated to the impact of the projectile against armor, but of primary importance for acceptance, are the "worn gun" tests. These assess the security of the attachment of the cap, the windshield, and the rotating band.

[7] Reproduced from: "Definitions of Terms Used in Ballistic Testing of Armor - Rev B," Naval Proving Ground Report 10-46 (Jun 1946).

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Section 15.5

Nonballistic Tests of AP Projectiles

Section 15.5

Nonballistic Tests of AP Projectiles

Hardness and bend strength correlate with the ability of a projectile to resist shatter and body failures, respectively. Electrical resistance and related measurements have been suggested because they provide a means of determining internal hardness. Magnetic and microscopic examinations are used to detect cracks and the projectile is sometimes subjected to large temperature changes to reveal residual stresses. These and other tests are treated.

by R. J. Emrich

Sec. 15.5 - Nonballistic Tests of AP Projectiles

Hardness is the principal nonballistic property of projectiles which has been correlated with ballistic performance. Hardness indentations (usually Rockwell or Vickers) are made either on the exterior of the projectile or on an axial section after sawing the projectile apart. Magnetic and electrical properties which are related to hardness have also been used to a limited extent.

Other nonballistic tests, notably compression and bend tests, are in the process of development, but these have not as yet been used for acceptance.[1] A variety of other tests related to composition, heat treatment, flaws, and similar properties have been used to insure uniformity throughout projectile lots.

15.51 - Hardness and Sectional Hardness Distribution

As has been indicated earlier,[1] hardness is related to the ability of the projectile nose to resist deformation and failure. It is also related to the ability of the body of the projectile to resist breakage. This latter relation, however, is an indirect one - only for projectiles of a given composition of steel and subjected to the same method of heat treatment, will hardness be a reliable criterion of bend strength. In spite of meager direct evidence, an increase in bend strength is strongly presumed to be accompanied by a corresponding decrease in body failures. For this reason detailed attention has been devoted to hardness distribution patterns.

For any given condition of attack, it is generally agreed that some "optimum hardness distribution" exists. This distribution will always show the highest hardness near the nose and a gradual decrease toward the base. The details of the "optimum" condition will, however, certainly vary for different conditions of attack.

Again, a given hardness distribution does not completely represent the characteristics of the projectile.[2] Only when the type of steel, its quality, and the method of heat treatment are kept the same is there assurance that the hardness is a reliable index. Under these conditions it is a very useful control.

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(1) Discussions of such tests will be covered in Sections 10.1 and 10.2, Frankford Arsenal Report R-910.

(2) H. W. Euker and T. A. Read, "Shatter of Brine Quenched and Air Quenched Caliber .60 FXS-318 Steel Cores," Frankford Arsenal Report R-616 (Apr 1945).

Extensive studies designed to relate hardness distributions of service projectiles to ballistic tests were carried out in Great Britain during the years 1942 to 1944. On the basis of information contained in reports by the NationalPhysical Laboratory (British), it was recommended that the proof firing of 2-pr, 6-pr, and 17-pr AP projectiles be reduced and supplemented, or replaced altogether, with hardness measurements made on sawed-open samples from the lots.[3] Proof along these lines was considered so satisfactory that the National Physical Laboratory further developed a method of measuring internal hardness by nondestructive means. The Armament Research Department also developed apparatus for performing nondestructive tests, in this case for small arms projectiles.[4]

The National Physical Laboratory (British) procedure combined a measurement of the electrical resistance of the projectile (taken across the bourrelet section), with a surface indentation hardness measurement. It then compared the result with subsequent indentation hardness determinations on an axial section of the projectile. With projectiles from any one maker, having their own characteristic surface hardness, the resistance values, together with these measurements, gave an indication of the hardness at the center of the shoulder.

In the Armament Research Department procedure, the magnetic retentivity of small arms cores was measured. A comparison was then made with indentation hardness values obtained on flats ground along the sides of the cores. The machine developed for this purpose was fully automatic and it was used in the production line to eliminate cores of insufficient hardness.

Direct or indirect hardness measurements never completely replaced firing tests for artillery projectiles, but they served as useful guides for the selection of samples for such tests. During most of World War II, particularly when serious dislocations caused the mixing of steel compositions and improper heat treatment, the rejection of inferior projectiles and lots was accomplished by electrical resistance measurements taken on apparatus set up in the manufacturing plants. Later, with improvements in heat treatment procedures and with the maintenance of more uniform conditions in

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(3)Report of the President of the Ordnance Board (Great Britain), 1941-1945."

(4)W. N. Hindley, "Quality Control of SAAP Bullet Cores," Armament Research Department Report MET 9/45 (Feb 1945).

the plants, it was found that the resistance tests were of appreciably less value.[3] The Armament Research Department hardness sorting machine, however, was used for final acceptance of small arms cores after samples from the sorted batches were shown to have the required Vickers Diamond Hardness. Two trials were made to obtain a direct correlation between magnetic hardness and ballistic results.[5,6] Unfortunately neither trial was properly designed to determine this correlation.

15.52 - <u>Control of Uniformity: Sampling Procedure</u>

Under the present procedure of acceptance, with the lack of nondestructive and definitive mechanical tests of ballistic quality, the control of uniformity is of extreme importance. Since the projectile manufacturers frequently are not steel makers, the provision of steel in bar form is sometimes accomplished under specifications separate from those outlining the requirements of projectile fabrication. Particularly in Great Britain, the selection of steels and the recommended heat treatment for small arms AP projectiles was aided by the use of torsion impact tests.[7]

In addition to the control of the chemical composition of projectile steel, the other factors to be considered are:

(a) Steelmaking process. Macroetch tests may be applied to ingots.

(b) Rolling or forging practices.

(c) Heat treatment. Microstructure is studied at various stages in the heat treatment process, and finished projectiles are sawed apart for study.

(d) Process of cap attachment. Caps are frequently soldered to the cores, and tempering or other metallurgical change must be avoided during the process. The security of the bond between cap and core is usually checked by loading the assembled projectile transversely in the center when supported at the ends.

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(3) Loc cit

(5) "Magnetic Hardness Testing of A. P. Cores. Penetration Trials with a .55 inch A. P. S.A.A. Alloy A Cores," Armament Research Department Report MET 33/44 (Feb 1944).

(6) "Comparative Performance of a Batch of .303-inch W Mark I Bullets with AP Cores Divided into Groups by Magnetic Hardness," Armament Research Department Report TB/AP 8/45 (Mar 1945).

(7) A. Knight, "The Torsion Impact Test," Armament Research Department Report MET 66/45 (Jun 1945).

(e) Soundness test. After heat treatment, the shot are tested magnetically, under certain prescribed magnetizing conditions, for cracks and imperfections or nonmetallic inclusions.

(f) Visual or magnetic inspection of finished projectile for surface cracks.

The variation that may be permitted in any of these factors is a matter of judgment. Current Army and Navy specifications leave the decisions mainly to the manufacturer (reserving, of course, the right of final judgment), although allowable variations have been assembled in proposed specifications.[8]

Finished lots of projectiles submitted for acceptance are sampled by a government inspector at the manufacturing plant. The maximum size of a production lot is usually specified. For example, for the U. S. Army 90 mm AP projectile, the maximum size of a lot is 10,000, and from 5 to 9 projectiles are fired against armor plate; for U. S. Navy projectiles, the size of a lot is 500, from which 3 projectiles are selected for plate firing tests. It is sometimes required that all projectile cores in a lot be made of steel from one heat or a restricted number of heats, and similar restrictions may be placed on the steel used for the caps.[9]

A qualification procedure, such as that used in armor acceptance testing, is generally not employed in projectile acceptance testing. However, the first lot submitted by a manufacturer is usually limited to a smaller size than subsequent lots.

The reasons for basing projectile acceptance in the United States on such relatively small samples (5 out of 10,000) in comparison with sample sizes in armor testing (1 out of 100) are not apparent from available reports.

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(8) U. S. Army Specifications:

MIL-P-20519, "Projectiles, Armor-piercing, Capped; Metal-parts Assembly" (4 Dec 1951).

MIL-P-20460, "Projectiles, Armor-piercing; Metal-parts Assembly" (4 Dec 1951).

MIL-S-13763(ORD), "Projectiles, Armor-piercing, Hyper-velocity; with Tungsten-Carbide Cores; Metal-parts Assembly" (8 Nov 1954).

(9) See Appendix A, Parts III and IV.

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Section 15.5 - Nonballistic Tests of AP Projectiles

Basic Material

1. W. N. Hindley, "Quality Control of SAAP Bullet Cores," Armament Research Department Report MET/ 9/45 (Feb 1945).

2. "Report of the President of the Ordnance Board (Great Britain) 1941-1945."

3. Specification MIL-S-13673 for Projectiles, Armor-piercing, Hyper-velocity with Tungsten-Carbide Cores; Metal-parts Assembly (8 Nov 1954). Supersedes 50-33-2A.

4. Specification MIL-P-20460 for Projectiles, Armor-piercing; Metal-parts Assembly (4 Dec 1951). Supersedes 50-33-5.

5. Specification MIL-P-20519 for Projectiles, Armor-piercing, Capped; Metal-parts Assembly (4 Dec 1951). Supersedes 50-33-4.

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1. A. Knight, "The Torsion Impact Test," Armament Research Department Report MET 66/45 (Jun 1945).

2. "Magnetic Hardness Testing of A.P. Cores. Penetration Trials with .55 inch A.P. S.A.A. Alloy A Cores," Armament Research Department Report MET 33/44 (Feb 1944).

3. "Comparative Performance of a Batch of .303-inch W Mark I Bullets with AP Cores Divided into Groups by Magnetic Hardness," Armament Research Department Report TB/AP 8/45 (Mar 1945).

4. H. W. Euker and T. A. Read, "Shatter of Brine Quenched and Air Quenched Caliber .60 FXS-318 Steel Cores," Frankford Arsenal Report R-616 (Apr 1945).

APPENDIX A

Part I

Military Specification MIL-A-12560 (ORD)
Armor, Steel: Plate, Wrought Homogeneous: Combat-vehicle-type
(1/4 to 12 inches, Inclusive)

MIL-A-12560(ORD)

9 March 1953

~~26 January 1953~~
SUPERSEDING
U. S. Army Specification
No. 57-115-11
11 November 1945
U. S. Army Specification
No. 57-115-18
16 November 1949

MILITARY SPECIFICATION

ARMOR, STEEL; PLATE, WROUGHT HOMOGENEOUS; COMBAT-VEHICLE TYPE (1/4 to 12 INCHES, INCL.)

1. SCOPE

1.1 This specification covers wrought-steel combat-vehicle type of homogeneous armor plate in thicknesses from 1/4 to 12-inches, inclusive. (See 6.1.)

2. APPLICABLE SPECIFICATIONS, STANDARDS, DRAWINGS, AND PUBLICATIONS

2.1 The following specifications of the issue in effect on date of invitation for bids, form a part of this specification:

SPECIFICATIONS

FEDERAL

QQ-M-151 - Metals; General Specification for Inspection of

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 Material.

3.1.1 Homogeneity.- Processes of manufacture shall be such as to produce armor having, as nearly as practicable, a homogeneous structure throughout.

3.1.2 Soundness.- The soundness of all plates, including qualification and acceptance balli...ic test plates and samples, with respect to laminations and inclusions shall be equal to or better than the applicable standard shown in figure 4 when inspected in accordance with 4.8. Minor scale, pitting, tears or other imperfections on the surface of the armor that are characteristic of manufacturing processes shall not be cause for rejection if they are not of such a nature as to affect the fabricability or serviceability of the material.

3.2 Qualification.- Wrought armor submitted under this specification shall be produced b... a manufacturer whose product has been qualified in accordance with 4.3.

3.3 Chemical requirements.

3.3.1 Composition.- The ladle analysis of all heats shall be within the limits established by the contractor, at the time of qualification, which shall conform with the requirements of table I. In addition, those additives or hardening agents intentionally added shall be declared. All limits established by the contractor shall be submitted in advance to the contracting officer. The contractor may establish and submit separate limits for each thickness of plate for which he desires to be qualified. Changes in composition shall not necessarily be cause for requalification but shall be subject to review by the contracting officer to determine whether requalification may be required.

TABLE I - Maximum ranges and limits for chemical composition (ladle analysis)

Element	Maximum Range	Maximum Limit
Carbon	.10	.32*
Manganese: Up to 1.00% incl.	.30	---
Over 1.00%	.40	---
Phosphorus	---	.04
Sulphur	---	.04
Silicon: Up to 0.60% incl.	.20	---
Over 0.60% to 1.00% incl.	.30	---
Over 1.00%	.40	---
Nickel	.50	---
Chromium: Up to 1.25% incl.	.30	---
Over 1.25%	.40	---
Molybdenum: Up to 0.20% incl.	.07	---
Over 0.20%	.15	---
Vanadium	.10	---

* See 3.3.2.

3.3.2 Carbon (check analysis).- The carbon content determined by check analysis as specified in 4.11 shall not exceed 0.34 percent for plates up to 4" inclusive in thickness and 0.36 percent for plates greater than 4" in thickness.

3.4 Weldability.- The chemical composition and heat treatment of the armor shall be such that the armor will be suitable for the manufacture of weldments by acceptable production methods.

3.5 Physical properties.

3.5.1 Hardness.- The average surface hardness of each plate including ballistic qualification and acceptance test plates and samples shall be within the range shown in Table II for the applicable thickness. The diameters of Brinell hardness impressions determined on the surface of any plate or sample shall not vary by more than 0.15mm respectively between the maximum and minimum values. When cross-section hardness tests are conducted on ballistic test plates or impact samples 4" or greater in thickness, the average of all hardness tests, both surface and cross-section, shall be within ± 0.05mm of the range specified for the thickness involved.

TABLE II - Brinell hardness requirements.

Specified Nominal Thickness of Plate in inches	Brinell Hardness Range (3000-Kg Load)	Brinell Indentation Diameters in Millimeters
0.25 to less than 0.5	363 - 401	3.20 - 3.05
0.5 to less than 0.75	341 - 388	3.30 - 3.10
0.75 to less than 1.25	331 - 375	3.35 - 3.15
1.25 to less than 2.0	293 - 331	3.55 - 3.35
2.0 to less than 4.0	269 - 311	3.70 - 3.45
4.0 to less than 7.0	241 - 277	3.90 - 3.65
7.0 to less than 9.0	223 - 262	4.05 - 3.75
9.0 to 12.0 incl.	212 - 248	4.15 - 3.85

3.5.2 Impact resistance.- The V-notch Charpy impact resistance of armor submitted either for qualification or for acceptance testing shall meet the requirements shown in table III for the applicable hardness and thickness. When interpolation is necessary, the curve of Figure 1 (which passes through the intercepts of table III) shall be employed to determine the required impact resistance.

TABLE III - Minimum V-notch Charpy impact resistance requirements in ft. lbs. at -40 degrees F. ± 2 degrees F.

Brinell Hardness	Brinell Diameter in Millimeters	Plate Thickness	Average of Original Tests		Average of All Tests When Retesting is Involved	
			Standard Specimen	Special Specimen	Standard Specimen	Special Specimen
207	4.20	4" to 12" incl	57.5	-	53.5	-
212	4.15	" " " "	55.5	-	51.5	-
217	4.10	" " " "	53.5	-	49.2	-
223	4.05	" " " "	50.7	-	47.0	-
229	4.00	" " " "	48.0	-	44.5	-
235	3.95	" " " "	45.5	-	41.7	-
241	3.90	" " " "	43.0	-	39.3	-
248	3.85	" " " "	40.0	-	36.3	-
255	3.80	" " " "	37.0	-	33.5	-
262	3.75	" " " "	34.0	-	30.5	-
269	3.70	4" to 12" incl	31.0	-	27.6	--
277	3.65	" " " "	27.6	-	24.5	--
285	3.60	" " " "	24.5	-	21.0	--
262	3.75	1/4" to less than 4"	46.5	-	43.5	--
269	3.70	" " " "	42.5	-	39.5	--
277	3.65	" " " "	38.4	-	35.4	--
285	3.60	" " " "	34.8	-	32.3	--
293	3.55	" " " "	31.5	-	29.0	--
302	3.50	" " " "	28.0	-	25.5	--
311	3.45	" " " "	25.4	-	23.0	--
321	3.40	" " " "	22.7	-	20.7	--
331	3.35	" " " "	20.6	-	18.6	--
341	3.30	" " " "	18.6	-	16.6	--
352	3.25	" " " "	16.7	-	14.7	--
363	3.20	" " " "	15.0	10.0	13.0	9.0
375	3.15	" " " "	13.5	9.3	11.8	8.3
388	3.10	" " " "	12.4	8.5	11.0	7.5
401	3.05	" " " "	11.5	7.7	10.0	6.7
415	3.00	" " " "	10.7	7.0	9.2	6.0

3.6 Ballistic requirements.

3.6.1 Resistance to penetration normal obliquity.- Each ballistic qualification and acceptance test plate shall be proof-fired for resistance to penetration, and a ballistic limit, BL(A), shall be obtained using the applicable projectile shown in table IV. Minimum requirements for acceptable ballistic limits shall be as shown in that table.

TABLE IV - Resistance to penetration; normal impact

Nominal thickness of plate	Ammunition to be used	Minimum distance between impacts	Minimum ballistic limit BL(A)
Inches		Calibers	Feet per second
1/4 (0.250)	Cal. .30 AP M2	3	1,130
5/16 (0.312)	" " " "	3	1,390
3/8 (0.375)	" " " "	3	1,640
7/16 (0.437)	" " " "	3	1,880
1/2 (0.500)	" " " "	3	2,110
9/16 (0.562	" " " "	3	2,330
9/16 (0.562)[1]	Cal. .50 AP M2	3	1,420
5/8 (0.625)	" " " "	3	1,560
11/16 (0.687)	" " " "	3	1,695
3/4 (0.750)	" " " "	3	1,825
7/8 (0.875)	" " " "	3	2,070
1 (1.000)	" " " "	3	2,300
1-1/8 (1.125)	" " " "	3	2,515
1-1/8 (1.125)[1]	37mm AP M74	3	1,010
1-1/4 (1.250)	" " "	3	1,100
1-1/2 (1.500)	" " "	3	1,280
1-5/8 (1.625)	" " "	3	1,370
1-3/4 (1.750)	" " "	3	1,460
2 (2.000)	" " "	3	1,630
2-1/4 (2.250)	" " "	3	1,790
2-1/4 (2.250)[1]	57mm AP M70	3	1,310
2-1/2 (2.500)	" " "	3	1,450
2-3/4 (2.750)	" " "	3	1,580
3 (3.000)	" " "	3	1,700
3-1/4 (3.250)	" " "	3	1,810
3-1/2 (3.500)	" " "	3	1,910
3-3/4 (3.750)[1]	75mm AP M72	3	1,525
4 (4.000)	" " "	3	1,600
4-1/4 (4.250)[1]	" " "	3	1,675
4-3/4 (4.750)[1]	90mm AP M77	3	1,800
5 (5.000)	" " "	3	1,900
5-1/4 (5.250)[1]	" " "	3	2,000

[1] Value for interpolation only.

3.6.2 Resistance-to-oblique-attack test.- Ballistic qualification and acceptance test plates 3" to 5" inclusive in thickness shall be proof-fired for resistance to oblique attack, and a ballistic limit BL(P) shall be obtained using the projectile shown in table V. Minimum requirements for acceptable ballistic limits shall be as shown in that table.

TABLE V - Resistance-to-oblique attack.

Nominal Thickness of plate Inches	Ammunition to be used	Obliquity- Degrees	Minimum Ballistic Limit BL(P) - Feet per second
2-3/4 (2.750)*	90mm APC M82	45	2,100
3 (3.000)	" " "	45	2,300
3-1/4 (3.250)*	" " "	45	2,500
3-3/4 (3.750)*	" " "	30	2,000
4 (4.000)	" " "	30	2,100
4-1/4 (4.250)*	" " "	30	2,200
4-3/4 (4.750)*	" " "	30	2,400
5 (5.000)	" " "	30	2,500
5-1/4 (5.250)*	" " "	30	2,600

* For purposes of interpolation only.

3.7 Dimensions and permissible variations.

3.7.1 Dimensions.- Plates shall comply with the dimensions shown on the drawings or specified in the contract or order.

3.7.2 Thickness.- The thickness of any plate, including qualification and acceptance ballistic test plates, after final heat treatment shall not vary by more than the amounts shown in table VII.

TABLE VII - Thickness tolerances.

Specified Plate Thickness - Inches	Permissible Variation (Plus or Minus) - Inches
0.25 to 0.500 incl.	0.015
Greater than 0.500 to 1.125 incl.	0.020
" " 1.125 to 1.499 incl.	0.025
" " 1.499 to 1.749 incl.	0.030
" " 1.749 to 1.999 incl.	0.035
" " 1.999 to 2.999 incl.	0.040
" " 2.999 to 4.000 incl.	0.045
" " 4.0 to 6.0 incl.	0.075
" " 6.0 to 8.0 incl.	0.083
" " 8.0 to 10.0 incl.	0.098
" " 10.0 to 12.0 incl.	0.122

3.8 Information required.- A statement showing the ladle analysis of each melt and complete details of the heat treatment of each lot shall be furnished for the files of the contracting officer. All elements of the chemical composition shall be shown in the statement, including special additives or hardening agents, whether shown in table I or not. Unless otherwise specified, this information shall be forwarded on an approved form and with the ballistic test plates to the proving ground making the ballistic test.

3.9 Workmanship.

3.9.1 Heat treatment.- All plates in each lot, including samples, shall receive the same heat treatment except for such variations in tempering temperature as may be necessary to produce the prescribed hardness. The hardening temperature may vary within a range 50 degrees above the temperature used for ballistic test plates, but in no case shall it exceed 1700 degrees F.

3.9.2 Heating.- Local or general heating shall not be performed after the final quenching and tempering operation, except as provided elsewhere in this specification. A detailed outline of the procedure to be used in each operation of the following processes shall be submitted in writing to obtain authorization.

3.9.2.1 Edge preparation.- Oxygen cutting or beveling of edges shall be permitted after final heat treatment provided the procedure is such that no cracks develop on any oxygen-cut edge. Stringers that occur on prepared edges which do not appear as cracks on the prepared edge and which do not exceed the limits of acceptability specified in 4.8 shall not be cause for rejection.

3.9.2.2 Repairing.- Weld repairs shall be made only when authorized by the Chief of the Supply Service involved.

3.9.2.3 Forming.- Forming after the final quenching and tempering operation shall not be done except when authorized by the Chief of the Supply Service involved.

4. SAMPLING, INSPECTION, AND TEST PROCEDURES

4.1 Purpose.- Inspection under this specification shall be for the purpose of:

(a) Qualification of a facility as a manufacturer of wrought armor plate.

(b) Primary acceptance of steel for processing as armor plate.

(c) Acceptance of individual production lots.

4.2 General.- Inspection and tests shall be made in accordance with the requirements of Federal Specification QQ-M-151, unless otherwise specified herein.

4.2.1 Responsibility for inspection and tests.- Unless otherwise specified or authorized, the responsibility for having inspection and tests performed shall be as specified in 4.2.1.1 to 4.2.1.3 inclusive. The results of tests shall be obtained before the material is shipped from the plant having responsibility for them unless otherwise specified. The right is reserved to perform inspection and tests at other places at the discretion of the contracting officer.

4.2.1.1 Chemical analysis and fracture test.- Chemical analysis and fracture tests for steel soundness shall be the responsibility of the plant where the steel is made.

4.2.1.2 Impact and hardness tests.- Charpy impact tests, and hardness determinations shall be the responsibility of the plant where the plate is heat-treated.

4.2.1.2.1 Qualification impact tests.- Charpy V-notch impact tests for qualification for all thicknesses shall be made at a laboratory designated by the procuring agency.

4.2.1.3 Ballistic tests.- Ballistic tests shall be the responsibility of the plant where the steel is heat-treated and shall be made at a place to be designated by the Chief of the Supply Service involved.

4.2.2 Identification of material.- Identification marks and records shall be such as to insure positive identification of all plates, including ballistic test plates for qualification and primary acceptance, samples and specimens with the lot and corresponding heat from which they were produced. The key to identification symbols shall be furnished to the inspector prior to submittal for inspection and test.

4.3 Qualification.

4.3.1 Thicknesses to 5.99" inclusive.- To qualify for thicknesses to 5.99" inclusive, the manufacturer shall submit ballistic test plates and impact test samples as specified in table VI which meet the requirements of this specification. Impact test samples shall be cut from ballistic test plates after heat treatment.

4.3.2 Thickness 6" to 12" inclusive.- To qualify for thicknesses 6" to 12" inclusive, the manufacturer shall submit three samples for each thickness he proposes to make in increments of 2 inches which meet the requirements of this specification. Samples shall be equal in thickness to the maximum thickness to be qualified within each 2-inch increment.

TABLE VI - Ballistic test plates and samples for qualification

Thickness of Plates and Samples*	No. of Ballistic Test Plates	No. of Impact Test Samples per plate	Minimum Size of Ballistic Test Plates Inches	To Qualify for Thickness Range Inches (Incl.)
3/8"	3	1	18 x 36	.25 to less than .50
5/8"	3	1	18 x 36	0.5 to less than .75
1.0"	3	1	18 x 36	0.75 to less than 1.25
1.5"	3	1	18 x 36	1.25 to less than 2.00
2"	3	1	18 x 36	2.00 to 2.99 incl.
3"	3	1	48 x 60	3.00 to 3.99 incl.
4"	3	1	48 x 60	4.00 to 4.99 incl.
5"	3	1	48 x 60	5.00 to 5.99 incl.

* At the option of manufacturer, the exact thickness to be rolled within any range may be substituted for the specified thickness of that range.

4.3.3 Plate representation.- Test plates or samples for qualification testing shall be made of the same chemical composition, by the same steel-making process, and with the same heat treatment as will be used for the production of wrought armor under this specification.

4.3.4 Heat treatment.- All qualification test plates or samples submitted as a group representing a single range of section thicknesses shall receive the same heat treatment.

4.4 Primary acceptance.- Prior to the production heat treatment of any thickness of any heat of steel for armor plate the charpy impact resistance, hardness, soundness, and ballistic properties shall be determined in accordance with 4.6, 4.7, 4.8, and 4.9 respectively. Material tested for impact resistance, hardness, and ballistic properties shall have received the same heat treatment, including the greatest time lag between the removal of the material from the austenitising furnace and the application of the quenching medium, that will be used in production for the lot it represents.

4.4.1 Option in heat treating. In the case of an integrated plant where all material from a heat is to be heat-treated at the same time, impact and hardness tests for primary acceptance shall not be required. In such cases acceptance for impact resistance and hardness shall be based on the results of tests conducted on production material. Testing for acceptance for steel soundness and ballistic resistance shall be as specified in 4.4, except that ballistic test plates may, at the option of the manufacturer, be heat-treated with the production plates of the heat they represent. (See 4.6.3)

4.4.2 Lot, primary. A lot for purposes of primary acceptance testing shall consist of all steel of the same heat, of the same thickness, and intended for the same production heat treatment.

4.5 Production acceptance.- Each lot of production armor plate shall be tested for charpy impact resistance and hardness in accordance with 4.6 and 4.7.

4.5.1 Lot, production. A lot for purposes of production acceptance testing shall consist of all steel of the same base type composition, of the same thickness, having the same treatment and heat treated in the same facility. The maximum size of the lot shall be as specified in table VIII.

4.6 Charpy V-notch impact tests.

4.6.1 Frequency of tests for acceptance testing.- At least 2 impact test specimens shall be taken from each sample in each lot. The number of samples per lot shall be as shown in table VIII.

TABLE VIII - Frequency of sampling

Area or Weight of Individual Plate, as Heat-Treated	Minimum Number of Samples
Greater than 60 square feet	1 from each 25 plates
Greater than 6 to 60 square feet	1 from each 50 plates
1 square foot to 6 square feet	1 from each 100 plates
1 square foot or less or 10 lbs. or less	1 from each 500 plates

4.6.1.1 The product of no heat shall be completely accepted without being represented by at least three impact test samples cut from production plates after heat treatment. Each heat treating facility shall conduct impact tests on at least one sample from each heat processed in that facility.

4.6.2 Number of tests for qualification testing.- One sample shall be cut from each qualification ballistic test plate. At least four impact test specimens shall be taken from each sample.

4.6.3 Number of tests for primary acceptance testing.- Except as provided in 4.4.1, one sample shall be taken from the top of the first usable ingot, one from the middle of the middle usable ingot, and one from the bottom of the last usable ingot in the heat. At least two impact test specimens shall be taken from each sample.

4.6.4 Additional samples.- In addition to the samples required above, further samples may be selected, as required, by the contracting officer or the inspector.

4.6.5 Reduced impact testing for acceptance.- If the results of impact tests on consecutive lots indicate that a satisfactory uniform product meeting the impact requirements is being produced, the number of impact tests may be reduced at the discretion of the Chief of the Supply Service involved.

4.6.6 Size of samples.- The samples shall be the same thickness as the plates they represent and of sufficient size to allow the number of test specimens required by 4.6.1 or 4.6.2 to be taken from them in such a manner that no part of any test specimen shall be from a location closer than 4 inches or 2T, whichever is less, from any quenched edge, as well as outside the heat-affected zone of any oxygen-cut edge. (See 6.5.)

4.6.7 Location of test specimens.

4.6.7.1 Samples less than 4" in thickness.- Specimens from samples less than 4" in thickness shall be taken from a location midway between the top and bottom surfaces of the plate and at least 4" or 2T, whichever is less, from any quenched edge as well as outside the heat-affected zone of any oxygen-cut edge.

4.6.7.2 Samples 4" or greater in thickness.- Specimens from samples 4" or greater in thickness shall be taken from a location such that the centerlines of the specimens are approximately 1" below the surface of the plate and at least 4" from any quenched edge as well as outside the heat-affected zone of any oxygen-cut edge.

4.6.8 Type of specimens.

4.6.8.1 Standard specimens.- Impact specimens from samples 7/16" in thickness or over shall be machined to the form and dimensions shown in figure 2a. Specimens shall be cut in a direction such that the fracture face of the specimen shall be parallel to the direction of major ratio of reduction in gage during working. The notch shall be cut perpendicular to the plate surface. (See 6.2.)

4.6.8.2 Special specimens.- Impact specimens from samples less than 7/16" shall be machined to the form and dimensions shown in figure 2b. Special specimens shall be cut in a direction such that the fracture face of the specimen shall be parallel to the direction of major ratio of reduction in gage during working. The notch shall be cut parallel to the plate surface.

4.6.9 Cooling and fracturing of specimens.- Each specimen shall be brought to a temperature of -40 degrees ± 2 degrees F. and maintained at that temperature in a liquid cooling medium for a period of at least 15 minutes prior to being broken. Specimens shall be broken in a beam-type impact testing machine within 5 seconds after removal from the cooling medium.

4.6.10 Interpretation of test results.

4.6.10.1 Qualification.- The impact resistance obtained on all specimens, taken from samples of the same thickness, which were submitted for qualification at the same time, shall be averaged. Failure of this average to meet the minimum requirements, for the appropriate hardness range specified in table III, shall be cause for rejection of the lot represented by the specimens. The hardness shall be the average of all hardness readings determined in accordance with 4.7.1.2 and 4.7.4.2.

4.6.10.2 Primary acceptance.- The impact resistance obtained on all specimens taken from each sample shall be averaged. Failure of the average obtained on any sample to meet the minimum requirements, for the appropriate hardness range specified in table III, shall be cause for rejection of all material from the heat which is taken from the same ingot location. In the event of such a failure all material bracketed by two acceptable samples shall be considered acceptable. The hardness shall be the average of all hardness readings determined on each specimen in accordance with 4.7.1.2.

samples representing

4.6.10.3 Production acceptance.- The impact resistance obtained on all specimens from a lot shall be averaged. Failure of this average to meet the minimum requirements, for the appropriate hardness range, specified in table III, shall be cause for rejection of the lot represented by the specimens. The hardness shall be the average of all hardness readings determined in accordance with 4.7.1.2 and 4.7.4.2.

4.6.10.4 In the event that the fracture of a test specimen exhibits a lamination which is revealed as an open split; or sharply defined shelves extending the full width of the fractured surface additional test specimens shall be prepared from the same sample until a satisfactory specimen is obtained to replace it.

4.7 Hardness tests.

4.7.1 Frequency of tests.-

4.7.1.1 Production plates and ballistic test plates.- Each plate in each lot, including acceptance ballistic test plates and qualification ballistic plates, shall be subjected to a Brinell hardness test in not less than two places on each face. Hardness tests may be made on the surfaces of pieces cut from the plate after heat treatment.

4.7.1.1.1 After it has been established to the satisfaction of the Government inspector that uniformly identical readings are obtained on both faces of plates he may, at his option, require that Brinell hardness testing be conducted on only one face. When this practice is used periodic check tests on both faces shall be made to insure that uniform hardnesses are being maintained.

4.7.1.2 Samples for impact test.- Each sample from which impact test specimens are taken shall have a cross-section hardness check made upon it, as follows: For samples less than 7/16" in thickness, a minimum of two hardness readings shall be taken on the surface. For samples 7/16" or greater to 3.99" in thickness, a minimum of two hardness readings shall be taken from a location midway between the surfaces of the plate. For samples 4" or greater in thickness, at least six hardness readings, equidistantly across the thickness of the plate, shall be taken. The average hardness samples 4" or greater in thickness shall fall within a range of ± .05mm of the range specified for the thickness involved.

4.7.2 Preparation for testing.-

4.7.2.1 Surface hardness.- Prior to testing the surface hardness of plates, all surface scale and decarburization shall be removed from the areas where the tests are to be made.

4.7.2.2 Cross-sectional hardness.- Sections upon which cross-sectional hardness tests are to be made shall be surface ground with the opposite faces parallel to one another.

4.7.3 Method of test.- Brinell hardness tests shall be made with a standard Brinell hardness testing machine, using a 10mm carbide ball and a 3000-kilogram load.

4.7.4 Interpretation of test results.

4.7.4.1 Surface hardness of production plates and ballistic test plates.- The hardness values obtained on each plate shall be averaged. If the average thus obtained is outside the range specified in Table II, or if the diameters of Brinell impressions made on any one plate vary by more than 0.15mm between the maximum and minimum values, the plate shall be subject to rejection.

4.7.4.2 Samples for impact tests.- The hardness readings obtained in accordance with 4.7.1.2 on all samples except primary acceptance test samples shall be averaged. For primary acceptance test samples the readings obtained on each sample shall be averaged separately (see 4.6.10.2). The average thus obtained shall be used to determine the level of impact resistance applicable to the lot as specified in Table III.

4.8 Fracture test for steel soundness.

4.8.1 Location of specimens for acceptance testing.- Specimens for the fracture test for acceptance testing shall be taken from plates from the top, middle, and bottom of the first, middle, and last usable ingots of each heat. Each fracture test specimen shall be cut from a location in the plate rolled from a slab so that the centerline of the sample falls within the central half of the length of the plate product of the slab in the case of cross-rolled plate and the width of the plate product of the slab in the case of transversely spread and longitudinally rolled plate. The test specimen shall be from the edge corresponding to the top of the slab in the case of top-slab and middle-slab products and from edge corresponding to the bottom of the slabs in the case of bottom-slab products. (See figure 3.)

4.8.1.1 When an ingot is processed into a single plate, specimens for fracture tests shall be taken from locations representing the top and the bottom of the ingot only and from locations as specified in 4.8.1.

4.8.2 Location of specimens for qualification testing.- Specimens for the fracture test for qualification testing shall be cut from a location in the plate rolled from a slab so that the centerline of the sample falls within the central half of the length of the plate product of the slab in the case of cross-rolled plate and the width of the plate product of the slab in the case of transversely spread and longitudinally rolled plate.

4.8.3 Size of specimens.- The fracture test specimens shall be of the full thickness of the plate, and a convenient length for fracturing under the press available. The long dimension shall be parallel to the direction of major ratio of reduction in gage. Dimensions of specimens shall be such as to provide, after notching, the following minimum width of fracture surface, as shown in table IX.

TABLE IX - Width of fracture surfaces.

Plate Thickness (Inches)	Minimum Width of Fracture Surface (Inches)
1/4 to 11/16, inclusive	3
Greater than 11/16, to 1-1/8, incl.	4
Greater than 1-1/8, to 2, incl.	5
Greater than 2, to 12, incl.	6

4.8.4 Preparation and fracturing of specimens.- The specimen shall be nicked in from the edges of the specimen at the center of, and perpendicular to, the longitudinal axis and shall be broken slowly in a press. In addition to the nicking prescribed above, specimens greater than 4" in thickness may be nicked on one surface to a depth not to exceed 1/2" to facilitate breaking. The steel soundness shall be rated only on fractures exhibiting a fibrous appearance. To avoid crystalline fractures, fracture test specimens may be softened by tempering at any desired temperature.

4.8.5 Standards for steel soundness.- To determine compliance with 3.1.2, all fractures made in connection with inspection for acceptance under this specification shall be rated as "acceptable" or "rejectable" by the inspector in accordance with the line drawings shown in figure 4.

4.8.5.1 Descriptions.- In borderline cases, the following descriptions of the standards shall be used in making decisions as to acceptability or rejectability (see figure 4):

A Fracture
- (a) Devoid of visible laminations.

B Fracture
- (a) Small laminations present but well distributed and not concentrated in any one plane.

C Fracture
- (a) Lamination or laminations present exceed limits for "B" fracture.
- (b) No single lamination exceeding 2T in length or 3", whichever is less.
- (c) No single lamination exceeding 1-1/2T or 3" in length, whichever is less, in conjunction with another disconnected lamination in the same plane.
- (d) No lamination or laminations in any one plane with a total length exceeding 50 percent of length of fracture.

D-1 Fracture
- (a) Lamination or laminations present exceeding limits for "C" fracture but contained entirely within the center third of the plate cross section.
- (b) Continuous or essentially continuous laminations (total length of lamination or laminations in same plane exceeding 50 percent of length of fracture, or 3", whichever is less) in not more than three planes, all of which are entirely within the center third of the plate cross section.

D-2 Fracture
- (a) Lamination or laminations present exceeding limits for "C" fracture, with one or more planes of such laminations located outside of the center third of the plate cross section.
- (b) Continuous or essentially continuous laminations (total length of lamination or laminations exceeding 50 percent of length of fracture) in not more than three planes, one or more of which is located outside of the center third of the plate cross section.

E Fracture
- (a) Continuous or essentially continuous laminations (total length of lamination or laminations in same plane exceeding 50 percent of length of fracture) in not more three planes located anywhere in plate cross section.

4.8.5.2 Thickness in heat.- When a heat is rolled into more than one thickness, the product of each thickness, for the purpose of fracture soundness tests, shall be considered as a separate heat and the standard prescribed in 4.8.5 for the applicable thickness shall apply.

4.8.5.3 Rejection.- Failure of any fracture test specimen to meet the standards shown in 4.8.5 shall be cause for rejection of the product of the slab represented.

4.8.5.3.1 Ingot location.- In case of failure of one or more of the three specimens from a given ingot location, the following procedure shall apply:

4.8.5.3.1.1 Rejectable.- The product of all slabs bracketed by two rejectable fractured specimens shall be subject to rejection.

4.8.5.3.1.2 Acceptable.- The product of all slabs bracketed by two acceptable fracture specimens shall be considered acceptable with regard to freedom of laminations and injurious inclusions.

4.8.5.3.1.3 Border-line.- When slabs of a given ingot location are bracketed by one acceptable and one rejectable fracture test specimen, a fracture test shall be made on a specimen from the same location in an ingot in the middle of the group bracketed by original test specimens and the test specimen from the middle of the group.

4.8.5.3.2 Slab bracketing.- In bracketing tested slabs, for those from which fractured test specimens have been taken and tested in accordance with 4.8.1 to 4.8.4 inclusive, the following procedure shall apply:

4.8.5.3.2.1 Ingots of six or more slabs.- Product to be bracketed between tested slabs of the same ingot, as well as between tested slabs from the same location in other ingots. Should a slab be bracketed in one direction by two acceptable test slabs and in the other by one acceptable and one rejectable test slab, the slab thus bracketed will be considered rejectable, unless otherwise definitely indicated by additional fracture tests.

4.8.5.3.2.2 Ingots of five slabs.- Product to be bracketed only between tested slabs in the same ingot position. Acceptability of the No. 2 and the No. 4 slabs shall be determined by the results of the fracture test on the bottom of the No. 3 slab.

4.8.5.3.2.3 Ingots of four slabs.- Product to be bracketed only between tested slabs in the same ingot position. Acceptability of the No. 3 slab shall be determined by the results of the fracture test on the bottom of the No. 2 slab.

4.8.5.4 Rejection of individual plates.- Any plate from which an unacceptable fracture test sample has been cut shall be subject to rejection.

4.8.5.5 Acceptance of individual plates.- Individual plates from an ingot location subject to rejection under 4.8.5.3 may be accepted if an acceptable fracture test sample has been cut from them, provided no rejectable fracture test sample has been cut from them.

4.9 Ballistic test. (See 6.3.)

4.9.1 Ballistic test plates for qualification.- The number and sizes of ballistic test plates for qualification shall be in accordance with the requirements of table VI.

4.9.2 Ballistic test plates for primary acceptance.- Each primary lot of armor shall be represented by one ballistic test plate of the thickness of the lot involved. The size of the acceptance ballistic test plates shall correspond to the size given in table VI.

4.9.3 Ballistic test plates for qualification and primary acceptance tests shall be tested to determine compliance with the requirements of 3.6. (see 6.4).

4.9.4 Definitions.

4.9.4.1 Army complete penetration, CP(A).- An Army complete penetration will have been obtained when a hole is made that allows the passage of light through the test plate, or when any part of the projectile in the plate can be seen from the rear of the test plate. If it is questionable whether any part of the projectile can be seen, the round shall be disregarded and another round shall be fired.

4.9.4.2 Protection complete penetration, CP(P).- A protection complete penetration is an impact that causes any fragments of projectiles or plates to pass beyond the limits of the back of the plate. This condition shall be determined by perforation of a 0.020-inch thick aluminum-alloy sheet (24ST or equivalent) placed 6 inches to the rear and parallel to the plate, or the equivalent thereof, at the discretion of the proof officer.

4.9.4.3 Partial penetration, PP(A) or PP(P).- Any fair impact that is not a complete penetration shall be considered a partial penetration.

4.9.4.4 Fair impact.- An impact which is three calibers or more away from another impact or two calibers or more away from any plate edge is a fair impact.

4.9.4.5 Ballistic limit BL.- The ballistic limit is the average of two velocities, one of which is the lowest at which a complete penetration occurs, and the other the highest partial penetration below the complete penetration. The difference between the two velocities shall not exceed 50 feet per second when projectiles 37mm in diameter or less are used, or 30 feet per second when projectiles greater than 37mm in diameter are used.

4.9.4.6 Impact velocities.- The required impact velocities for ballistic limits (tables IV and V) between two consecutive tabulated thicknesses, shall be determined by the correction factors shown in tables I and II.as applicable.

4.9.4.7 *Thickness determination.* The average thickness of test plates shall be the average of five thickness measurements, one at each corner of the plate, 2 inches from either edge, and one at the center. Thickness readings shall be taken to the nearest 0.01 inch.

4.9.4.8 Cracking - Cracking of ballistic test plates to such an extent that, in the opinion of the proof officer, satisfactory ballistic limit determinations cannot be made shall constitute failure of the ballistic tests and the rejection requirements of 4.9.5 or 4.9.6 shall apply.

4.9.4.9 Laminations or inclusions.- When the ballistic tests reveal injurious laminations or inclusions in any test plate that in the opinion of the Chief of the supply service involved, are detrimental to the strength, ballistic properties or serviceability of the armor, the material represented by the plate shall be subject to rejection.

4.9.5 Failure of qualification test plate.- Failure of any one of the qualification ballistic test plates or test samples to meet any of the tests when inspected in accordance with this specification shall be cause for rejection of the manufacturing process represented by the thickness of the failing plate or plates. No retesting of the originally submitted qualification ballistic test plates shall be permitted. To achieve qualification, the manufacturer must submit 3 new ballistic test plates all of which shall pass all tests outlined in this specification.

4.9.6 Failure of primary acceptance test plates.- Failure of the primary acceptance ballistic test plate to meet any of the tests when inspected in accordance with this specification shall be cause for rejection of the lot represented by the failing plate.

4.10 Retesting.

4.10.1 Hardness.- Plates rejected for low or high hardness may be retested without retreatment at the option of the contractor. Under such conditions twice the original number of hardness readings shall be taken and the results of all readings taken on the plate shall be averaged to determine compliance with the requirements of table II. Plates rejected for high hardness may be retempered, in which case only those readings taken after retempering shall be used to determine acceptability. Plates rejected for low hardness may be requenched and retempered, in which case testing shall be conducted in accordance with the requirements for original testing.

4.10.2 Primary and production impact resistance.- A primary sample or production lot rejected for low impact resistance may be retested without retreatment by taking not less than six additional specimens from the steel under consideration. Additional specimens shall be taken from the same sample as the original tests. If the average impact resistance of all tests from the sample meets the requirements of table III for the appropriate hardness range, the primary sample or production lot shall be accepted, otherwise it shall be subject to rejection.

4.10.3 Ballistic properties.- A primary lot rejected for failure of primary acceptance ballistic test plates to meet the requirements of 3.6 may be retested using the same heat treatment at the option of the contractor. Under such conditions, two additional plates shall be submitted from the lot under test. Failure of either of these plates shall be cause for rejection of the lot represented and no further testing shall be permitted on the material using the same heat treatment.

4.10.4 Retest after reheat treatment.- A primary sample or production lot that has been rejected may be reheat-treated by quenching and tempering and resubmitted for test in accordance with the requirements for original testing. Failure of samples and or ballistic test plates after reheat treatment shall be cause for rejection of the lot they represent. However, production plates rejected for failure to meet the impact resistance requirements may be accepted individually on the basis of tests made on each plate.

4.10.4.1 Production plates that are retempered only to meet the hardness requirements shall not be subject to retest for impact resistance. Production plates requenched and retempered to meet the hardness requirements shall be tested for impact resistance and hardness as a new lot.

4.11 Check analysis for carbon content.- The sample shall be taken by drilling or milling completely through the plate at any location. Surface chips shall be discarded and the remaining chips shall be thoroughly mixed before analysis.

5. PREPARATION FOR DELIVERY

5.1 Preparation.- Unless otherwise specified all machined surfaces of plates shall be coated with a suitable preventive to insure against corrosion during transportation. Machined surfaces shall be clean and free from moisture before this coating is applied. The preventive coating shall be such as can be easily removed.

5.2 Packing for shipment.- All plates shall be packed for shipment in such a manner as to insure acceptance by common or other carrier, for safe transportation, at the lowest rate, to the point of delivery.

5.3 Marking for identification.- Plates (green and heat-treated) shall be indelibly and legibly marked with the melt, heat, and lot number or symbols that will definitely identify the plates with inspection and test reports and with shipping documents.

6. NOTES

6.1 Intended use.- The armor specified herein is for use on combat vehicles, emplacements, and the like. It is for protection against armor-piercing projectiles, bursting shell, and fragments of high-explosive ammunition.

6.2 Impact specimen.- Tolerances on the notch of the Charpy impact test specimens may be checked by means of a comparator or metalloscope at a magnification of at least ten in the following manner: Project the profile of the base of the notch on the ground glass; fit a circle with a radius .10" (10X) drawn on transparent paper to the profile of the notch base. Deviations of .001" from the standard .01" radius can be detected by this means. If there is any question as to the radius, it may be compared with circles of .09" and .11" (10X). At the time the radius is measured, the notch may be checked to ascertain that the sides make an angle of 45 degrees and are tangent to the arc at the notch.

6.3 Ownership of ballistic test plates.

6.3.1 Qualification test plates.- Qualification test plates are the property of the manufacturer seeking qualification. Arrangements should be made by him to have them returned at the conclusion of ballistic tests or to authorize, in writing, the scrapping of the plates by the proving ground making the tests.

6.3.2 Acceptance test plates.- Acceptance test plates that comply with the requirements of this specification are considered as part of the lot of steel they represent and ownership of them passes to the Government with the acceptance of that lot. Acceptance test plates that fail to comply with the requirements of this specification are considered as part of the lot they represent and remain the property of the producer just as does the rejectable lot they represent.

6.4 Acceptability criteria.- When the ballistic limit is actually less than that called for by applicable requirements, the plate may be accepted under border conditions as follows.

6.4.1 Criterion on 50 f/s difference.- Acceptance is granted in those cases where a 50 f/s difference between the high-partial and low-complete penetration is allowed for ballistic-limit determination when a partial occurs at or above the specified minimum impact velocity minus 25 f/s, providing no complete penetration is obtained at or below the required minimum impact velocity.

6.4.2 Criterion on 30 f/s difference.- Acceptance is granted in those cases where a 30 f/s difference between the high-partial and low-complete penetration is allowed for ballistic-limit determination when a partial occurs at or above the specified minimum impact velocity minus 15 f/s, providing no complete penetration is obtained at or below the required minimum impact velocity.

6.5 Thickness.- The symbol "T" is used throughout this specification to indicate the nominal thickness of the plate under consideration.

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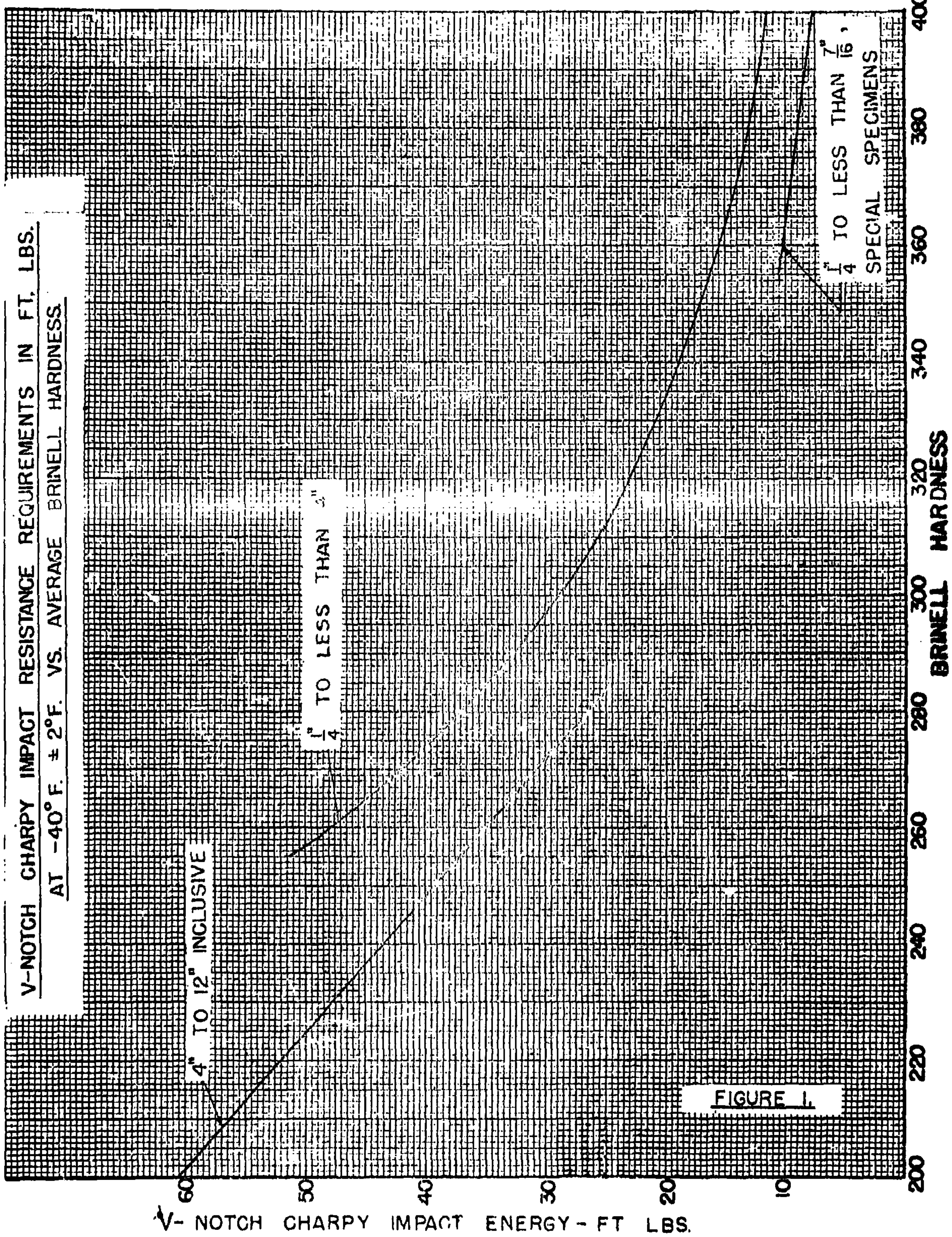
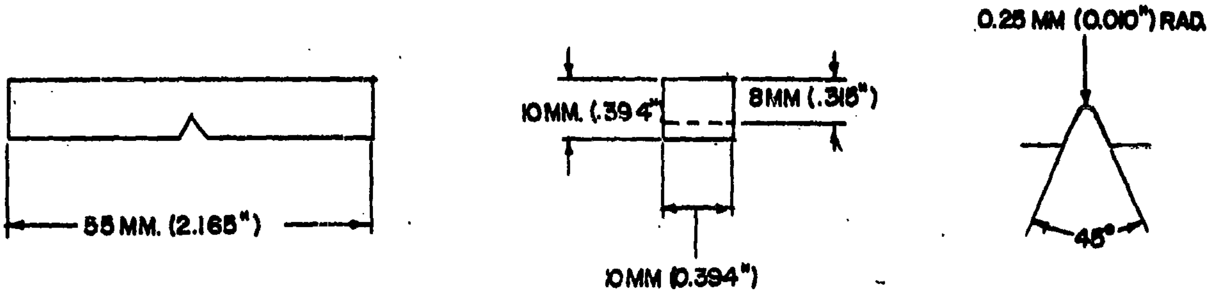
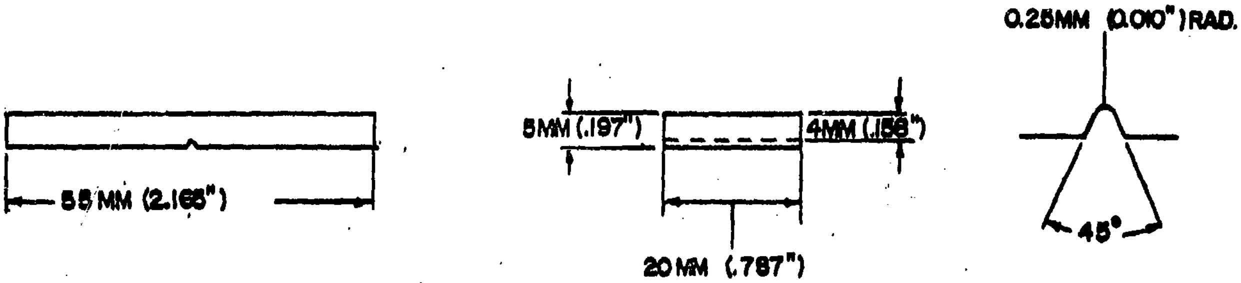


V-NOTCH CHARPY IMPACT RESISTANCE REQUIREMENTS IN FT. LBS.
AT -40° F. ± 2°F. VS. AVERAGE BRINELL HARDNESS
4" TO 12" INCLUSIVE
1/4" TO LESS THAN 4"
1/4" TO LESS THAN 7/16", SPECIAL SPECIMENS
FIGURE I.
BRINELL HARDNESS
200
220
240
260
280
300
320
340
360
380
400
V- NOTCH CHARPY IMPACT ENERGY - FT LBS.
60
50
40
30
20
10



STANDARD V-NOTCHED CHARPY SPECIMEN

FIGURE 2a

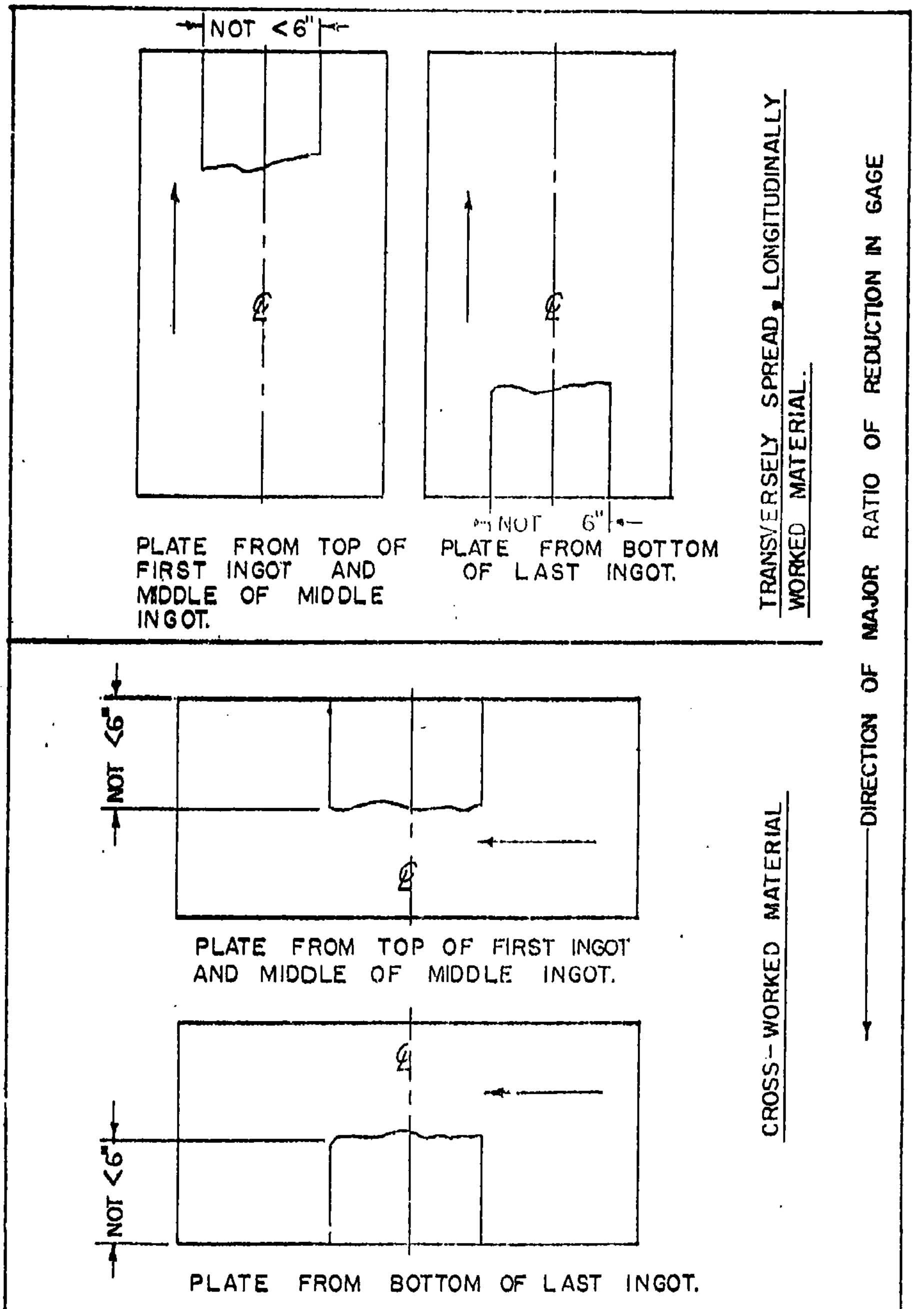


SPECIAL V-NOTCHED CHARPY SPECIMEN

FIGURE 2b

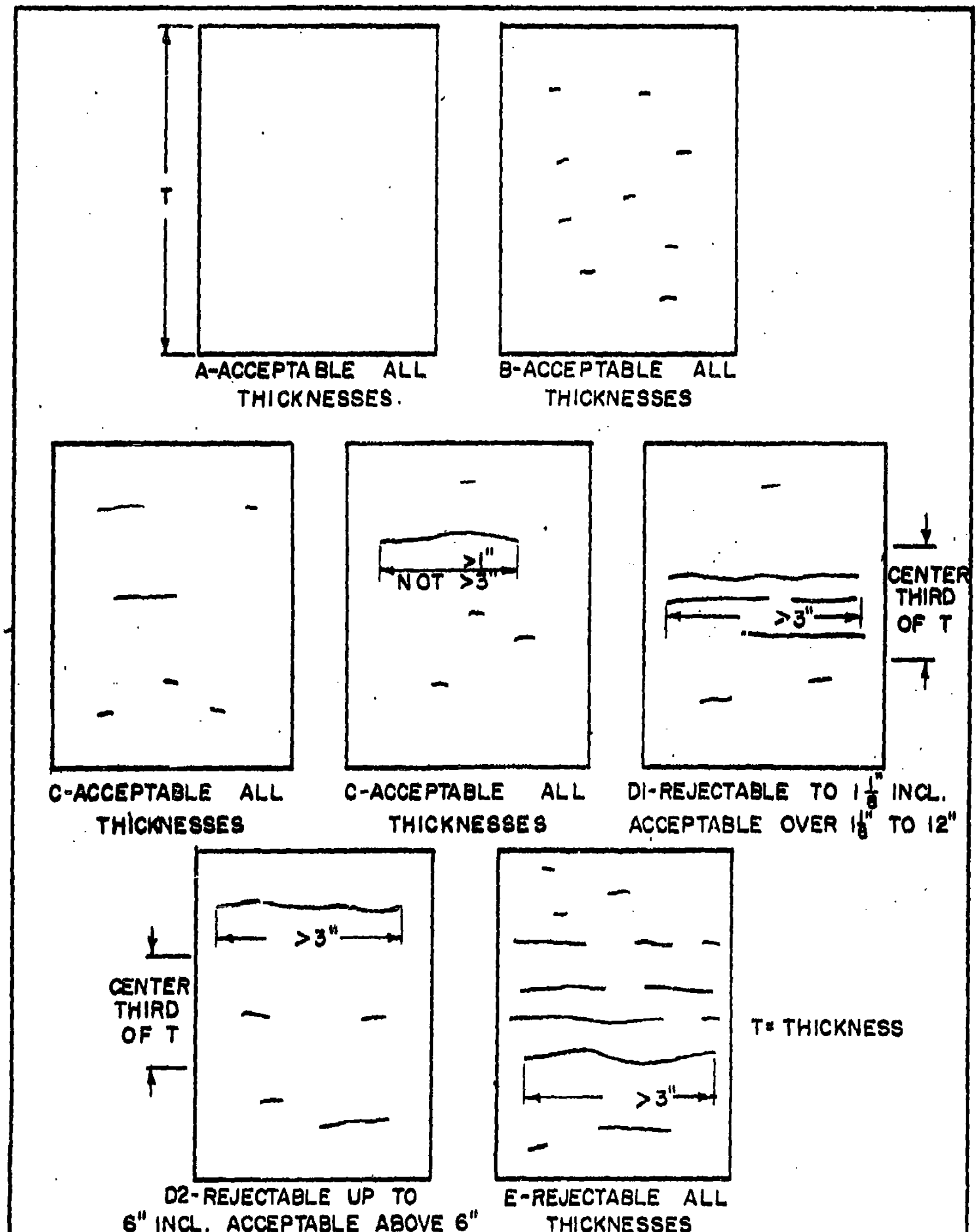
NOTES: PERMISSIBLE VARIATIONS: (tolerances)

CROSS-SECTIONAL DIMENSIONS ± 0.025 MM (0.001")
LENGTH OF SPECIMEN........ ± 0.25 MM (0.010")
ANGLE OF NOTCH............ ± 1°
RADIUS.................... ± 0.001"
OUT-OF-SQUARENESS......... ± 0.001"
(OF ADJACENT SURFACES)



SAMPLING PROCEDURE, INGOT AND PLATE LOCATIONS FOR FRACTURE TEST SAMPLES (STEEL SOUNDNESS)

FIGURE 3.



FRACTURE STANDARDS FOR ROLLED PLATE
1/4" TO 12" IN THICKNESS.

FIGURE 4

APPENDIX A

Part II

Military Specification MIL-A-11356B (ORD)
Armor, Steel, Cast, Homogeneous; Combat-vehicle-type
(1/4 to 12 inches, Inclusive)

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373

MIL-A-11356B(Ord)
NOTICE - 1
28 October 1954

MILITARY SPECIFICATION

ARMOR, STEEL, CAST, HOMOGENEOUS; COMBAT-VEHICLE TYPE (1/4 to 12 Inches, Inclusive)

This notice forms a part of specification MIL-A-11356B dated 10 September 1953, and shall constitute the covering page of the specification.

The security classification of MIL-A-11356B, dated 10 September 1953, is changed from "Restricted Security Information" to "Confidential Modified Handling Authorized" as of the date of this Notice.

Change the words "Restricted Security Information" appearing at the top and bottom of each page of the specification to read "Confidential Modified Handling Authorized" to indicate the proper security classification.

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

Authentication:
CHESTER D. NIELSON
Lt Col, Ord Corps
Office, Chief of Ordnance

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#419

MIL-A-11356B (ORD)
AMENDMENT-2
10 September 1953
SUPERSEDING
AMENDMENT-1
28 May 1953

MILITARY SPECIFICATION

ARMOR, STEEL, CAST, HOMOGENEOUS; COMBAT-VEHICLE TYPE
(1/4 to 12 Inches, Inclusive)

The following changes shall be made in Specification MIL-A-11356B (ORD), dated 2 January 1953:

*Page 9, para. 4.5.1.8. Delete and substitute:

"4.5.1.8 Interpretation of test results.- Except as provided in 4.5.1.8.1 the impact resistance obtained on all specimens from a block shall be averaged and the excess or deficiency of this average determined over or under the minimum requirement, for the appropriate hardness range. The excesses (plus) and deficiencies (minus) thus determined for all blocks from the lot shall be averaged. If the average of the excesses (plus) and deficiencies (minus) from a lot is less than zero, the lot represented shall be subject to rejection. The hardnesses shall be those determined in accordance with 4.5.2.1.2 and 4.5.2.4.2."

*Page 11, para. 4.5.2.4.2. First sentence:

Delete "all blocks" and substitute "each block".

Second sentence:

Delete "lot" and substitute "block".

*Page 12, paragraph 4.6.2. Delete last sentence and substitute:

"The excesses and deficiencies shall be redetermined for each block and the average excess or deficiency redetermined for the lot. If the average of the excesses (plus) and deficiencies (minus) from a lot, after redetermination, is less than zero, the lot represented shall be subject to rejection."

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Page 35, Table B-II. Delete in its entirety and substitute the following table:

"TABLE B-II CLASSIFICATION OF DEFECTS
FOR THICKNESS 1/4 to 12 INCHES INCLUSIVE

Classifications A & B; Defects subject to complete heat treatment after being welded; i.e., hardened and tempered, shall be classified as Class A. Defects subject to tempering only shall be classified as Class B. Extent of heat treatment (i.e., complete or tempering) shall be as established by the recorded repair welding procedure.

Size of defect	Depth, Maximum	Surface Area, Maximum
1	T	100 sq. in. or 30T sq. in. (whichever is greater)
2	T	T width, no limit in length
3	1/4T	250 Sq. in. or 80T sq. in. (whichever is greater)
4	1/8T to 3/16 in.	No limit

Classification C; Defects requiring no thermal treatment after welding.

Size of defect	Depth, Maximum	Surface Area, Maximum
1	T to 4 in.	2 in. width, 8 in. length
2	T to 2 in.	24 Sq. in.
3	1/2T to 1 in.	36 Sq. in.
4	1/4T to 1/2 in.	48 Sq. in.
5	1/8T to 3/16 in.	96 Sq. in.

Notes:

1. The symbol "T" as used in this table represents the thickness of the casting at the location involved.
2. If the dimensions of any size of defect in the C condition does not exceed 1/2 of that allowed above, both for depth and area, and if the electrode employed is one that has been qualified ballistically, a ballistic qualification plate will not be required.
3. For the A & B conditions only, a size-1 defect may be repaired within the boundary of a size-3 or -4 defect, provided the total area does not exceed that allowed for the size-3 or -4 defect and the repaired area for size-1 defect does not exceed the area allowed for that category."

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*Asterisk indicates changes differing from or in addition to previous amendment.

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364

MIL-A-11356B(ORD)
2 January 1953
SUPERSEDING
MIL-A-11356A(ORD)
20 December 1951

MILITARY SPECIFICATION

ARMOR, STEEL, CAST, HOMOGENEOUS; COMBAT-VEHICLE TYPE (1/4 TO 12 INCHES, INCLUSIVE)

1. SCOPE

1.1 This specification covers two grades of cast steel, combat-vehicle-type homogeneous armor in thicknesses from 1/4 to 12 inches inclusive. (See 6.1.)

1.2 Classification.-

1.2.1 Grade-1 cast armor is armor which is so heat-treated that maximum resistance to penetration is developed.

1.2.2 Grade-2 cast armor is armor which is so heat-treated that maximum resistance to shock is developed.

2. APPLICABLE SPECIFICATIONS AND STANDARDS

2.1 The following specifications and standards, of the issue in effect on the date of invitation for bids, form a part of this specification:

SPECIFICATIONS

FEDERAL

QQ-M-151 - Metals, General Specification for Inspection of

MILITARY

MIL-R-11469(ORD) - Radiographic Inspection; Soundness Requirements for Steel Castings

STANDARDS

MILITARY

MIL-STD-129 - Marking of Shipments

(Copies of specifications and standards required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 Material and workmanship.

3.1.1 Structure.- Processes of manufacture shall be such as to produce armor having, as nearly as practicable, a homogeneous structure throughout.

3.1.2 Heat treatment.- All castings in each lot shall receive the same heat treatment except for such variations in tempering temperatures as may be necessary to produce the prescribed hardness.

3.1.3 Soundness.- Finished castings shall be free of blow holes, porosity, shrinkage, cracks, and other defects that may be detrimental to strength or ballistic value.

3.1.4 Heating after final heat treatment.- General heating in the temperature range above 600 degrees F. shall not be performed after the final hardening and tempering operation, except when the manufacturer is qualified for this procedure by the procuring agency. Local or general heating in a temperature range up to 600 degrees F. shall be permitted.

3.1.5 Edge preparation.-Oxygen cutting or beveling of edges shall be permitted after final heat treatment provided the procedure is such that no cracks develop on any oxygen-cut edge.

3.1.6 Weld repairs.- Weld repairs on castings produced under this specification shall be performed in accordance with the applicable requirements of Appendix B.

3.2 Qualification.- Castings submitted under this specification shall be produced by a manufacturer whose product has been qualified in accordance with Appendix A. Only manufacturers qualified to produce Grade 1 castings shall be permitted to produce Grade 2 castings.

3.2.1 Requalification.- Manufacturers that have been out of production for a period of 6 months or more may be required to requalify in accordance with Appendix A.

3.3 Chemical requirements.-

3.3.1 Composition.- The chemical composition of all castings shall be within the limits established by the manufacturer at the time of qualification and shall conform to the requirements of Table I. In addition to those elements for which limits are specified in Table I, the percentages of all other elements or materials intentionally added shall be declared. All limits established by the manufacturer shall be submitted in advance to the contracting officer. The manufacturer may establish and submit separate limits for each thickness of casting for which he desires to be qualified. (See Appendix A.) Changes in composition shall not necessarily be cause for requalification but shall be subject to review by the contracting officer to determine whether requalification may be required.

TABLE I - Maximum ranges and limits for chemical composition (ladle or check analysis).

Element	Maximum Range	Maximum Limit
Carbon	.10	.35
Manganese; Up to 1.00%[2] incl.	.30	---
Over 1.00%[2]	.50	---
Phosphorus	---	.05
Sulphur	---	.05
Silicon	.50	---
Nickel	.70	---
Chromium; Up to 1.50%[2] incl.	.50	---
Over 1.50%[2]	.70	---
Molybdenum	.20	---
Vanadium	.10	---
Copper	.50	---
Aluminum	---	---(1)
Boron	---	---(1)
Titanium	---	---(1)
Calcium	---	---(1)

(1) To be reported as amount added. (See 3.9.)
(2) Average of declared range.

3.4 Weldability.- The chemical composition and heat treatment of the armor shall be such that the armor will be suitable for the manufacture of weldments by production methods.

3.5 Physical properties.-

3.5.1 Hardness.- The average hardness of each casting, including ballistic test plates, shall be within the range shown in Table II for the casting thickness as established by the applicable drawing. The diameter of Brinell hardness impressions determined on any one casting shall not vary by more than 0.25mm between the maximum and minimum. The average hardness of test samples shall be within a range of ± 10 points Brinell or ± .05mm impression diameter whichever is greater, of that specified for the casting thickness involved.

TABLE II - Brinell hardness requirements (3000-Kg load).

Casting Thickness Specified - Inches	Armor Grade	Brinell Hardness Range	Brinell Diameter Range - Millimeters	Rockwell C Hardness Range
1/4 to 1-1/4 incl.	1	302-341	3.50-3.30	32 - 35.5
1/4 to 1-1/4 incl.	2	241-293	3.90-3.55	22 - 30
Over 1-1/4 to 2-1/4 incl.	1&2	241-293	3.90-3.55	22 - 30
Over 2-1/4 to 3-3/4 incl.	1&2	229-269	4.00-3.70	19.5 - 27
Over 3-3/4 to 7 incl.	1&2	217-262	4.10-3.75	16.5 - 25.5
Over 7 to 12 incl.	1&2	201-241	4.25-3.90	13 - 22

3.5.2 Impact resistance.- The V-notch Charpy impact resistance of armor shall meet the requirements shown in Table III for the applicable hardness.

TABLE III - Minimum V-notch Charpy impact resistance requirements in ft. lbs. at -40 degrees F. ± 2 degrees F.

Brinell Hardness Numbers (See 4.5.2.1.2)	Rockwell C Hardness Numbers	Minimum Impact Resistance Average of Two or More Tests
Inclusive	Inclusive	Foot Pounds
191 - 200		48
201 - 212	13.0 - 15.0	43
213 - 229	15.1 - 19.5	38
230 - 248	19.6 - 23.4	33
249 - 269	23.5 - 26.8	28
270 - 277	26.9 - 27.9	26
278 - 285	28.0 - 29.0	24
286 - 302	29.1 - 31.1	21
303 - 311	31.2 - 32.2	18
312 - 321	32.3 - 33.3	15
322 - 331	33.4 - 34.4	13
332 - 341	34.5 - 35.4	11
342 - 352	35.5 - 36.6	10

3.6 Ballistic requirements.- Ballistic requirements shall be as specified in the applicable requirements of Appendix A.

3.7 Dimensions and permissible variations for production castings.- Both the thickness tolerance (see 3.7.1) and the weight tolerance (see 3.7.2) shall indicate tolerance limits in one direction only. The absence of a tolerance in the other direction does not mean a limitation of zero tolerance. The plus tolerance for thickness shall be controlled by the weight limitations, and the minus tolerance for weight shall be automatically controlled by the limitations on thickness.

3.7.1 Thickness.- Unless otherwise specified, the thickness of any section shall not vary from that shown on the drawing by more than -5 percent or by minus 1/16 inch, whichever is greater.

3.7.2 Weight.- Unless otherwise specified, the weight of any casting shall not vary from that shown on the drawing or in the contract or order by more than +5 percent.

3.7.2.1 For casting designs for which official weights have not been established and specified, the weight of any casting shall not vary by more than +5 percent from the average weight of not less than the first ten castings shipped for production vehicles. The official weight of castings may be reestablished at any time considered necessary for the improvement of military characteristics.

3.8 Casting identification.- In addition to the marking required by 5.3, each casting subjected to radiographic inspection shall be legibly and indelibly marked to assure positive identification until after final acceptance is made.

3.9 Information required.- The manufacturer shall furnish, for the files of the contracting officer, a statement showing the ladle analysis of each melt and the hardness and impact test results of each lot. All elements of the chemical composition shall be shown in the statement, including special additives or hardening agents, whether shown in Table I or not.

3.9.1 Changes in casting procedure.- If, at any time, important changes are made in casting procedure, the manufacturer shall notify the Government inspector in writing. Important changes shall be considered to be any one or more of the following:

(a) A change in gate or riser system, including type, size, and location.
(b) A change in internal and external chills; size, type, and location.
(c) A change in positioning of pattern within the flask.

4. SAMPLING, INSPECTION, AND TEST PROCEDURES

4.1 Purpose of inspection.- Inspection under this specification shall be for the purpose of:

(a) Qualification:

(1) As a producer of cast armor (see Appendix A)
(2) Of a casting procedure (see 4.4)

(b) Acceptance of individual production lots.

4.2 General.- Inspection and test procedures required by this specification shall be made in accordance with the requirements of QQ-M-151, unless otherwise specified herein. Only tests specified herein shall be used in the inspection of cast armor.

4.2.1 Place of inspection and tests.- Unless otherwise specified or authorized, the responsibility for having inspection and tests performed shall be as specified in 4.2.1.1, 4.2.1.2 and 4.2.1.3. The results of tests shall be obtained before the material is shipped from the plant having responsibility for them. However, the right is reserved to perform inspection and tests at other places at the discretion of the contracting officer.

4.2.1.1 Chemical analysis (ladle) and radiographic tests for steel soundness are the responsibility of the plant where the steel is made.

4.2.1.2 Charpy impact tests, and hardness determinations are the responsibility of the plant where the castings are heat-treated.

4.2.1.3 Ballistic tests are the responsibility of the Ordnance Corps and shall be made at a location designated by the Chief of the Procuring Agency involved.

4.2.2 Identification of material.- Identification marks and records shall be such as to insure positive identification of all test plates and specimens with the lot and corresponding heat from which they were produced. The key to identification symbols shall be furnished to the inspector prior to submittal for inspection and test.

4.3 Definitions.-

4.3.1 Lot.- Except as specified in 4.3.1.1 a lot for purposes of non-ballistic inspection testing shall consist of all castings of the same melt of steel, of the same thickness, and having the same heat treatment (see 3.1.2). When two or more melts are combined in a single ladle, the ladle charge shall be considered as a single melt.

4.3.1.1 Lot for ballistic testing.- A lot, for purposes of ballistic inspection, shall consist of all castings, of the same thickness as specified on the drawing, from one melt or group of melts of the same composition, and subjected to the same heat treatment except that, in the case of grouped melts, a lot shall consist of not more than 20,000 pounds of shipped castings.

4.4 Procedure for radiographic inspection of armor castings.-

4.4.1 First casting.- The first casting (when made from a pattern of a design not previously employed by manufacturer or from a pattern out of production in manufacturer's foundry for a period of three months or more), shall be radiographed in all routine and random positions described on the position chart. (To be provided by the Chief of the Procuring Agency involved; see 3.1.3 herein.) (See 6.2.)

4.4.2 Second casting.- The second casting shall be radiographed in those positions which on the first casting failed to comply with the standards prescribed on the position chart.

4.4.3 Third casting.- The third casting shall be radiographed in those positions which on the second casting failed to comply with the standards prescribed on the position chart.

4.4.4 Subsequent castings.- In the event that rejectable defects occur in any areas which were radiographed in the third casting, subsequent castings shall be radiographed in those areas which were defective in the immediately preceding casting radiographed until compliance with the required standards has been obtained.

4.5 Inspection for acceptance.-

4.5.1 Charpy V-notch impact tests.-

4.5.1.1 Frequency of tests.- At least 2 impact test specimens shall be taken from each impact test block in each lot. The number of blocks per lot shall be as shown in Table VI, except that not more than one block shall be required for any casting.

TABLE VI - Frequency of sampling.

Weight of Castings; pounds each (as heat-treated)	Minimum Number of Samples; per weight of castings in lot
Less than 2,000	1 from each 10,000 lb.
2,000 or greater	1 from each 20,000 lb.

4.5.1.2 Reduced impact testing.- If the results of impact tests on consecutive lots indicate that a satisfactory uniform product meeting the impact requirements is being produced, the number of impact tests shall be reduced in accordance with a quality control system approved or established by the Chief of the Procuring Agency involved.

4.5.1.3 Size of blocks.- The thickness of the blocks or the length of test bars, as applicable, used for impact tests shall be not less than that established by the applicable drawing for the casting involved. (See 4.5.1.5.1 and 4.5.1.5.2.) The use of a thicker block or longer test bar will be permitted provided the hardness obtained thereon is within the range specified for the established thickness.

4.5.1.4 Heat treatment of blocks.- Blocks shall be attached to or shall accompany castings which they represent throughout the hardening and tempering cycle. Blocks shall be so placed that their cooling rate during quenching shall be comparable to that of the casting or castings represented. If the castings are of such a design and mass that the cooling rates are in excess of the samples involved, the blocks may be quenched on an individual basis under similar quenching conditions to approximately the same final temperature as the thickness of the casting as established on the applicable drawing.

4.5.1.5 Location of test specimens.-

4.5.1.5.1 Blocks to 2" thick inclusive.- Specimens from blocks up to 2", inclusive, in thickness shall be taken from a location midway between the top and bottom surfaces of the block and at least 2T from any quenched edge. When blocks thicker than that required by the casting drawing are used at the option of the manufacturer, specimens shall be taken 1/2T from the top or bottom surface where T is the specified thickness of the casting represented. (See 6.3.)

4.5.1.5.2 Blocks greater than 2" in thickness.- Specimens from blocks greater than 2" in thickness shall be taken from a location not less than 1" below the surface of the block and at least 4" from any quenched edge.

4.5.1.5.3 Test bars.-

4.5.1.5.3.1 Specimens 2" or greater in thickness.- At the option of the manufacturer, specimens representing castings 2" or greater in thickness may be taken from a test bar, which is heat-treated in a test block, as shown in Figure 1 or 2. Test bars shall be equivalent in length to the casting thickness they represent. Test bars shall be inserted in and fixed to the test block in such a manner as to prevent the quenching medium from contacting the side of the test bar.

4.5.1.5.3.2 Specimens less than 2" in thickness.- At the option of the manufacturer, specimens representing castings less than 2" in thickness may be taken from a test bar, which is heat-treated in a test block, as shown in Figure 2. Test bars shall be of sufficient length that the requisite number of samples may be obtained therefrom. Test bars shall be inserted in and fixed to the test block in such a manner as to prevent the quenching medium from contacting the side of the test bar.

4.5.1.6 Impact specimens.- Impact specimens shall be machined to the form and dimensions shown in Figure 3. (See 6.5.)

4.5.1.7 Cooling and fracturing of specimens.- Each specimen shall be brought to a temperature of -40 ± 2 degrees F. and maintained at that temperature in a liquid cooling medium for a period of at least 15 minutes prior to being broken. Specimens shall be broken in a beam-type impact testing machine within 5 seconds after removal from the cooling medium.

4.5.1.8 Interpretation of test results.- Except as provided in 4.5.1.8.1, the impact resistance obtained on all specimens from a lot shall be averaged. Failure of this average to meet the minimum requirements, for the appropriate hardness range, specified in Table III, shall be cause for rejection of the lot represented by the specimens. The hardness shall be the average of all hardness readings determined in accordance with 4.5.2.1.2 and 4.5.2.4.2.

4.5.1.8.1 Retest.- In the event that a lot of castings fails to meet the impact requirements when the results are interpreted in accordance with 4.5.1.8 retesting shall be permitted in accordance with 4.6.2 or 4.6.3 as applicable, or at the option of the manufacturer individual castings or parts of a lot may be submitted for acceptance. When this latter practice is followed all castings represented by samples yielding acceptable test results shall be considered acceptable. For batch-type furnaces, a sample shall be considered to represent a casting if it is heat treated with the casting or if both received the same heat treatment except that castings heat-treated with the sample which caused failure of the original lot may not be included. For continuous-type furnaces, a rejectable sample shall be considered to represent all castings heat-treated subsequently to the last acceptable sample and prior to the following acceptable sample.

4.5.1.9 Local defects.- In the event that test specimens fail because of the presence of obvious local defects, substitute test specimens may be made and tested.

4.5.2 Hardness tests.-

4.5.2.1 Frequency of tests.-

4.5.2.1.1 Hardness of castings.- Each casting weighing more than 300 pounds shall be subjected to two Brinell hardness tests, and each casting weighing 300 pounds or less shall be subjected to one hardness test. Hardness tests shall be made in a location the thickness of which corresponds approximately to the specified thickness of the casting.

4.5.2.1.2 Blocks for impact test.- Except as provided in 4.5.2.1.2.1, each block from which impact test specimens are taken shall have a cross-section hardness check made upon it. For blocks 1/4" to 2" in thickness, two hardness readings shall be taken from a location midway between the quenched surfaces of the block and at least one "T" from any quenched edge. For blocks greater than 2" in thickness, two hardness readings shall be taken, one from a location not less than 1" from the top surface, and one from a location not less than 1" from the bottom surface.

4.5.2.1.2.1 At the option of the contractor, two Rockwell-C hardness tests may be made on each impact test specimen from a lot, in lieu of the cross-sectional-hardness test required in 4.5.2.1.2. When this procedure is followed, the results of all tests taken from each lot shall be averaged and the average thus obtained shall be converted to Brinell hardness using the conversion table in Table II.

4.5.2.2 Preparation for testing.-

4.5.2.2.1 Surface hardness.- Prior to testing the surface hardness of castings, all surface scale and decarburization shall be removed from the areas where the tests are to be made.

4.5.2.2.2 Cross-sectional hardness.- Sections upon which cross-sectional-hardness tests are made shall be surface-ground and shall be flat with opposite faces parallel to one another, except that when test bars are used with a V-block only one side need be ground.

4.5.2.3 Method of test.- Brinell hardness tests shall be made with a standard Brinell hardness-testing machine, using a 10mm tungsten-carbide ball and a 3000-kilogram load, except that surface hardness tests may be made with a portable Brinell hardness-testing machine, previously calibrated for the range involved.

4.5.2.4 Interpretation of test results.-

4.5.2.4.1 Production castings.- The hardness values obtained on each casting shall be averaged. If the average thus obtained is outside the range specified in Table II, or if the diameters of Brinell impressions made on any one casting vary by more than 0.25mm between the maximum and minimum, the casting shall be subject to rejection.

4.5.2.4.2 Blocks for impact tests.- The hardness readings obtained on all blocks shall be averaged. The average thus obtained shall be used to determine the level of impact resistance applicable to the lot as specified in Table III.

4.5.3 Radiographic tests.- Radiographic tests on production castings shall be performed in accordance with the requirements of the applicable drawings or contract. The occurrence of a rejectable defect in any area on a casting shall require the radiographic inspection of each subsequently poured casting in that area until the defective condition is corrected. (See 6.6.)

4.5.3.1 Reduced radiographic testing.- If results of radiographic tests on consecutive lots of material indicate that a satisfactory uniform product meeting the soundness requirements is being produced, the amount of radiographic testing shall be reduced in accordance with a system approved or established by the Chief of the Procuring Agency involved.

4.5.4 Ballistic testing.- Ballistic testing for the acceptance of production castings shall be in accordance with the requirements of Appendix A.

4.6 Retesting.-

4.6.1 Hardness.- Castings rejected for low or high hardness may be retested without retreatment at the option of the contractor. Under such conditions, twice the original number of hardness readings shall be taken and the results of all readings taken on the castings shall be averaged to determine compliance with the requirements of Table II. Castings rejected for high hardness may be retempered, in which case only those readings taken after retempering shall be used to determine acceptability. Castings rejected for low hardness may be requenched and retempered, in which case testing shall be conducted in accordance with the requirements for original testing.

4.6.2 Impact resistance.- Castings rejected for low impact resistance may be retested without retreatment at the option of the manufacturer by taking additional specimens from the lot under consideration. These additional specimens should be distributed as uniformly as possible among all the samples of the lot. If the average impact resistance of all tests from the lot meet the requirements of Table III for the appropriate hardness range, the lot shall be accepted, otherwise it shall be subject to rejection.

4.6.3 Retest after reheat treatment.- Castings which have been rejected may be reheat-treated by quenching and tempering or tempering only and resubmitted for test in accordance with the requirements for original testing.

4.6.3.1 Castings which are retempered only to meet the hardness requirements shall not be subjected to retest for impact. Castings requenched and retempered to meet the hardness requirements shall be tested for impact as a new lot.

4.6.4 Test specimens from production castings.- In the event that it is impossible to obtain additional test specimens from samples or test bars, specimens may be taken, at the option of the manufacturer, from a casting at a location the thickness of which is equivalent to the specified casting thickness.

4.7 Ballistic testing of production castings.- At the option of the Chief of the Procuring Agency involved, production castings may be selected at random for ballistic testing. The number of castings thus selected may vary but the total number shall not exceed 2 percent of the total production of each given pattern number being produced under a contract.

5. PREPARATION FOR DELIVERY

5.1 Preparation.- All machined surfaces of castings shall be coated with a suitable preventive to insure against corrosion during transportation. Machined surfaces shall be clean and free from moisture before this coating is applied. The preventive coating shall be such as can be easily removed.

5.2 Packing for shipment.- All castings shall be packed for shipment in such a manner as to insure acceptance by common or other carrier, for safe transportation, at the lowest rate, to the point of delivery.

5.3 Marking for identification.- Castings (both green and heat-treated) shall be indelibly and legibly marked with symbols that will definitely identify the castings with inspection and test reports and with shipping documents in accordance with Standard MIL-STD-129.

6. NOTES

6.1 Intended use.- The armor specified herein is intended for use on combat vehicles, but may also be applicable to armor for emplacements, shields, pill boxes, and the like.

6.1.1 Grade 1.- Grade 1 cast armor is intended for use in those areas where maximum resistance to penetration by armor-piercing types of ammunition is required.

6.1.2 Grade 2.- Grade 2 cast armor is intended for use in those areas where maximum resistance to failure under conditions of high rates of shock loading is required and where resistance to penetration by armor-piercing ammunition is of secondary importance. It is for protection against anti-tank land mines, hand grenades, bursting shell, and other blast-producing weapons.

6.2 Position drawing.- A position drawing is a drawing that will be supplied by the Chief of the Procuring Agency involved, as one of the applicable drawings. It will show those areas to be radiographed, the radiographic standards which apply and the frequency of radiographic testing.

6.3 Thicknesses.- The symbol "T" is used to indicate the thickness of plate, or of castings at the section concerned and corresponds to that indicated on the drawings as the Charpy-impact-test-block thickness.

6.4 Patterns.- The inquiry or invitation for bids and the contract or order should definitely state whether the casting manufacturer or the Government is to furnish the patterns. Government contracts ordinarily should include a provision that patterns furnished by the manufacturer shall become the property of the Government upon completion of the contract.

6.5 Measurement of Charpy notch.- Tolerances on the notch of the Charpy impact test specimens may be checked by means of a comparator or metalloscope at the magnification of at least ten in the following manner:- Project the profile of the base of the notch on a ground glass. Fit a circle of radius .10" (10X) drawn on transparent paper to the profile of the notch base. Deviations of .001" from the standard .01" radius can be detected by this means. If there is any question as to the radius, it may be compared with circles of .09" and .11" (10X). At the time the radius is measured, the notch may be checked to ascertain that the sides make an angle of 45 degrees and are tangent to the arc at the notch. Generally, it is not necessary to inspect all specimens for notch tolerances. The first specimen cut with a freshly ground milling cutter may be examined, and thereafter every tenth or fifteenth specimen prepared from this milling cutter should be measured.

6.6 Radiography.- Radiography of production castings under this specification is limited in amount and the provisions are intentionally stated in such a way that normally no interference with production should result. As provided for, radiography is to be used as a tool for the development of satisfactory foundry procedures and to provide sufficient checking at intervals so that a manufacture will know when something has gone wrong with the procedure and can take steps to make the necessary corrections. Radiography as incorporated in this specification is not intended to be used for the purpose of ascertaining that each casting accepted meets the standards specified on the radiographic position charts. Instead, it is intended to assure that lowering of quality will be disclosed and remedial measures taken by the manufacturer.

6.7 Ownership of ballistic test plates.-

6.7.1 Qualification test plates.- Qualification test plates are the property of the manufacturer seeking qualification. Arrangements should be made by him to have them returned at the conclusion of ballistic tests.

6.7.2 Acceptance test plates.- Acceptance test plates, which comply with the requirements of this specification will be considered as part of the lot of castings they represent and ownership of them passes to the Government with the acceptance of that lot. Acceptance test plates which fail to comply with the requirements of this specification are considered as part of the lot they represent and remain the property of the manufacturer just as the rejectable lot they represent.

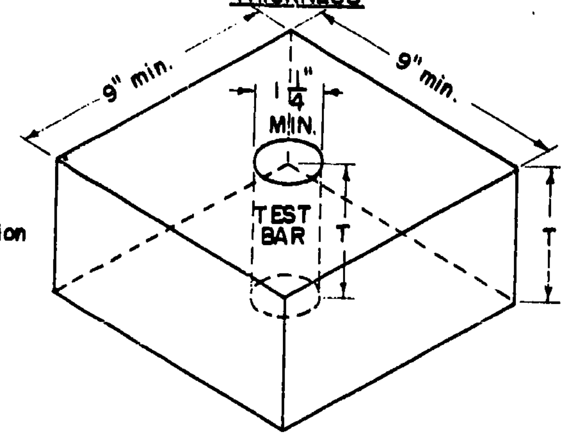
6.7.2.1 When retesting without reheat treatment is involved, all plates including those originally tested from a lot accepted after retesting without reheat treatment will be considered as part of an acceptable lot. Original plates from a lot accepted after retesting after reheat treatment will not be considered as part of an acceptable lot and remain the property of the manufacturer.

NOTICE: When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specification, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

Custodian:

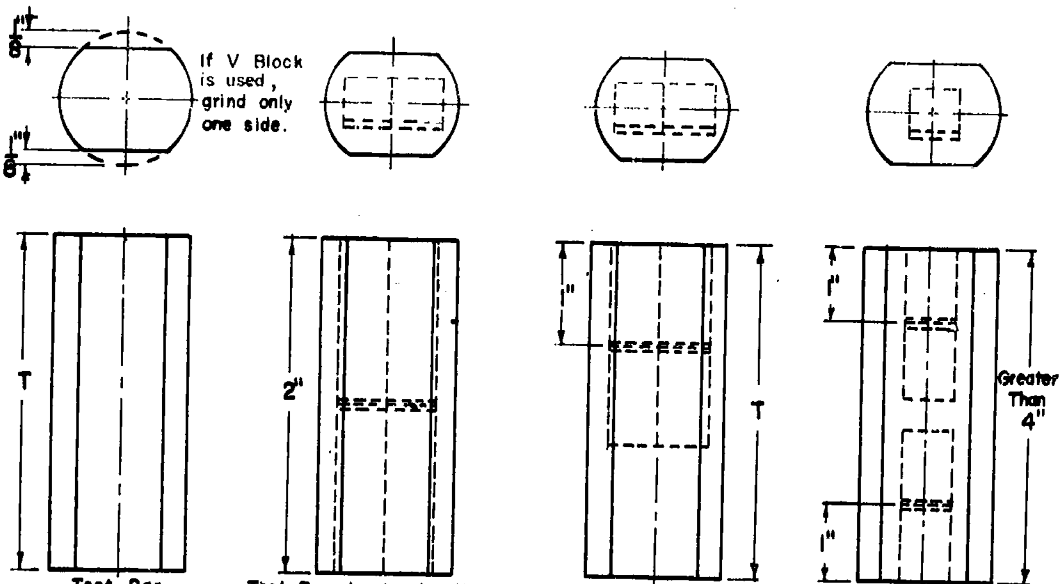
Army - Ordnance Corps

TEST BLOCK WITH TEST BAR INSERTED THRU THE THICKNESS



Notes
1. Steel of any chemical composition may be used for test block.
2. Minimum thickness "T" shall be 2".

TEST BAR & TEST BLOCK
(FOR ARMOR 2" TO 12" THICK, INCLUSIVE)



Test Bar
Surface ground for hardness survey.

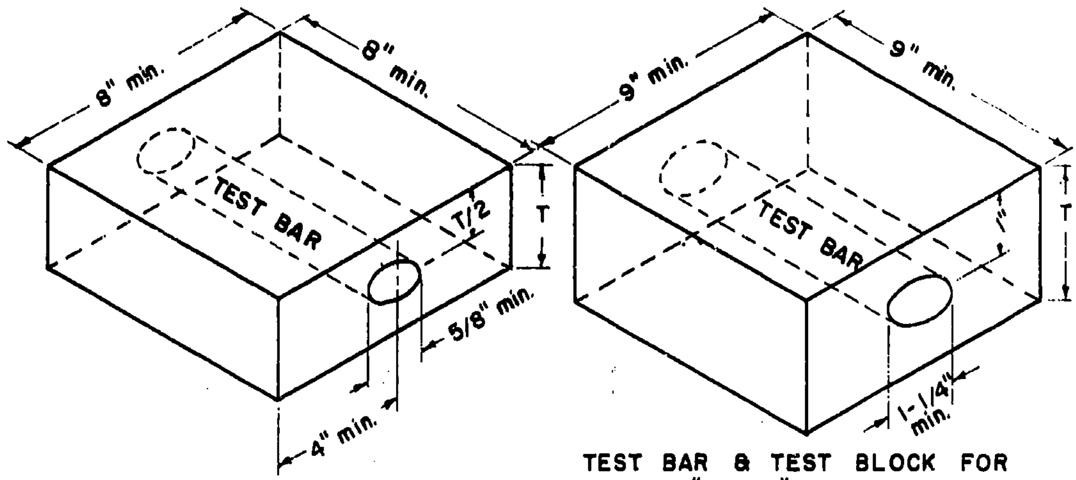
Test Bar showing location of V-notched Charpy specimens representing 2" thick castings.

Test Bar showing location of V-notched Charpy specimens representing castings greater than 2" thick.

Alternative method of taking V-notched Charpy specimens from test bars representing castings greater than 4" thick.

FIGURE 1.

TEST BLOCKS WITH TEST BARS INSERTED IN SIDE OF BLOCKS

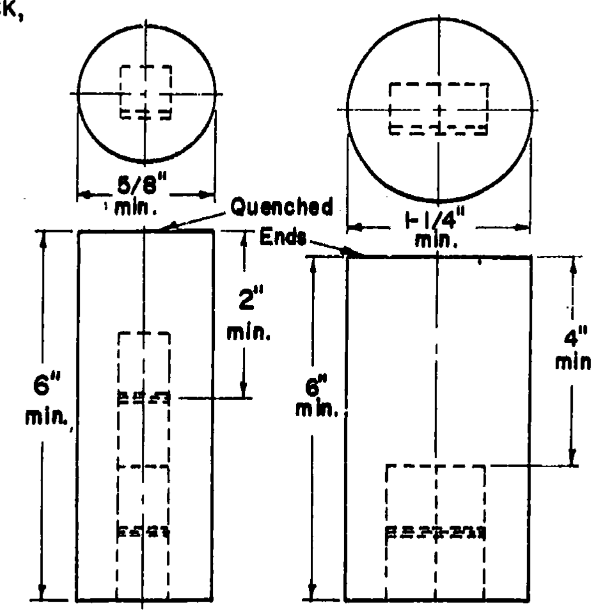


TEST BAR & TEST BLOCK FOR ARMOR UP TO 1-3/4" THICK, INCLUSIVE.

TEST BAR & TEST BLOCK FOR ARMOR 2" TO 12" THICK, INCLUSIVE.

NOTE

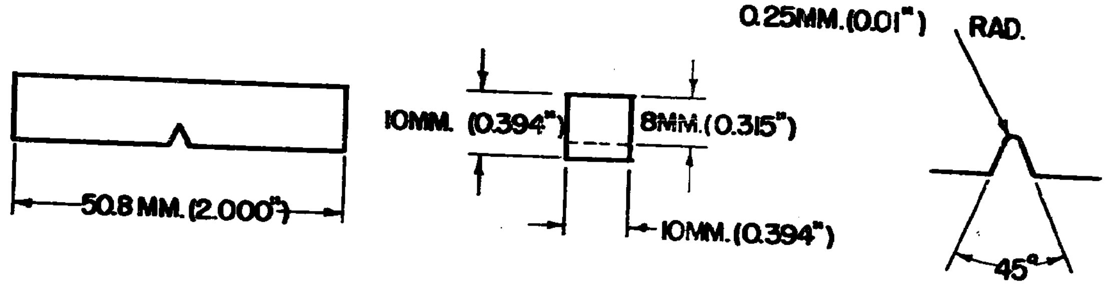
1. End of 1-1/4" Diam. test bar should be indexed so that impact specimens are taken 1" below quenched surface of test block.



Test Bar showing location of V-notched Charpy specimens representing castings up to 1-3/4" thick.

Test Bar showing location of V-notched Charpy specimens representing castings 2" and greater in thickness.

FIGURE 2



V-NOTCHED SQUARE CHARPY SPECIMEN

PERMISSIBLE VARIATIONS:

CROSS-SECTIONAL DIMENSIONS ± 0.025MM. (0.001")
LENGTH OF SPECIMEN ______ + 4.2 MM. (0.165") − 0.25MM. (0.010")
ANGLE OF NOTCH __________ ± 1°
RADIUS ________________ ± 0.001"
OUT-OF-SQUARENESS ______ ± 0.001"
(OF ADJACENT SURFACES)

FIGURE 3

APPENDIX A
MIL-A-11356B(Ord)

QUALIFICATION PROCEDURE FOR PRODUCERS OF CAST ARMOR AND REQUIREMENTS FOR BALLISTIC TESTING FOR ACCEPTANCE OF CAST ARMOR

A-1 SCOPE

A-1.1 This appendix covers the requirements for qualification as a producer of cast armor and ballistic testing for acceptance of production lots of armor castings.

A-2 APPLICABLE SPECIFICATIONS AND STANDARDS (See Section 2 of the Specification.)

A-3 REQUIREMENTS

A-3.1 Qualification.- Prior to the acceptance of any contract for production of cast armor under this specification, the manufacturer shall have been qualified as a producer of cast armor in accordance with the applicable requirements of this appendix. (See A-6.1.)

A-3.1.1 Thicknesses to 3-3/4" inclusive.- To qualify for thicknesses to 3-3/4" inclusive, the manufacturer shall submit ballistic test plates and test blocks or test bars which meet the requirements of this appendix. A manufacturer may qualify for one or more thickness ranges by submitting ballistic test plates and test blocks or test bars as specified in Table A-I.

A-3.1.2 Thicknesses 4" to 12" inclusive.- To qualify for thicknesses from 4" to 12" inclusive, the manufacturer shall submit two test bars for each thickness he proposes to make in increments of 2" which meet the requirements of this appendix. Test bars shall be equal in length to the maximum thickness to be qualified within each 2" increment.

TABLE A-1

BALLISTIC TEST PLATES AND TEST BLOCKS
OR TEST BARS FOR QUALIFICATION

Thickness of Plates & Blocks Inches	Number of Plates, Blocks, or Bars	Minimum Size of Plates (1) Inches	To Qualify for Thickness Range - Inches
1	1	18 x 36	1/4 to 1-1/4 incl. (2)
2	1	18 x 36	over 1-1/4 to 2-1/4 incl.
3	2	36 x 48(3)	over 2-1/4 to 3-3/4 incl.

(1) See A-4.3.1 for size of test blocks and insert blocks for test bars.

(2) At the option of the manufacturer, qualification may be made for the production of armor greater than 1-1/4 to 1-3/4 inches, inclusive, by the submission of one ballistic test plate 18" x 36" x 1-1/2" thick.

(3) A plate 48" x 60" is preferred to a 36" x 48" plate for the 3" thickness. The larger size of plate will insure the conduct of a satisfactory ballistic test, thereby eliminating the possible necessity or supplying additional smaller plates.

A-3.1.3 Test plates, blocks, or bars for qualification testing shall be made of the same chemical composition, by the same steel-making process, and with the heat treatment that will be used for the production of armor castings under this specification.

A-3.1.4 Processes of manufacture shall be such as to produce cast armor test plates, blocks, or bars which are, as nearly as practicable, homogeneous throughout.

A-3.1.5 Heat treatment.- All qualification test plates, blocks, or bars submitted as a group representing a single range of section thickness shall receive the same heat treatment.

A-3.1.6 Soundness.- There shall be no evidence of surface cracks on ballistic plates upon unaided visual examination. Radiography of ballistic test plates will not be required.

A-3.1.7 Chemical composition.- The chemical composition of qualification test plates, blocks, or bars shall be within the limits established by the contractor for the production or armor castings of the thickness range represented by the test plates, blocks, and bars in accordance with 3.3 of the specification.

A-3.1.8 Hardness.- The average surface hardness of each test plate shall be within the range shown in Table II of the specification. When cross-section hardness tests are conducted on test plates, blocks, or bars the average of all hardness tests, both surface and cross-section, shall fall within the stipulated hardness range.

A-3.1.9 Impact resistance.- The V-notch Charpy impact resistance of each test plate, block, or bar shall meet the requirements shown in Table III of the specification for the applicable hardness and thickness.

A-3.1.10 Ballistic tests.-

A-3.1.10.1 Resistance-to-penetration test at normal obliquity.- The test plates shall be proof-fired for resistance to penetration, and a ballistic limit, BL(A), shall be obtained in accordance with paragraphs A-4.5.1 and A-4.5.5 and Table A-II. Minimum requirements for acceptable ballistic limits shall be as shown in the table.

TABLE A-II

RESISTANCE-TO-PENETRATION; NORMAL-OBLIQUITY IMPACT

Thickness of Plate - inches		Ammunition to be used	Minimum Number of impacts	Minimum Ballistic Limit f/s	B. L. Correction, f/s per 0.01" thickness
1	(1.00)	cal. 50 AP M2	2	2175	18
1-1/2	(1.50)	37 MM AP M74	2	1125	7
2	(2.00)	37 MM AP M74	2	1500	8
3	(3.00)	75 MM AP M72	2	1150	4

A-3.1.10.2 Resistance-to-oblique-attack test.- A protection ballistic limit, BL(P), at 45 degrees obliquity shall be obtained in the case of 3" thick qualification ballistic test plates in accordance with Table A-III:

TABLE A-III

RESISTANCE TO ATTACK AT 45° OBLIQUITY

Thickness of Plate - Inches		Ammunition to be used	Minimum Ballistic Limit f/s	B.L. Correction f/s per 0.01" thickness
3	(3.00)	90 MM APC M82	2125	6

A-3.2 Acceptance tests.- Each lot of production castings of Grade 1 armor shall be represented by one ballistic test plate of the thickness established by the applicable drawing for the casting involved. The size of the acceptance ballistic test plates shall correspond to the size given in Table A-I. Grade 2 armor shall not be subject to ballistic acceptance tests.

A-3.2.1 Ballistic test plates.- Test plates for acceptance ballistic testing shall be made from the same heat of steel as the casting they represent or from one of the heats included in the ballistic lot (see 4.3.1.1 of the specification) and receive the same heat treatment as the armor castings they represent.

A-3.2.2 Test requirements.- Test plates for acceptance testing shall meet the soundness, hardness, and ballistic test requirements of A-3.1.6, A-3.1.8, and A-3.1.10.

A-3.2.3 Thickness tolerances.- The average thickness of qualification and acceptance ballistic test plates shall not differ from the required thickness by more than plus or minus 5%.

A-3.2.4 Identification.- Each ballistic test plate submitted for qualification and acceptance tests shall be legibly and indelibly marked with the manufacturer's mark and a plate or heat number to insure positive identification. The key to identification symbols shall be furnished to the inspector prior to submittal for inspection and test.

A-3.2.5 Information required.- The manufacturer shall furnish for the files of the proving ground making the ballistic tests, a statement showing the ladle analysis of each melt and the complete details of the heat treatment of each group of plates. All elements of the chemical composition shall be shown in the statement, including special additives or hardening agents, whether shown in Table I of the specification or not. This information shall be forwarded on an approved form. The results of hardness and notched-bar impact tests shall also be provided.

A-4. SAMPLING, INSPECTION, AND TEST PROCEDURE

A-4.1 General inspection and test procedures required by this specification shall be made in accordance with the requirements of Federal Specification QQ-M-151, unless otherwise specified herein. Only tests specified herein shall be used in the inspection of armor.

A-4.2 Place and responsibility for inspection and tests.- Unless otherwise specified or authorized, the place of inspection and test shall be as specified in A-4.2.1 and A-4.2.2. However, the right is reserved to perform inspection and tests at other places at the discretion of the procuring agency.

A-4.2.1 Chemical analysis (ladle), examination for freedom of visual cracks, hardness determinations, and notched-bar impact tests are the responsibility of the manufacturer of the armor. In the case of qualification testing for thicknesses to 3-3/4", inclusive, all tests except impact tests shall be made at a laboratory selected by him. Impact tests for qualification on all thicknesses shall be made at a laboratory selected by the procuring agency.

A-4.2.2 Ballistic tests shall be made at a place to be designated by the Chief of the Procuring Agency involved.

A-4.3 Blocks or bars for hardness and impact testing.-

A-4.3.1 Thicknesses to 3-3/4" inclusive.- A test block 9" x 9" x T" in size or, at the option of the manufacturer, a test bar of the type specified in the specification for production testing as shown in Figures 1 and 2 of the specification shall be tack-welded to each ballistic test plate and shall accompany it through the quenching and tempering cycles. Blocks or bars shall be attached at such a location that neither the thickness of the block or bar nor the thickness of the test plate will be effectively increased during heat treatment.

A-4.3.2 Thicknesses 4" to 12" inclusive.- A test block 9" x 9" x T" in size or, at the option of the manufacturer, test bars of the type specified for production testing as shown in Figure 1 and 2 of the specification shall be used for thicknesses 4" to 12" inclusive. If test bars are used they shall remain in the blocks throughout the quenching and tempering cycles.

A-4.3.3 Hardness and impact tests on test blocks and bars.- After heat treatment, the test blocks or test bars shall be subjected to Brinell hardness tests and notched-bar impact tests as required in 4.5.1 and 4.5.2 of the specification.

A-4.4 Ballistic test plates.- The number and sizes of ballistic test plates for qualification shall be in accordance with the requirements of Table A-I. The number and sizes of acceptance ballistic test plates shall conform to the requirements of Table A-I and A-3.2 as applicable. (See 6.7.)

A-4.4.1 Surface hardness tests.- Each qualification and acceptance ballistic test plate shall be subjected to three Brinell hardness tests on each face where accessible and practicable. If hardness tests cannot be practicably made on both faces, five tests shall be made on one face, one near the middle of each side and one in the middle of the plate area.

A-4.4.2 Average thickness of test plates.- The average thickness of test plates shall be the average of five thickness measurements, one at each corner of the plate, 2 inches from either edge, and one at the center. Thickness readings shall be taken to the nearest 0.01 inch.

A-4.5 Definitions.-

A-4.5.1 Army complete penetration, CP(A).- An Army complete penetration will have been obtained when a hole is made that allows the passage of light through the test plate, or when any part of the projectile in the plate can be seen from the rear of the test plate. If it is questionable whether any part of the projectile can be seen, the round shall be disregarded and another round shall be fired.

A-4.5.2 Protection complete penetration, CP(P).- A protection complete penetration is an impact that causes any fragments of projectile or plate to pass beyond the limits of the back of the plate. This condition shall be determined by perforation of a 0.020-inch thick, aluminum-alloy sheet (24ST or equivalent) placed 6 inches to the rear and parallel to the plate, or the equivalent thereof, at the discretion of the proof officer.

A-4.5.3 Partial penetration, PP(A) or PP(P).- Any fair impact that is not a complete penetration shall be considered a partial penetration.

A-4.5.4 Fair impact.- An impact which is three calibers or more away from another impact or two calibers or more away from any plate edge is a fair impact.

A-4.5.5 Ballistic limit.- The ballistic limit is the average of two velocities, one of which is the lowest at which a complete penetration occurs, and the other the highest partial penetration below the complete penetration. The difference between the two velocities shall not exceed 50 feet per second when projectiles 37-MM in diameter or less are used, or 30 feet per second when projectiles greater than 37-MM in diameter are used. (See A-6.2 and A-6.3.)

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A-4.5.6 Impact velocities.- The required impact velocities for ballistic limits (Table A-II and A-III) of test plates, the thickness of which (see A-4.5.7) is between two consecutive tabulated thicknesses, shall be determined by the correction factors shown in Table A-I and A-II as applicable.

A-4.5.7 Thickness, impact area.- The thickness of ballistic test plates used for determining ballistic limits shall be that of the area subjected to ballistic testing.

A-4.5.8 Cracking.- Cracking of ballistic test plates to such an extent that, in the opinion of the proof officer, satisfactory ballistic limit determinations cannot be made shall constitute failure of the ballistic tests and the rejection requirements of A-4.5.9 shall apply.

A-4.5.9 Failure of qualification test plate.- Failure of the qualification ballistic test plates or test samples to meet any of the tests when inspected in accordance with this appendix shall be cause for rejection of the manufacturing process represented by the thickness of the failing plate or plates. To achieve qualification, the manufacturer must submit a new series of ballistic test plates which shall pass all tests outlined in this appendix.

A-4.5.10 Failure of acceptance test plates.- Failure of the acceptance ballistic test plates to meet any of the tests when inspected in accordance with this appendix shall be cause for rejection of the lot of castings represented by the failing plate or plates.

A-4.5.11 Retests.- In case of failure of acceptance ballistic test plates to meet the requirements of this Appendix, the manufacturer shall have the right to resubmit a lot under the following conditions.

A-4.5.11.1 Retesting without reheat treatment.- The manufacturer shall have the right to submit twice the number of plates originally submitted from the lot under test. Each of the additional plates must meet the ballistic requirements or the lot shall be subject to rejection.

A-4.5.11.2 Retesting after reheat treatment.- The manufacturer shall have the right to reheat-treat and resubmit any lots in accordance with the requirements for original testing.

A-4.5.12 Reduced ballistic acceptance testing.- If the results of acceptance ballistic testing indicate that a satisfactory uniform product meeting the ballistic requirements is being produced, the number of ballistic test plates shall be reduced in accordance with a quality control system approved or established by the Chief of the Procuring Agency, involved.

A-4.5.13 Additional test for information.- At the option of the Chief of the Procuring Agency involved, additional rounds may be fired for information on any casting or test plate after completion of acceptance testing.

A-5 PREPARATION FOR DELIVERY

A-5.1 Marking for identification.- Plates shall be indelibly and legibly marked with symbols that will definitely identify them with inspection and test reports and with shipping documents.

A-6 NOTES

A-6.1 Records.- Copies of all records pertaining to qualification tests required by this appendix should be forwarded to the Detroit Tank Arsenal, Center Line, Michigan.

A-6.2 Small-arms and small-artillery ammunition.- In those cases where a 50-f/s difference between the high-partial and low-complete penetration is allowed for ballistic-limit determination, if a partial penetration occurs at or above the specified minimum impact velocity minus 25 f/s, and no complete penetration is obtained at or below the minimum impact velocity required, the plate will be acceptable when the ballistic limit is actually less than that called for by the applicable requirements.

A-6.3 Medium and large artillery ammunition.- In those cases where a 30-f/s difference between high-partial and low-complete penetration is allowed for ballistic-limit determination, if a partial penetration occurs at or above the specified minimum impact velocity minus 15 f/s, and no complete penetration is obtained at or below the minimum impact velocity required, the plate will be acceptable when the actual ballistic limit is less than that called for by the applicable requirements.

QUALIFICATION PROCEDURE AND REPAIR-WELDING REQUIREMENTS FOR THE REPAIR OF ARMOR CASTINGS

B-1. SCOPE

B-1.1 This appendix covers the requirements for the qualification of welding procedures and welders involved in the repair of armor castings.

B-2. APPLICABLE SPECIFICATIONS AND STANDARDS

B-2.1 <u>Applicable specifications</u>.- The following specifications (in addition to those specified in Section 2 of the specification), of the issue in effect on the date of invitation for bids, form a part of this specification:

SPECIFICATIONS

MILITARY

MIL-R-11468 - Radiographic Inspection; Soundness Requirements For Arc and Gas Welds in Steel

U. S. ARMY

57-203-7 - Electrodes; Welding, Steel, Covered, Ferritic

B-2.2 <u>Applicable standards</u>.- The following standards of the issue in effect on the date of invitation for bids, form a part of this specification.

STANDARDS

MILITARY

JAN-STD-19 - Welding Symbols

MIL-STD-20 - Welding Nomenclature and Definitions

B-3. REQUIREMENTS

B-3.1 <u>Qualification</u>.- Prior to repair welding Grade 1 or Grade 2 production castings, the contractor shall qualify the welding procedure to be used and the welders who are to perform the work in accordance with the requirements of B-3.1.1 and B-3.1.2 respectively. Qualification for repair welding Grade 1 castings shall serve as qualification to repair weld Grade 2 castings, provided all the factors listed in Table B-1 are identical.

B-3.1.1 <u>Qualification of procedure</u>.-

B-3.1.1.1 Contractors recorded procedure for repair welding.- The manufacturer shall establish a recorded repair-welding procedure for the repair of castings. The recorded repair-welding procedure shall include all the factors listed in Table B-1.

TABLE B-I

FACTORS IN THE RECORDED REPAIR-WELDING PROCEDURES AND CHANGES WHICH REQUIRE PROCEDURE REQUALIFICATION AND ARC-WELDER REQUALIFICATION

Factor included in recorded welding procedure.	Recorded welding procedure shall be revised and procedure requalified, as indicated below.	Welder shall be requalified as indicated.
1. Composition of steel.	Procedure shall be revised and requalified when a change in composition outside of the declared range established in accordance with this specification is made unless a specific waiver is granted by the Chief of the Procuring Agency involved.	Not required.
2. Minimum dimension at the root, minimum included angle and minimum root radius.	Recorded welding procedure shall be revised. Requalification not required.	Not required.
3. Electrode: type and class or brand, manufacturer, covering type and deposited analysis range if not qualified under 57-203-7(1).	When the electrode used for procedure qualification does not meet the requirements of 57-203-7, substitution of any other electrode wherein a change is made in brand, manufacturer, covering type or deposited analysis range will require revision of procedure and requalification. However, when the electrode used for production qualification has met the requirements of 57-203-7 for a specific type and class and provided all other factors remain the same, any other electrode which has met the requirements of 57-203-7 for the same type and class may be substituted without requalification of procedure but the procedure shall be revised.	Not required.

(1) Acceptable brands - Manufacturers will not substitute electrodes conforming to 57-203-7 until a list of acceptable proprietary brands of electrodes has been issued. Such a list will also include information as to type and class to which the electrodes conform.

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TABLE B-I (Cont'd)

FACTORS IN THE RECORDED REPAIR-WELDING PROCEDURES AND CHANGES WHICH REQUIRE PROCEDURE REQUALIFICATION AND ARC-WELDER REQUALIFICATION

Factor included in recorded welding procedure.	Recorded welding procedure shall be revised and procedure requalified, as indicated below.	Welder shall be requalified as indicated.
4. Maximum electrode diameters, for all passes based on minimum groove width.	When a decrease is made in the actual width of groove at which any given size of electrode is used procedure shall be revised and requalified.	When a decrease is made in the actual width of groove at which any given size of electrode is used.
5. Welding-current and arc-voltage range for each diameter or electrode.	When the limits established in the recorded repair-welding procedure are exceeded the procedure shall be revised and requalified.	When the limits established in the recorded welding procedure are exceeded.
6. Preheat temperature range local or general, which shall be specified.	When the minimum temperature is reduced the procedure shall be revised and requalified.	Not required.
7. Thermal treatment after welding.	When any temperature in the Thermal treatment established in the original procedure is changed the procedure shall be revised and requalified unless otherwise authorized by Chief of the Procuring Agency involved.	Not required.
8. Method of preparing welding groove: i.e., Thermal or mechanical.	In case of change from mechanical to thermal method, only the procedure shall be revised and requalified.	Not required.
9. Position in which welding will be performed.	When change is made from the position qualified, the procedure shall be revised and requalified, except that area-defect plates shall be qualified in the flat position only.	(See par. 3.1.2.4.)

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TABLE B-I (Cont'd)

FACTORS IN THE RECORDED REPAIR-WELDING PROCEDURES AND CHANGES WHICH REQUIRE PROCEDURE REQUALIFICATION AND ARC-WELDER REQUALIFICATION

Factor included in recorded welding procedure.	Recorded welding procedure shall be revised and procedure requalified, as indicated below.	Welder shall be requalified as indicated.
10. Type & Sequence of passes.	In case of change from beading to weaving only the procedure shall be revised and requalified.	Not required.
11. Source of power, a.c. or d.c. (polarity if d.c. is used.)	When change is made from a.c. to d.c., or vice-versa; or if d.c., when polarity is changed the procedure shall be revised and requalified.	Not required.

B-3.1.1.2 Test plates required.-

B-3.1.1.2.1 Complete heat treatment after welding (hardened and tempered).- The manufacturer shall submit a test plate of each type shown in Figures B-1 and B-2 for radiographic and ballistic tests. Each test plate shall be welded after annealing, normalizing or normalizing and tempering, and subjected to such hardening and tempering as will produce the hardness required for thickness of plate involved.

B-3.1.1.2.2 Tempering only after welding.- The manufacturer shall submit a test plate of each type shown in Figures B-1 and B-2 for radiographic and ballistic tests. Each plate shall be welded in the fully heat-treated state and tempered after welding at a temperature within 50 degrees F. of the original tempering temperature.

B-3.1.1.2.3 No thermal treatment after welding.- The manufacturer shall submit a test plate of the type shown in Figure B-1 for radiographic and ballistic tests. The plate shall be welded in the fully treated state and tested ballistically with no thermal treatment after welding.

B-3.1.1.2.4 Option for repair of Classification-C-sized defects.- For repair of defects not exceeding the dimensions specified for Classification-C size of defects but subject to heat treatment, if required after welding as specified in B-3.1.1.2.1 and B-3.1.1.2.2 respectively, the manufacturer shall submit a test plate or plates of the type shown in Figure B-I for radiographic and ballistic tests. The processed condition of each test plate prior to welding, and the heat treatment of each test plate after welding shall be the same as will be used on production castings.

B-3.1.1.2.5 Coverage of test plates.- Plates of 1-inch thickness shall qualify the manufacturer to repair-weld armor castings of the thicknesses represented by

1-inch ballistic test plates. Those of 2-inch thickness shall qualify the manufacturer to repair-weld armor castings of any thickness provided the chemical composition is within the range established for the thickness or thicknesses for which qualification is sought.

B-3.1.1.2.6 Interpass temperature.- The interpass temperature of qualification plates shall be not more than 100° F. above the preheat temperature. The interpass temperature shall be measured immediately before the deposition of each layer at the point indicated on Figures B-1 and B-2.

B-3.1.1.3 Soundness.- Finished procedure qualification test plates shall comply with Standard II of MIL-R-11468 when radiographed in accordance with the requirements of appendix C.

B-3.1.1.4 Ballistic testing of welding procedure qualification plates.-

B-3.1.1.4.1 Double-I plates.- The 1-inch Double-I plate (Figure B-I) shall be tested for resistance to shock using two rounds of 57-mm plate-proofing (PP) projectiles, M1001, at a velocity of 975 feet per second. The 2-inch Double-I plate (Figure B-1) shall be tested for resistance to shock using two rounds of 105-mm plate-proofing (PP) projectiles, M1004, at a velocity of 1,050 feet per second. A correction in velocity shall be made for each .01" of variation from the nominal thickness, of 6 feet per second on 1" plates and 5 feet per second on 2" plates. One round shall be directed at each leg weld, so that the edge of the projectile at least touches the edge of the weld (fair impact). The welding procedure used for double-I welded plates shall be subject to rejection should either round develop any cracking (in plate, weld, or weld zone) outside a circle of the size indicated below, the center of which is coincident with the center of impact.

Plate Thickness	Allowable Cracking
2"	Within a circle of 9" diameter, the center being the center of impact.
1"	Within a circle of 8" diameter, the center being the center of impact.

B-3.1.1.4.2 Area-defect plate.- Plates of the type shown in Figure B-2 shall be tested for resistance to penetration using the projectiles indicated in Table A-II of Appendix. A. The 1" area-defect plate shall have a minimum ballistic limit of 2150 feet per second and the 2" area-defect plate a minimum ballistic limit of 1450 feet per second when tested in accordance with A-4.5 and appropriate sub-paragraphs thereto. The thickness correction factor of Table A-II shall apply.

B-3.1.1.5 Data forms.- Properly executed forms, available through the Resident Inspector of Ordnance, shall accompany each test plate to the proving Ground.

B-3.1.2 Qualification of welders.-

B-3.1.2.1 Each welder shall be qualified by the manufacturer. Qualification of a welder by one manufacturer shall not serve as qualification when the welder is employed by another manufacturer.

B-3.1.2.2 Type of joint.- The welder qualification test specimen shall be made of either mild steel or steel of similar composition to production castings. The qualification shall be made by the welding of a butt joint of the design shown in Figure B-3 of this appendix between two plates 1 by 4 by 12 inches. All dimensions of the plates shall be considered as minimum.

B-3.1.2.3 Current and electrodes.- The welder shall use the same current, a.c. or d.c., and polarity if d.c. is used, as will be used in production; and the electrodes shall be of the ferritic type to be used for production repair welding. The diameter of electrode used for qualification shall be the maximum diameter that will be used as required by the recorded welding procedure at any particular groove width. (See factor 4, Table B-I.)

B-3.1.2.4 Position of welding.- Each welder shall be required to qualify in the positions in which he will weld on production, by welding a test specimen of the type specified in B-3.1.2.2 in the positions prescribed in paragraphs B-3.1.2.4.1 to B-3.1.2.4.4 inclusive, as applicable. However, welders qualified in one or more positions shall be considered qualified in additional positions under conditions as allowed below:

Position in which qualified	Qualifies welder to weld in
Flat position	Flat position only
Horizontal position	Flat and horizontal positions
Vertical position	Flat and vertical positions
Overhead position	Flat, horizontal, and overhead positions.

B-3.1.2.4.1 Flat positions.- To qualify the welder in the flat position, the test plate shall be placed in an approximately horizontal plane and the weld metal shall be deposited from the upper side.

B-3.1.2.4.2 Horizontal position.- To qualify the welder in the horizontal position, the test plates shall be placed in an approximately vertical plane with the welding groove in an approximately horizontal plane.

B-3.1.2.4.3 Vertical position.- To qualify the welder in the vertical position, the test plates shall be placed in an approximately vertical plane with the welding groove in an approximately vertical position.

B-3.1.2.4.4 Overhead positions.- To qualify the welder in the overhead position, the test plates shall be placed in an approximately horizontal plane and the weld metal shall be deposited from the underside position.

B-3.1.2.5 Soundness.- Finished welder-qualification test plates shall comply with Standard II of MIL-R-11468 when radiographed in accordance with the requirements of Appendix C, except defects within 1" of either end of a weld may be disregarded.

B-3.2 Requirements for repair of armor castings.-

B-3.2.1 General.- All weld repairs shall be made using a procedure and by welders qualified in accordance with this appendix.

B-3.2.2 Repairable defects.- Defects which may be repaired by welding shall not exceed the weld-area dimensions specified for each classification shown in Table B-II. The size of defect shall be considered as the size of the cavity resulting from chipping, grinding, or oxygen cutting to remove the defect, or as the size of the area to be welded to obtain the dimensions specified on the applicable drawings.

B-3.2.2.1 Large defects.- Greater defects (than those listed in B-3.2.2) may be repair-welded subject, in case of each repair, to the written authorization of the procuring agency.

B-3.2.2.2 Inserts.- Cast sections may be inserted by welding in the production castings, provided each plate is of the same chemical composition range as the casting, and subject to the following dimensional limits: Thickness of section shall be equal to that of casting section to which it is welded; maximum length or maximum width of insert shall not exceed 16 times the thickness; and width of weld shall not be greater than twice the thickness.

B-3.2.3 Interpass temperature.- The interpass temperature of production castings shall be not less than the minimum preheat temperature established in the recorded welding procedure. The interpass temperature shall be measured immediately before the deposition of each layer at a location approximately 3" from the edge of the weld on the base metal.

B-3.2.4 Type of electrode.- Unless otherwise authorized by the procuring agency, all repair welding shall be performed using ferritic-type electrodes conforming to 57-203-7.

B-3.2.5 Radiographic requirements.- The repair welds shall meet the radiographic requirements of Standard III, MIL-R-11468(Ord). Any welds that do not comply with the standard specified shall be repaired, and subsequently radiographed. When the width of the weld is greater than 2 inches, for the purpose of radiographic interpretation, the weld shall be considered to be a series of welds 2 inches wide.

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B-3.2.5.1 Radiography of repaired castings.- One casting in every thirty production castings having repair welds exceeding the dimensions specified under classification C, in paragraph B-3.2.2 shall be selected for radiographic inspection. Only those areas, in the casting selected, with repair welds exceeding the dimensions specified under classification C in B-3.2.2 shall be radiographed.

[redacted]

TABLE B-II
CLASSIFICATION OF DEFECTS

Thickness of Section (inches) Greater than--	To and including	Size of defect	All Dimensions in Inches[1] Depth Maximum	Width Maximum	Length Maximum
Classifications A & B. Defects subject to complete heat treatment after being welded; i.e., hardened and tempered, shall be classified as A. Defects subject to tempering only shall be classified as B. Extent of heat treatment (i.e., complete or tempering) shall be as established by the recorded repair welding procedure.					
-	3½	1	T	6	18
-	3½	2	T	T	No limit
-	3½	3	1/4T	12	24
-	3½	4	1/8T not to exceed 3/16	No limit	No limit
3½	7	1	T	7	4T
3½	7	2	T	T	No limit
3½	7	3	1/4T	4T	6T
3½	7	4	1/8T not to exceed 3/16	No limit	No limit
7	-	1	T	14	24
7	-	2	T	T	No limit
7	-	3	1/4T	4T	6T
7	-	4	1/8T not to exceed 3/16	No limit	No limit
Classification C. Defects requiring no thermal treatment after welding.					
-	3½	1	1/4T not to exceed 1/2	4	12
-	3½	2	T	T not to exceed 2	4
-	3½	3	1/2T not to exceed 1	T not to exceed 2	24
-	3½	4	1/8T not to exceed 3/16	8	12 or equiv. area
3½	-	1	1/2	4	12
3½	-	2	1	2	18
3½	-	3	3/16	8	12 or equiv. area

(1) This symbol "T" as used in this table represents the thickness of the casting at the location involved.

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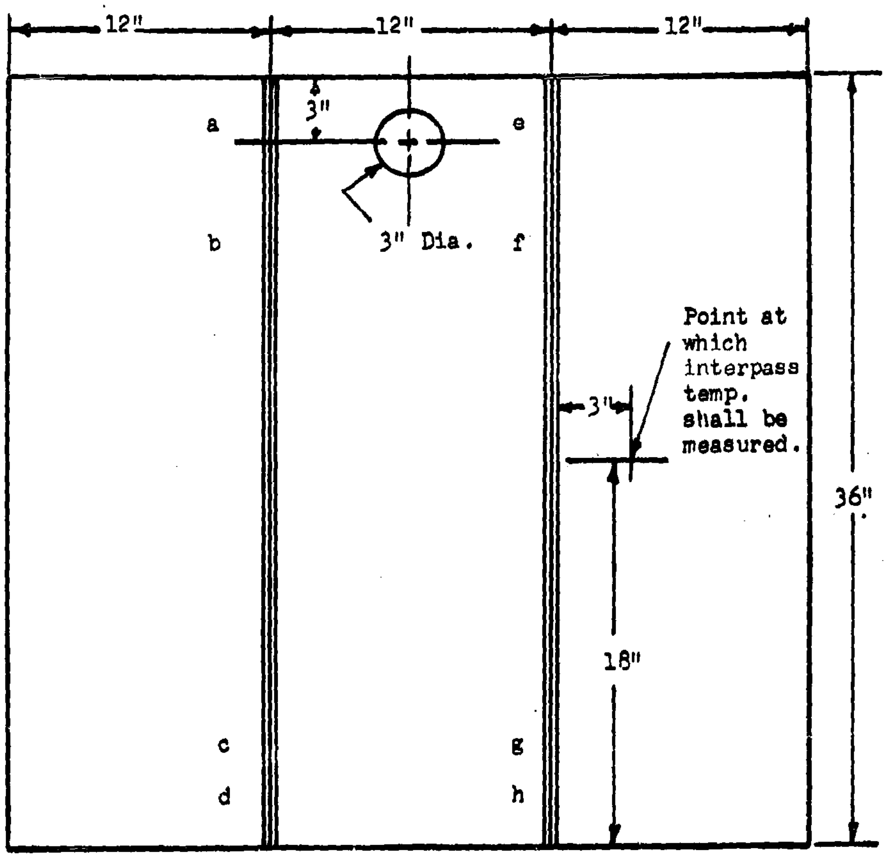

FIGURE B-1. Double-I Ballistic Test Plate.

Notes:
(1) Plate thickness shall be 1 or 2 inches.
(2) Sections "ab" and "cd" shall be completely welded on both sides before "bc" is welded. Sections "ef" and "gh" shall be completely welded on both sides before "fg" is welded. Prior to welding of section "bc" and "fg", the plate shall be cooled to the recorded preheat temperature.
(3) Lengths of sections "ab," "cd," "ef," and "gh" shall be not less than 6 and not more than 8 inches.
(4) Plate shall be welded in accordance with Recorded Repair-welding Procedure for size (2) defects extending completely through the section. (See paragraph B-3.2.2.)

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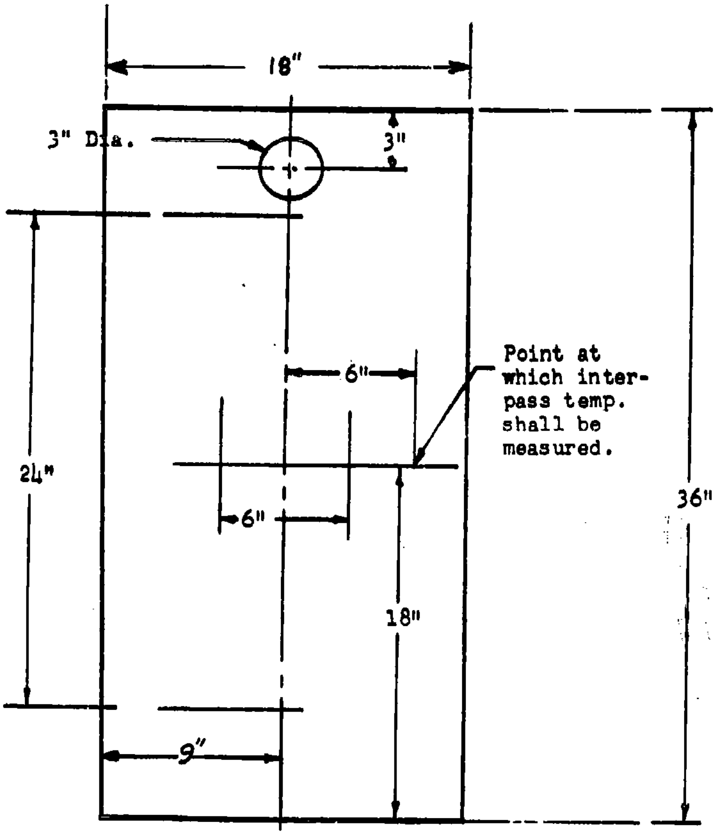

FIGURE B-2. Area-Defect Ballistic Test Plate.

Notes: (1) Plate thickness shall be 1 or 2 inches.
(2) Weld area shall be centered on long dimension of plate.
(3) Welded area shall be 6 by 24 inches, completely through the section; except for 1-inch plate, the weld area dimensions shall be 6 by 15 inches.
(4) Plate shall be welded in accordance with Recorded Repair-welding Procedure for size (1) Classification A and/or B defects extending completely through the section. (See B-3.2.2)

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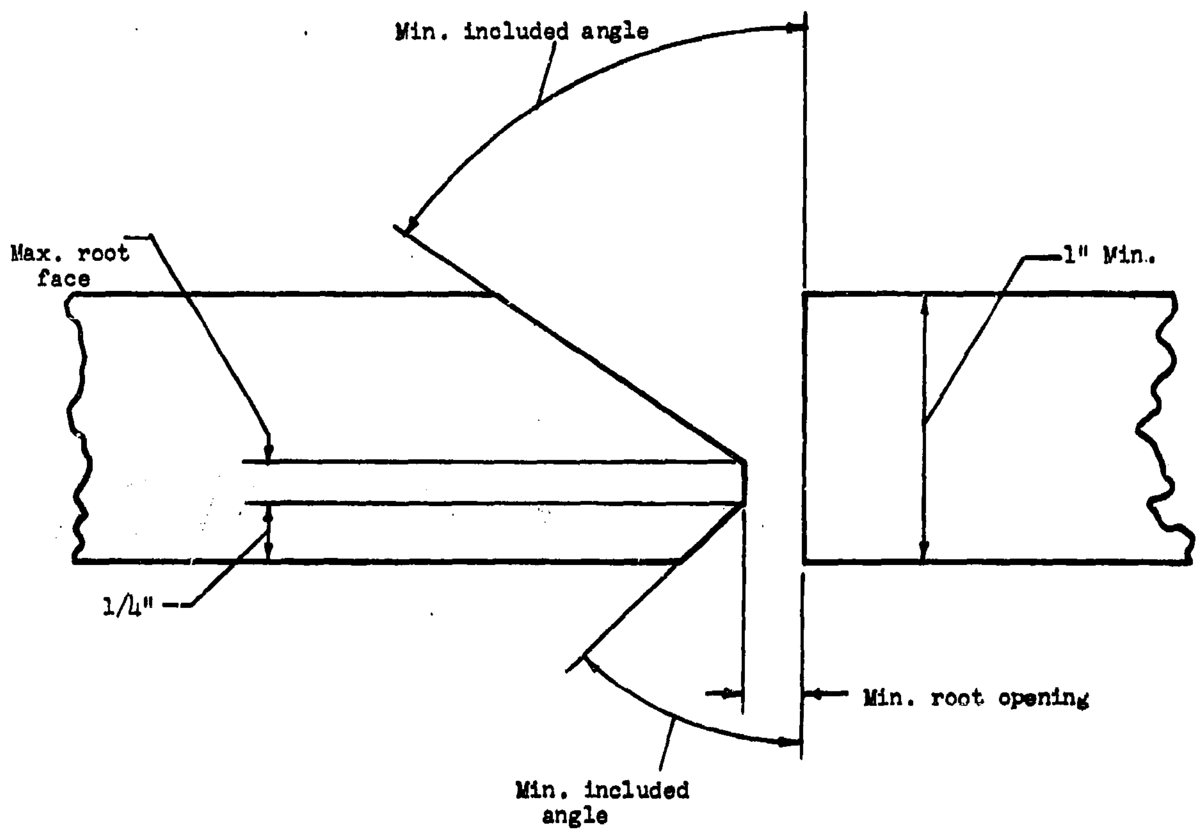

FIGURE B-3. Welder Qualification Test Specimen.

Note: The minimum and maximum dimensions indicated in Figure B-3 are exact dimensions and shall be those specified as such in the Recorded Repair-welding Procedure for size (2) Classification-A defects extending completely through the section. (See paragraph B-3.2.2.)

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QUALIFICATION AND REQUIREMENTS FOR THE RADIOGRAPHIC INSPECTION OF ARMOR CASTINGS

C-1. SCOPE

C-1.1 The appendix covers the requirements for the qualification of supervisors involved in the radiographic inspection of armor castings and the requirements for such inspection.

C-2. APPLICABLE SPECIFICATIONS AND STANDARDS

C-2.1 Applicable specifications.- The following specifications (in addition to those specified in Section 2 of this specification), of the issue in effect on the date of invitation for bids, form a part of this specification:

SPECIFICATIONS

MILITARY

MIL-R-11468 - Radiographic Inspection; Soundness Requirements for Arc and Gas Welds in Steel

MIL-R-11469 - Radiographic Standards for Inspection of Steel Castings Including Cast Armor

C-2.2 Applicable standards.- The following Military Standard of the issue in effect on the date of invitation for bids, forms a part of this specification:

MIL-STD-23 - Nondestructive Test Symbols

C-3. REQUIREMENTS

C-3.1 Qualification.- The manufacturer shall qualify radiographic sources and supervisors in accordance with C-3.3 (see C-6.3).

C-3.2 Qualification test block.- The test blocks (Models L-2 and H-2) shall be used in the qualification tests and will be supplied by the procuring agency upon proper request.

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[redacted]

C-3.3 Supervisor and source qualified requirements.- The supervisor qualification test shall consist of the radiographing of the test blocks referred to in C-3.2 in accordance with 3.3.1. Supervisors shall qualify for thicknesses to 3" inclusive using a test block 1" thick and for thicknesses greater than 3" using a test block 3-1/2" thick. This qualification test shall be conducted for each source of radiation to be employed for production radiography.

C-3.3.1 The supervisor shall select all details of radiographic technique to be employed by himself and the technicians under his jurisdiction in the conduct of the test. Using these details, the supervisor shall produce a radiograph of the applicable test block as stated in 3.3, shall examine the radiograph, and report in writing his findings of the images thereon to the procuring agency. The correct identification from the negative of at least 90% of the information contained in the test block shall constitute qualification of the supervisor for the radiographic inspection of cast armor.

C-3.3.2 Information required.- In addition to the report required in C-3.3.1, the manufacturer shall furnish the procuring agency with the negative with which qualification was obtained as well as a detailed statement covering:

a. Type, model, name of manufacturer and machine rating as stated by the manufacturer.

b. For Gamma radiography, the type of source and the strength of the source in Curies.

c. d/t ratio employed with negatives submitted (see Figure C-1).

C-3.3.3 Requalification.- Requalification shall be required whenever a change in supervisors takes place in the radiographic facility or whenever the source of radiation is changed. Requalification shall not be required for changes in technical personnel who are not supervisors or for direct replacements of the source of radiation. (See C-6.4.)

C-3.4 Inspection of production castings.-

C-3.4.1 General.- Radiographic inspection shall be used to reveal, within the limits of its sensitivity, discontinuities in metals. Parts shall be examined in locations specified in the applicable specifications, contract, order, or drawing.

C-3.4.1.1 Supplementary radiography.- Radiographic inspection in addition to that specified by the preceding paragraph may be performed at the discretion of the inspector to determine the extent of a defect which has been located by previous inspection.

[redacted]

C-3.4.2 Materials.- Radiographs shall be made on noninflammable X-ray film, free of inherent flaws that may interfere with interpretation of the radiographic image and capable of acceptable clarity and definition.

C-3.4.3 Viewing equipment.- Suitable facilities shall be provided for the viewing and examination of negatives and for the comparison of negatives with standards when required.

C-3.4.4 Workmanship.-

C-3.4.4.1 Quality of negative.- Radiographic negatives shall be free of blemishes (See C-6.1) that may interfere with interpretation of the radiographic image. Whenever the quality of a radiographic negative is unsatisfactory in the areas to be inspected, re-radiography will be required.

C-3.4.4.2 Qualification.- Radiographs shall be made under the supervision of personnel qualified in accordance with the requirements of this appendix.

C-3.4.4.3 The d/t ratio.- The minimum d/t ratio used for production radiography shall not be less than that employed by the supervisor for the test negative upon which his qualification for each thickness was based.

C-3.4.5 Standards of acceptance.- The standards of acceptance shall be in accordance with the requirements of Specification Nos. MIL-R-11468 and MIL-R-11469 as applicable.

C-3.4.6 Test symbols.- When position drawings (See C-6.2) are required or furnished by the procuring agency, symbols used shall be in accordance with the applicable requirements of MIL-STD-23.

C-3.4.7 Inspection records.- The contractor shall submit radiographic negatives and suitable identification in accordance with the requirements of the procuring agency for each article or unit of manufacture that has been radiographed.

C-3.4.7.1 Availability of negatives.- Exposed radiographic negatives shall be available for examination by the procuring agency at any location and for a period not to exceed 12 months from the date of exposure.

C-3.4.8 Sharpness of penetrameter image.- The image of the penetrameter shall be resolved in the negative.

C-3.4.9 Identification.- Areas which have been radiographed shall be marked in such a manner as to identify them with the radiographic negatives of the applicable areas and castings until final radiographic acceptance is obtained.

[redacted]

C-3.4.10 Direction of radiation.- When not otherwise indicated in the position drawings, the direction of radiation shall be perpendicular to the surface of the metal and the radiographic film. When, because of a peculiar condition of test the required direction of radiation is not the most effective, a sketch showing the actual direction of radiation used shall be made on the negative or attached to it. When the same set-up is used for a number of radiographs, a single sketch will suffice for the entire set of negatives.

C-3.4.11 Location of film.- The film during exposure shall be as close as practicable to the surface of the object being radiographed.

C-3.4.12 Location markers.- When required by the procuring agency, location markers shall be placed on or adjacent to the metal surface being radiographed and their images shall appear distinctly on the film. The exact location of the markers shall be marked on the surface of the metal in a manner not injurious to the serviceability of the part, so that the radiographs may be accurately located whenever desired up to final radiographic acceptance.

C-3.4.13 Identification of negatives.- A system for identification of negatives approved by the procuring agency shall be used. When required by the procuring agency, each negative shall carry the image of the lead markers identifying the individual part and the area radiographed. (See C-3.4.7.)

C-3.5 Penetrameters.-

C-3.5.1 Penetrameter design.- Unless otherwise specified, penetrameters shall have dimensions in accordance with Figure C-2.

C-3.5.1.1 Identification.- The penetrameters shall be identified with an identification number, made of lead alloy and attached to the penetrameter. This number shall be equal to the thickness, in inches, of the metal to which the penetrameter is normally applicable.

C-3.5.2 Penetrameter placement.- Penetrameters shall be placed on the side of the metal away from the film (source side) in such a location that the d/t ratio is the smallest possible value for the area involved.

C-3.5.2.1 Placement on welds.- Penetrameters shall be placed on the base metal at least 1/8 inch from the edge of the weld.

C-3.5.2.2 Placement on identical parts.- When a number of identical parts are simultaneously exposed, the penetrameter shall be placed on the irradiated surface of that part at the outer edge of the cone of radiation.

C-3.5.2.3 Placement on blocks.- When it is impractical to place the penetrameter upon the part radiographed, the penetrameter may be placed on the irradiated surface of a block of metal of the same base metal and approximately the same density and thickness as the part or parts radiographed. This block shall be placed upon a part of the film at the outer edge of the cone of radiation.

C-3.5.3 Number of penetrameters.- Except as specified below, the image of at least one penetrameter shall appear on each radiographic negative submitted to the inspector.

C-3.5.3.1 Simultaneous exposures.- When a number of films is exposed simultaneously and all conditions of exposure are the same for all films, only one negative from the group shall be required to bear the image of a penetrameter. This negative, which shall be taken from a location at the outer edge of the cone of radiation, shall accompany the other negatives of the same group when they are submitted to the inspector.

C-4. SAMPLING, INSPECTION, AND TEST PROCEDURE (Not Applicable)

C-5. PREPARATION FOR DELIVERY (Not Applicable)

C-6. NOTES

C-6.1 Blemishes defined.- Blemishes on radiographic negatives are defined as marks, discoloration, or abrasions that are not representative of variations in the opacity of the metal being radiographed. Some examples are discolorations caused by chemical stains, scratches, and blackened areas caused by light leaks in the film pack.

C-6.2 Position drawings.- The radiographic position drawings are drawings used for the purpose of designating the amount, locations, and frequency of radiographic examination.

C-6.3 Supervisor defined.- For purposes of qualification the supervisor will be regarded as one or more members of the radiographic facility designated by that facility as responsible for radiographic inspection.

C-6.4 Sources of radiation.- Supervisor qualification is intended to be accomplished on all X-ray machines up to and including the Betatron type, as well as all radioactive sources now known.

C-6.5 Direct replacement defined.- For purposes of requalification a direct replacement is defined as an X-ray machine of the same type, voltage and manufacture, or in the case of an X-ray tube of the same tube type and manufacturer or in the case of natural radioactive, or induced radioactive isotope sources, a source of the same type and strength.

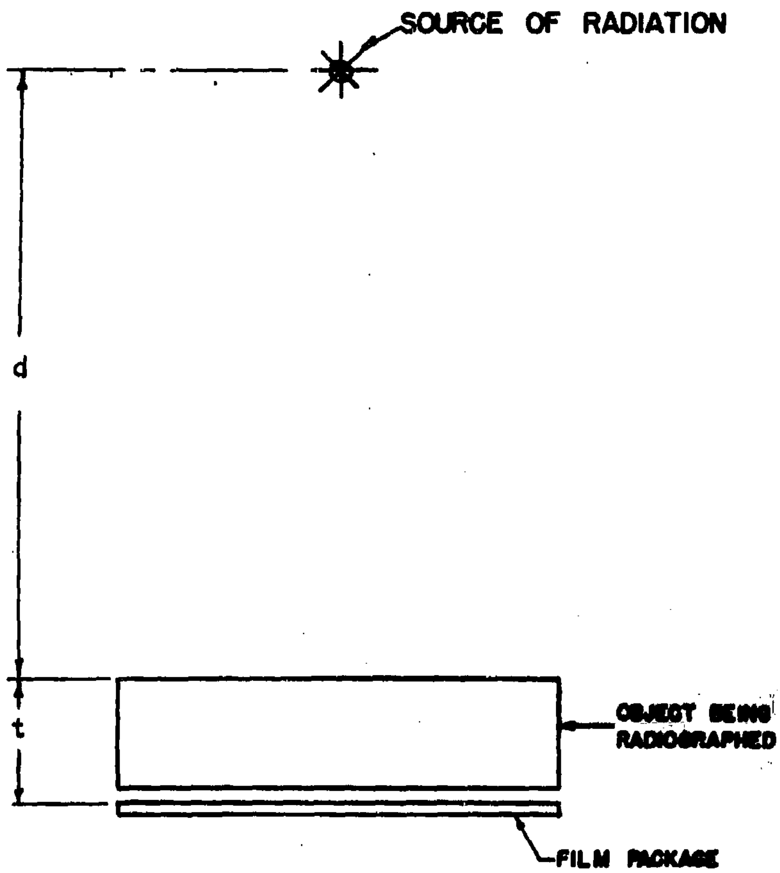
SOURCE OF RADIATION
d
t
OBJECT BEING
RADIOGRAPHED
FILM PACKAGE

FIG. C-1

[redacted]

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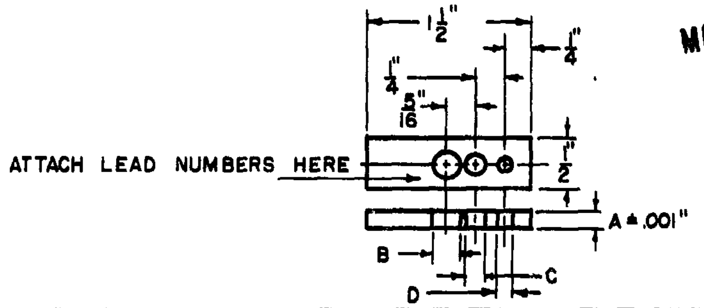
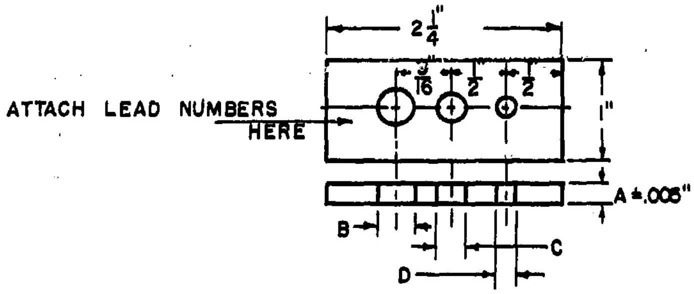
X-RAY PENETRAMETERS



METAL THICKNESS INCHES*	PENETRA-METER NO.	DIMENSIONS - INCHES (USE NEAREST DRILL SIZE)			
		A	B	C	D
1/2	.50	.010	.06	.06	.06
1	1.0	.020	.08	.06	.06
1- 1/2	1.5	.030	.12	.09	.06
2	2.0	.040	.16	.12	.08



METAL THICKNESS INCHES*	PENETRA-METER NO.	DIMENSIONS - INCHES (USE NEAREST DRILL SIZE)			
		A	B	C	D
3	3.0	.060	.24	.18	.12
4	4.0	.080	.32	.24	.16
5	5.0	.100	.40	.30	.20
6	6.0	.120	.48	.36	.24
7	7.0	.140	.56	.42	.28
8	8.0	.160	.64	.48	.32

* WHENEVER THE METAL THICKNESS TO BE RADIOGRAPHED FALLS BETWEEN TWO CONSECUTIVE THICKNESSES INDICATED, THE PENETRAMETER TO BE USED SHALL BE THAT APPROPRIATE TO THE GREATER THICKNESS.

Figure C-2.

[redacted]

GPO 83-49142

APPENDIX A

Part III

Military Specification MIL-S-20460
Shot, Armor-piercing; Metal-parts Assembly

MIL-P-20460
4 December 1951

MILITARY SPECIFICATION

PROJECTILES, ARMOR-PIERCING; METAL PARTS ASSEMBLY

This specification was approved by the Departments of the Army, the Navy, and the Air Force for use of procurement services of the respective Departments, and supersedes the following specification:

Army 50-33-5
23 February 1950

This specification consists of this cover sheet and Specification 50-33-5, dated 23 February 1950, attached hereto, without modification.

When a request for this specification is received by a supplying activity it will be necessary to attach this cover sheet to the pertinent specification before issue.

Copies of specifications required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer .

Custodian:
Army- O

50-33-5
23 February 1950

U. S. ARMY SPECIFICATION

PROJECTILES, ARMOR-PIERCING; METAL - PARTS ASSEMBLY

1. SCOPE AND CLASSIFICATION

1.1 This specification covers armor-piercing (AP) shot with or without windshields but without piercing cap, manufactured from bar stock or forgings in all sizes from 20mm through 120mm.

2. APPLICABLE SPECIFICATIONS

2.1 The following specifications, of the issue in effect on date of invitation for bids, form parts of this specification:

FEDERAL SPECIFICATION

QQ-M-151 Metals: General Specification for Inspection of.

MILITARY SPECIFICATION

JAN-C-490 Cleaning and Preparation of Ferrous Metal Surfaces for Organic Protective Coatings.

U. S. ARMY SPECIFICATIONS

50-0-1 General Specification for Ammunition except Small Arms Ammunition

50-27-1 Blanks, Rotating Band for Projectiles

57-0-4 Macro-etch Test and Standards for Steel Bars, Billets, Blooms and Slabs

57-0-5 Magnetic-particle Inspection; Process for Ferro Magnetic Materials

100-2 Standard Specification for Marking Shipments by Contractors.

(Copies of specifications should be obtained from the procuring agency or as directed by that agency. Both the title and identifying number or symbol should be stipulated when requesting copies.)

3. REQUIREMENTS

3.1 General. The projectiles shall meet all requirements prescribed on drawings and in applicable specifications.

3.2 Materials. Materials and parts shall be in accordance with applicable specifications and drawings.

3.3 Chemical composition. The composition of the steel used in projectiles shall be at the option of the contractor, provided the projectiles meet the functioning requirements and tests prescribed herein.

3.4 Heat treatment. The heat treatment given the projectile bodies shall be uniform for each heat of steel. All details concerning heat treatment must be shown on the data card. (See 5.1.2 and 6.6.)

3.5 Soundness. All projectile bodies shall be sound and free from internal strains, and other defects which would affect their armor piercing properties. Each projectile shall be free of imperfections that are detectable when inspected as prescribed in 4.6.

3.6 Cleaning before assembly. (Applies only to projectiles with windshields). The projectile bodies and windshields shall be cleaned and free of foreign material at the time of attaching the windshield to the shot bodies.

3.7 Attachment of windshields. After heat treatment of the projectile bodies, the windshields shall be firmly and rigidly attached thereto in the manner prescribed on the applicable drawing and shall be concentric with the projectile body within the limits prescribed on the drawing. The assembly shall be free of cracks and tears. (See 4.6.)

3.8 Band seating. Prior to banding, the band seat shall be clean and free from oil, grease, dirt, rust, and other foreign material. Shot or sand blasting is not permitted for cleaning the band seat after knurling. The rough rotating band shall be in the form of a solid ring, annealed and carefully pressed into the band seat so as to completely fill it and fit tightly. The band shall be applied cold after final heat treatment of the projectile body.

3.9 Physical properties of gilding-metal rotating bands. Before assembly to the projectile, rotating band blanks shall meet the requirements of specification 50-27-1, Class B, annealed condition, and after assembly shall meet a 180° bend test. (See 4.5.3.2.)

3.10 Protection of rotating bands. The machined rotating bands shall be carefully protected from being nicked, burred, or otherwise damaged in subsequent handling and shipping.

3.11 Preparation for painting after assembly. All surfaces of projectile parts shall be prepared by Grade I treatment, Specification JAN-C-490, except rotating band and rotating-band seat which need not be so prepared. Cleaned surfaces shall remain uncontaminated prior to painting. After application of the paint prescribed on the drawing, the paint-phosphate system shall be capable of withstanding a 72-hour salt spray test. (See 4.7.)

3.12 Coating. The exterior coating and the tracer cavity coating specified on the drawing for the projectile shall be applied in such a manner as to produce a tightly adherent coating of uniform thickness over the entire specified areas. The projectiles shall be stencilled or marked as prescribed on the drawing. All paint and marking shall be dry to the touch before the projectiles are packed for shipment.

3.13 Ballistic performance.

3.13.1 Armor plate performance. The projectiles shall be capable of penetrating armor plate of the type and thickness and under the conditions specified in 4.8.4.

3.13.2 Security of component attachment. The projectiles shall withstand firing in a worn but serviceable gun without the loss of the windshield or rotating bands.

3.14 Pilot lot. The contractor shall produce and submit to the contracting officer or representative designated by him, a pilot lot of the size specified in Table I for metallurgical, ballistic and other tests to determine the satisfactoriness of his materials and methods. Any production under the contract prior to the approval of the pilot lot will be at the risk of the contractor.

4. SAMPLING, INSPECTION AND TEST PROCEDURE

4.1 Inspection general. Inspection shall be as prescribed in specifications 50-0-1 and QQ-M-151.

4.2 Lots.

4.2.1 Size of lots. The size of regular lots shall be limited in accordance with Table I. The first production lot manufactured on any contract shall not exceed that specified in Table I except where a new contract immediately follows the manufacture of satisfactory projectiles of the same caliber under this specification. To avoid many small lots, projectiles left over from previously accepted lots shall be assembled into miscellaneous lots not exceeding limits shown in Table I. The number of miscellaneous lots shall be kept to a minimum.

TABLE I

Caliber	Pilot Lot (Min.)	1st Prod. Lot Max.	Reg. Prod. Lot Max.	Misc. Lot Max.
20mm	100	1,000	20,000	2,000
37mm	50	1,000	20,000	2,000
40mm	50	1,000	20,000	2,000
75mm, 76mm (3")	30	700	15,000	1,000
90mm	25	500	10,000	1,000
120mm	25	500	5,000	500

4.2.2 Make-up of lots: heats, composition. In no one lot shall more than one composition of steel be used in the projectile body. Not more than six heats of steel shall be used in the projectile bodies in any one lot except that in the make-up of miscellaneous lots, only the restriction on composition shall apply.

4.3 Sampling. All samples shall be selected by the inspector as required by the provisions of each separate test and as outlined in Table II.

TABLE II
CONSOLIDATED TABLE OF SAMPLE SIZES
(See appropriate sampling and test paragraphs for method of sampling, test, and size of retest sample.)

Test	20mm thru 40mm	75mm thru 3-in.	90mm thru 120mm
A. Hardness	25%	100%	100%
B. Rotating Band			
1. Tightness (b)	1/1000/machine(a)	1/1000/machine	1/1000/machine
2. Character of Seating(b)	1/1000/machine	1/1000/machine	1/1000/machine
3. Bend Test (b)	1/4000	1/4000	1/4000
C. Cracks	100%	100%	100%

TABLE II (Cont'd.)
CONSOLIDATED TABLE OF SAMPLE SIZES

Test	20mm thru 40mm	75mm thru 3-in.	90mm thru 120mm
D. Plate Penetration Test			
1. First Lots	10/lot	7/lot	5/lot
2. Reduced Samples (c)	5/lot	4/lot	4/lot
E. Security Test			
1. First Lots	5/lot	4/lot	3/lot
2. Reduced Samples (c)	3/lot	2/lot	2/lot
F. Velocity Test			
1. First Lot	5/lot	5/lot	5/lot
2. Reduced Sample (c)(d)	1/lot	1/lot	1/lot

NOTES:

(a) Tightness of band on 20mm projectiles will be determined in accordance with 4.5.2. (See 6.2.1.)
(b) Samples for these tests may be combined.
(c) Applies after 10 consecutive lots have passed this test without resort to retest.
(d) Samples from five successive lots may be held by the manufacturer and shipped to the proving ground together.

4.4 Hardness test.

4.4.1 Instrument used. Hardness test shall be made with any of the hardness testing instruments mentioned in specification QQ-M-151, except Brinell; or any other device approved by the chief of the supply service involved.

4.4.2 Location. On projectiles that have a body diameter less than the bourrelet diameter, at least one test shall be made on the body approximately .25" to the rear of the bourrelet, except that 20mm and 40mm projectiles shall be tested approximately .15 inches to the rear of the windshield seating shoulder. Projectiles on which the full bourrelet diameter extends from ogive to rotating band shall be tested for hardness at a point approximately 1/2" to the rear of the ogive-bourrelet intersection.

4.5 Rotating band tests.

4.5.1 Measurement of tightness. (Does not apply to 20mm). The band shall be removed from the prescribed sample of projectiles for examination of seating, except when production is less than 1,000 per working shift, in which case one projectile from each banding machine from each shift shall be tested for seating. Prior to removal, the diameter of the finished band shall be measured on three diameters, 60° apart, and on at least two points along the length of the cylindrical portion, near the front and near the rear (a minimum of six diametral measurements). These points of measurement shall be marked on the bands as well as the orientation of the band on the projectile. After removal, the thickness of the band shall be measured at each of the marked points, (12 measurements), and the diameter of the band seat shall be measured opposite those points.

The diameters of the band seat at each point shall be added to the corresponding exterior diameter of the band previously determined. The result will indicate total diametral clearance between the band and its seat. If the band is well seated, a negative clearance or interference may be indicated on some of the measurements or even on the average of all measurements. When wavy band-seat ribs or irregular band profile interferes with ease of measurement, the manufacturer is authorized to machine the outside of the band in order to obtain an adequately cylindrical surface. The diameter of the machined band shall exceed the bourrelet diameter.

4.5.1.1 Measurement of tightness retest. In case the indicated clearance thus determined is greater than .006 inch on any one diameter, either front or rear, the band shall be removed from 10 additional shot from the group represented. If a clearance greater than .006 inch on any one diameter is indicated on any one of these additional projectiles, the entire group represented shall be rejected subject to rebanding and retest.

4.5.2 Character of seating. Bands shall be removed from the prescribed sample of projectiles for examination of character of seating. (See 6.2.2.)

4.5.3 Physical tests of gilding-metal rotating bands.

4.5.3.1 Bend test. The prescribed sample of bands shall be removed from the projectile and bent cold by pressure, without hammering, in the direction of the curvature of the band, until it tightly encloses 180° of a rod equal to the thickness of the specimen.

4.5.3.2 Bend retest. Double the number of samples shall be used for the retest and if failure occurs in the retest, the projectiles represented by the sample shall be rebanded and resubmitted for test.

4.6 Testing for cracks. In magnetic testing an electric current equal to that prescribed in Table III shall be used. Procedure shall be followed as prescribed in specification 57-0-5. All projectiles shall be demagnetized after the magnetic test. Projectile bodies containing definite indications of cracks as defined below shall be rejected. Imperfections coming under the following definitions will be considered indications of objectionable cracks:

a. Any cracks or indications of imperfections whatsoever, which run other than parallel to the axis; or

b. Any cracks or indications of imperfections running parallel with the axis which appear in the band seat, crimping groove, or windshield seating surface, or extend into the ogive.

Projectiles containing indications not defined above will be considered acceptable. The acceptability of border-line material shall be determined by comparison with samples furnished and/or approved by the chief of the supply service involved.

TABLE III
Magnetizing Current Required

Caliber (size)	Bodies (amperes)
20mm	300-600
37mm & 40mm	800-1000
75mm, 76mm (3")	800-1200
90mm	1000-1500
120mm	1200-1700

4.7 Salt-spray resistance. After completion of painting as prescribed on the drawing, a representative sample of the assembled projectiles shall be subjected to a salt-spray test as prescribed in specification QQ-M-151. After 72 hours in the salt spray the shell surfaces shall not show evidence of rusting to an extent greater than that shown by Plate No. 9, Type 1, of ASTM Photographic Reference Standards for Evaluating Degree of Resistance to Rusting Obtained with Paint on Iron or Steel Surfaces, ASTM Designation D610-41T.

4.8 Proving-ground tests.

4.8.1 Armor-plate penetration test samples. The prescribed sample shall be selected after heat treatment of each lot and each projectile of the sample tested for hardness. After hardness determination has been made, the projectiles shall be assembled with rotating bands (and windshields when applicable) by the production method employed by the contractor. The sample shall include all heats of steel in projectile bodies in the lot insofar as allowable by the sample size and the heat identification shall be plainly distinguishable. The sample shall also represent the hardness range within the lot insofar as consistent with full heat representation and the hardness of each shall be recorded on the data cards. The number of samples shall be in accordance with Table II. The assembled projectiles shall be packed and shipped to the proving ground, marked "For Plate Test." (See 4.8.4.)

4.8.2 Security test samples. Samples for the security test shall be assembled by the production method used by the contractor, packed and shipped to the proving ground marked "For Security Test." The sample size shall be that specified in Table II. (See 4.8.5.)

4.8.3 Velocity test samples. For velocity tests, the inspector shall select the prescribed sample from equal parts of a regular lot or at random from a miscellaneous lot. The sample projectiles shall be forwarded by the contractor to the proving ground marked "For Velocity Test." (See 4.8.6.)

4.8.4 Armor-plate penetration test. The projectiles submitted for plate penetration tests shall be fired from a gun for which the projectile is standard against armor plate of accepted quality placed approximately 300 feet from the gun. Type of plate, thickness and obliquity shall be as specified in Table IV. The striking velocity of the projectiles shall be 10% ± 25 f/s in excess of the ballistic limit of the plate. The lot shall be considered to have satisfactorily passed the armor plate penetration test if the number of projectiles specified in the appropriate line of Table IV completely penetrate the plate. Firing shall be discontinued when the required number of complete (or incomplete) penetrations have occurred. An impact which occurs under the following conditions will be disregarded and another projectile fired in its stead:

a. Any projectile which bounces off face of plate and remains intact;

b. Any projectile which fails to completely penetrate the plate but remains intact in the plate;

c. Any projectile which strikes in the spalled area of a previous impact;

d. Any projectile which strikes within one caliber of the nearest edge of a previous impact. The measurement shall be in terms of the caliber of the larger hole.

e. Any projectile which strikes within two calibers of the edge of the plate.

f. Any projectile which fails to completely penetrate at less than the prescribed velocity. One which does satisfactorily penetrate the plate at less than the prescribed velocity shall however be counted.

NOTES: The ballistic limit of an armor plate is defined as the mean of the velocities of one partial and one complete penetration which velocities differ by not more than 50 f/s. The velocity of the partial penetration must be less than the complete. This value is obtained using projectiles of accepted quality of the same caliber and model as the samples being tested. When possible, the calibration area for obtaining the ballistic limit will be the thickest portion of the plate.

A complete penetration is obtained if the projectile, or a major portion thereof, passes through the plate. The proof officer's decision shall be final as to whether a major portion of the projectile has passed through the plate.

TABLE IV

Caliber (Size)	Armor Plate Thickness	Obliquity	Class	Discontinuance of Test: After Successful Impact, First Lots	After Successful Impact, Reduced Sample	Unsuccessful Impact, First Lots	Unsuccessful Impact, Reduced Sample
20mm	3/4"	20°	Face hard.	8	4	3	2
37mm	1"	20°	Homo.	8	4	3	2
40mm	1½"	20°	Homo.	8	4	3	2
75mm	2½"	55°	Homo.	6	3	2	2
76mm (3")	2½"	55°	Homo.	6	3	2	2
90mm	3"	55°	Homo.	4	3	2	2
120mm	4	55°	Homo.	4	3	2	2

4.8.4.1 Armor plate penetration retest. If the contractor so requests, a lot, the samples which fail to meet the standards of paragraph 4.8.4, may be submitted once for retest without reprocessing, in which case the sample size shall be twice that shown in the appropriate line of Table II and shall include all projectiles not fired in the original plate penetration test. These projectiles shall be the first fired in the retest. If in the retest, failures occur in excess of the number allowed in the original test, the lot shall be rejected. Rejected lots may be reprocessed (see 4.8.4.2) in which event they shall in all respects be tested as new lots. A lot of projectiles may be reprocessed twice and after each reprocessing, submitted once to the proving ground for test.

4.8.4.2 Reprocessing. Within this specification the term "reprocessing" shall mean re-stress-relieving, reheat-treatment, etc. Reprocessed lots shall be assigned a suffix "A" or "B", etc., after the lot number according to the number of times the lot is reprocessed.

4.8.5 Security test, windshield, and rotating band. The test samples selected in accordance with 4.8.2 shall be assembled into complete rounds with sufficient propellant to give 112% of the rated maximum pressure of the gun and fired through chipboard screens at suitable distance from the gun. The gun used shall be in the last quarter of its service life. There shall be no observable loss of windshield or rotating band.

4.8.5.1 Security retest. Failure of only one sample in the security test shall permit the retest of a triple number of samples from the lot. The failure of two or more projectiles in the original test or any projectiles in retest shall require rebanding or re-assembly of windshields, depending on the component which failed, of all projectiles in the lot.

4.8.6 Velocity tests. Proving-ground tests for velocity and dispersion are not acceptance tests, but the results will be scrutinized carefully by the Ordnance Department to determine quality of the ammunition produced. Failure in any phase of the proving-ground tests will result in re-inspection of the lot by the Ordnance Department. The projectiles representing each lot and marked "For Velocity Test" shall be fired for comparison with a group of five projectiles from a reference lot of accepted projectiles which has been selected for the purpose, utilizing the service charge. Velocities will be measured on all rounds. Velocities of the test lots will be compared with results of the concurrently fired reference group to indicate whether re-inspection of the test lot is necessary. Not more than five different lots of the test projectiles marked "For Velocity Test" shall be fired for comparison with one group of five test projectiles of the reference lot. Projectiles from each of the test lots shall be fired in rotation, that is, one reference projectile shall be followed successively by one projectile from each of the lots under test, continuing until the series is completed.

4.8.6.1 Dispersion test (20mm projectiles only). The dispersion of 20mm projectiles will be measured during the velocity test. This will be accomplished by firing the velocity test samples against a chipboard screen, placed approximately 300 feet from the muzzle of the gun. Dispersion of test rounds will be compared with that of the reference group.

5. PREPARATION FOR DELIVERY

5.1 Packing.

5.1.1 Container. The projectiles shall be packed in a commercial-type container so constructed as to insure acceptance by common or other carrier, for safe transportation, at the lowest rate, to the point of delivery. Each projectile shall be protected by means of suitable partitions from coming into contact with another projectile. The packing container shall be sufficiently rigid to permit storing in tiers at least 10 feet high without damage to either the containers or contents. The gross weight of any container shall not exceed 200 lbs. except when pallets are used. The lot numbers of contents shall be marked on each container.

5.1.2 Data cards. The data cards, 5 x 8 inches, made of commercial manila tagboard approximately 200 lbs. ream weight, shall be prepared for each lot of accepted projectiles to provide the information specified below. Quantities (approximately 50 cards per lot) and distribution of data cards shall be in accordance with instructions issued by Office, Chief of Ordnance. (See 6.7.)

DATA CARD

Kind____________________ Ammunition Lot No.____________
Quantity in Lot____________
Drawing No.*________________ Spec. No.*____________
Body pcmk.________________ Windshield Pcmk.____________
Manufactured by________________ Date____________
Contract No.________________________
Packed____________ in a box____________ boxes____________
Remarks________________________
*State revisions and amendments. Certified to by____________, Inspector (Print here name of inspector, district, arsenal, or loading plant, and sub-district where applicable.)

5.2 Marking. The marking for shipment shall be in accordance with specification 100-2.

6. NOTES

6.1 Intended use. Projectiles manufactured according to this specification are intended for use against armored combat vehicles and armored aircraft.

6.2 Seating of band. The necessity for firmly seating the rotating band so that it is in contact with the projectile at all points cannot be overemphasized. Air gaps of even a few thousandths of an inch result in differences in starting resistance when the band enters the rifling. This causes variations in the burning characteristics of the powder which in turn affects the muzzle velocity and finally the accuracy. Bands must be fully and uniformly applied in order to obtain satisfactory results.

6.2.1 It is impractical to inspect 20mm rotating bands for tightness in accordance with 4.5.1 and 4.5.1.1. Bands of 20mm projectiles which pass inspection for character of seating of 4.5.2 will be presumed to have met tightness requirements.

6.2.2 Completely filled corners of the band seat, complete impression of knurling and machine marks which have been transposed to bottom of band from band seat are indications of proper seating.

6.3 Waiting for ballistic results. The manufacturer may wait until results of ballistic tests are known before proceeding with banding and assembling windshields to projectile bodies.

6.4 This specification replaces Ordnance Department Tentative Specifications AXS-667, AXS-668, AXS-687, and AXS-1203.

6.5 Armor plate. For proving ground tests, the armor used will be wrought armor acceptable under specifications 57-115-11 and 57-115-18 or JAN-A-784, whichever is applicable.

6.6 Recommended heat treatment. Past experience has indicated that best results are obtained if differential hardness patterns in projectile bodies are developed by heat treatment cycles which consist of uniformly hardening the entire projectile body followed by differential tempering to obtain the desired hardness pattern. A suitable hardness pattern has been found to be one in which the hardness is (a) not less than Rc60 at or near the center of the transverse plane which passes through the intersection of ogive and bourrelet, and (b) in the range of Rc47 through Rc53 at or near the center of the transverse plane just forward of the rotating-band seat. The hardness pattern is best examined by sectioning the projectile on an axial plane.

6.7 Mandatory clause. The use of this specification, whenever applicable, is mandatory on all procuring agencies of the Army.

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APPENDIX A

Part IV

Military Specification MIL-S-13763 (ORD)
Shot, Armor-piercing, Hyper-velocity; with Tungsten-Carbide Cores; Metal-parts Assembly

MIL- S-13763 (Ord)
8 November 1954
SUPERSEDING
50-33-2A
22 December 1949
PA-PD-591
21 September 1954

MILITARY SPECIFICATION

SHOT, ARMOR-PIERCING, HYPER-VELOCITY; WITH TUNGSTEN-CARBIDE CORES; METAL — PARTS ASSEMBLY

1. SCOPE

1.1 This specification covers hyper-velocity armor-piercing (HVAP) shot, the cores of which are made from tungsten carbide and the carriers of which are made from steel, or aluminum. (See 6.1.)

2. APPLICABLE DOCUMENTS

2.1 The following specifications, together with the Ordnance Corps Drawing and Standard Inspection Procedure pertaining to the shot under contract, and all drawings and specifications referenced thereon, of the issue in effect on date of invitation for bids, form a part of this specification:

SPECIFICATIONS

FEDERAL

QQ-M-151 Metals; General Specification For Inspection of

MILITARY

MIL-G-2550	General Specification for Ammunition Except Small-arms Ammunition
MIL-P-10025	Packing and Marking for Domestic Shipment of Inert Ammunition Components; General Specifications for
MIL-R-11073	Rotating Band Blanks, Sintered Iron
MIL-B-20292	Blanks, Rotating for Projectiles

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 Materials.-Materials and parts shall be in accordance with applicable drawings and specifications.

3.2 Components.-The metal parts shall comply with all requirements specified on the applicable drawing and all drawings referenced thereon, and with all requirements specified in applicable specifications.

3.3 Cores.-Cores shall be manufactured by a commercially acceptable process, and shall comply with all dimension and weight requirements specified on the applicable drawing.

3.4 Assembly of components.-

3.4.1 Body parts.-The bourrelet ring shall be attached to the body by either a press or a shrink fit.

3.4.2 Support of cores.-Core shall be rigidly supported within the metal-parts assembly as shown on the drawing with no movement evident after painting.

3.5 Banding (applicable only to shot having separate rotating bands).-

3.5.1 Band seat.-Prior to banding, the band seats shall be clean and free from oil, grease, dirt, rust, and other foreign material.

3.5.2 Rotating band (gilding metal).-

3.5.2.1 Blanks.-The rotating-band blank shall be in the form of a solid ring, annealed if necessary to comply with the requirements of Specification MIL-B-20292, except that in the case of hot banding at not less than 800° F, no prior annealing shall be necessary.

3.5.2.2 Distortion.-The band shall be applied after final heat treatment of the shot body. It shall be applied in such a manner so as not to distort the walls of the shot. Distortion shall not be considered to have taken place if the band seat, and the shot body immediately adjacent to the band are within drawing tolerances specified.

3.5.2.3 Application.-The bands may be applied either hot or cold, but if applied hot, the contractor shall perform the banding operation in a manner that will hold the scale remaining between the band and the seat to a minimum.

3.5.2.4 Heating.-The bands shall not be heated above 1,600°F to prepare them for application to the shot. The bands shall be heated uniformly throughout and in a manner that will prevent undue oxidation (loose scale).

3.5.2.5 Band seating (applicable to destructive test only).-After seating the rotating band the clearance between the band and band seat shall not exceed .006 inch when tested as specified in 4.6.1.

3.5.2.6 Band seating (applicable to non-destructive test only).-The rotating band shall comply with the requirements specified in Table I when tested as specified in 4.6.2.

TABLE I

CALIBER	SHELL MODEL	INDENTOR SIZE IN INCHES	INDENTOR FACE RADIUS IN INCHES	RAM PRESSURE IN POUNDS (APPROX)	AVERAGE INDICATED DIAMETRAL CLEARANCE
76MM	T66E3	.3125 x .3125	1.55	9,000	.010

3.5.2.7 Physical properties of rotating bands.-The material for the rotating bands shall have the following physical properties when tested as specified in 4.6.3.

Tensile Strength psi minimum	32,000
Percent Elongation Min. in 1 inch	15

3.5.3 Rotating band (sintered iron).-

3.5.3.1 Band tightness.-The rotating band shall respond with a metallic ringing sound when tested for tightness as specified in 4.7.1.

3.5.3.2 Rockwell hardness.-The Rockwell H reading shall not exceed 100 when tested as specified in 4.7.2.

3.5.3.3 Rotating bands.-The band blanks shall be carefully pressed into band seat so as to have no gap between bottom of band seat and rotating band and so as to make contact with the side walls of the rotating-band seat for minimum distance of 1/2 of the band-seat depth when tested as specified in 4.7.3.

3.5.3.4 Blanks.-The rotating-band blanks shall be in strict compliance with Specification MIL-R-11073.

3.5.4 Protection of rotating band.-The machined rotating bands shall not be nicked, burred, or otherwise damaged and shall be protected from such damage during subsequent handling and storage.

3.6 Pilot-lot requirements.-

3.6.1 The contractor shall produce and submit a pilot-lot sample of a least 40 metal-parts assemblies to the Contracting Officer or representative designated by him, for metallurgical, ballistic, and other tests in order to determine the satisfactoriness of his methods and materials. The pilot lot shall be given 100 percent inspection by gaging and other non-destructive tests. Of this lot, 38 metal parts assemblies shall be assembled by the contractor into complete shot, and forwarded to the Proving Ground for ballistic tests. The remaining 2 metal parts assemblies shall be retained at the inspection arsenal for destructive metallurgical examination as deemed necessary. Production continued under the contract, prior to the approval of the pilot lot, shall be at the risk of the contractor.

3.6.2 Ballistic requirements.-(pilot-lot)

3.6.2.1 Plate penetration.-The Protection Ballistic Limit, BL(P), of the pilot-lot samples shall not exceed the BL(P) of the reference lot samples by more than 100 f/s when tested as specified in 4.8.1.

3.6.2.2 Security.-There shall be no loss, or breakup, of any shot component either in the gun bore or in flight when tested as specified in 4.8.2.

3.7 Ballistic requirement (production lot).-

3.7.1 Plate penetration.-The BL(P) of the production lot samples shall not exceed the BL(P) of the reference lot samples by more than 100 f/s when tested as specified in 4.9.1.

3.7.2 Security.-There shall be no loss, or breakup, of any shot component either in the gun bore or in flight when tested as specified in 4.9.2.

3.8 Cleanliness.-All parts shall be free of chips, dirt, grease, rust, and other foreign material.

3.8.1 Cleaning before assembly.-The surfaces of all shot parts shall be clean and free of foreign material at the time of assembly. The cleaning method used shall not be injurious to any of the parts nor shall the parts be contaminated by the cleaning agents used.

3.9 Workmanship.-The workmanship shall be of such quality that all parts shall be acceptable under visual inspection and shall meet all dimensional and physical properties prescribed.

4. QUALITY ASSURANCE PROVISIONS

4.1 Lot.-A lot shall consist of all assemblies manufactured by one manufacturer under one contract, in one unchanged process in accordance with the same drawing, same drawing revision, same specification, and same specification revision. Each lot shall contain cores made by one manufacturer, in accordance with one unchanged process and consisting of tungsten-carbide powdered-metal mixture from batches made in accordance with one unchanged process and binder of not more than one type (i.e. cobalt, or a nickel-cobalt mixture, etc.).

4.2 Sampling.-Number of samples, acceptance, and rejection criteria used for determination of lot acceptance for tests specified in 4.4, 4.5, 4.6 and 4.7 shall be in accordance with the applicable Standard Inspection Procedure. Samples for proving ground tests specified in 4.8 and 4.9 shall be selected by the inspector in accordance with Table II.

TABLE II

Proving-ground Samples

A. Plate Penetration	
1. Pilot lot	18
2. Production lot[a]	9
B. Security	
1. Pilot lot	10
2. Production lot	5
C. Velocity-Accuracy	
1. Pilot lot	10
2. Production lot	2[b]

NOTES:

[a]The manufacturer may wait until the results of the armor plate penetration test are available before proceeding with banding and assembly of the complete lot. Assembly of the lot shall be completed prior to selection and submission of the balance of proving-ground samples.

[b]Two sample shot from each production lot shall be retained by the manufacturer until 10 samples have been accumulated. These samples shall then be shipped to the proving ground for test.

4.3 Inspection.-General inspection shall be as specified in Specification MIL-G-2550 and QQ-M-151. (When applicable)

4.4 Integral rotating-band hardness test.-Sample shot shall be selected and subjected to a hardness test using a Rockwell or similar type of hardness-testing machine to determine that the rotating-band hardness does not exceed the requirement specified on the drawing.

4.5 Core tests.-

4.5.1 Hardness.-Each core shall be tested on the base, or on the cylindrical portion approximately at the center, to determine compliance with the hardness requirement specified on the drawing for the core. A spot may be ground on the cylindrical portion not to exceed .010 inch deep. The hardness of cores shall be shown on the data card, by listing the quantity of cores in each range of not more than two points, Rockwell "A".

4.5.2 Bend.-Each core shall be tested for gross flaws by being subjected to a bending load in the manner specified on the applicable drawing. In the case of minor superficial flaws, the core shall be positioned with the flaw in tension during the application of load. After completion of the bend test each core shall pass freely through a tube of the dimensions specified on the drawing.

4.5.3 Chemical.-A certified chemical analysis of the blended powder produced shall be furnished on the data card by the contractor (see 6.2).

4.6 Rotating-band test (gilding metal).

4.6.1 Destructive method of inspecting rotating-band tightness of shot other than those listed in Table I.-The rotating band of the sample shot shall be tested as follows: Prior to removal, the diameter of the finished band shall be measured on three diameters 60° apart, and on two points along the cylindrical portion of its length (near the front and near the rear edge). This comprises six diametral measurements. These points of measurement shall be marked on the bands as well as the orientation of the band on the shot. The band shall be carefully removed so as to keep deformation to a minimum. After removal, the thickness of the band shall be measured at each of the marked points (a total of twelve measurements) and the diameter of the band seat corresponding to these points shall be also be measured. To each of the diameters of the band seat the sum of the corresponding two thicknesses of the band shall be added and the result subtracted from the corresponding exterior diameter of the band previously determined. The result shall indicate the total diametral clearance between the band and its seat to determine compliance with 3.5.2.5. If the band is well seated, a negative clearance or interference may be indicated on some of the measurements or even on the average of all measurements. When irregular band profile interfere with ease of measurement, the manufacturer shall be authorized to machine the outside of the band in order to obtain an adequate cylindrical surface. The diameter of the machined band shall exceed the bourrelet diameter.

4.6.2 Non-destructive method of inspecting rotating-band tightness.-The rotating band of the sample shot shall be tested in an approved machine consisting of a hydraulic press having one movable ram capable of exerting a total ram pressure of 12,000 pounds minimum. Two indentors (or anvils) of rectangular cross section, each having a face radius to match the band diameter (see Table I) shall be provided, one on a fixed adjustable post and one on the movable ram of the press but both on a common center line. The press shall be fitted with indicators to show the pressure on ram and the motion of the ram. The band seating shall be inspected by pressing the band between the indentors in two planes (normal to the longitudinal axis of the shot) approximately 90° apart and measuring the travel of the indentors due to the application of pressure. Care shall be exercised so as not to take readings until after full pressure has been applied and the motion of the ram ceased as shown by the dial indicator. Information regarding the types of approved machine and their specific operating instructions may be obtained from the procuring agency. The pressure used (see Table I) shall be great enough to seat the band under the indentors, but not so great that permanent deformation of the shot occurs. The difference in the measured diameter of the rotating band before and after the application of pressure represents the sum of the clearance under the band in that plane. The readings in the two planes shall not exceed the value shown in Table I. The impression left by the indentors shall not be cause for rejection of the shot. The non-destructive test shall be performed after the O.D. band inspection; the slight increase in O.D. over the maximum shall not be cause for rejection. The degree of rotating-band tightness shall be read to determine compliance with 3.5.2.6.

4.6.3 Physical-property tests of rotating bands.-A sample of unmachined bands, from which a light surface cut (.02 maximum) has been taken, shall be removed to provide specimens to be subjected to each of the tests specified in 3.5.2.7. The bands shall be carefully removed from the shot and carefully flattened without hammering. Each test specimen shall be cut along the direction of the flattened length and prepared in such manner as to hold to the minimum any additional cold working. Samples shall be selected and tested in accordance with Specification QQ-M-151 for determination of percent elongation and tensile strength. In addition, test specimens for elongation and tensile strength shall be machined to the form and dimensions specified in Specification MIL-B-20292; for tensile properties of bands less than .5 inch in width a specimen machined to the maximum rectangular cross-section that can be obtained from an unmachined band shall be used.

4.7 Rotating-band test (sintered iron).

4.7.1 Non-destructive method of inspecting rotating-band tightness.- The rotating band of the sample shot shall be subjected to a sonic test. A hammer of copper, bronze, or soft iron shall be caused to give a light clean blow on the soft surface of the band to determine compliance with 3.5.3.1.

4.7.2 Rockwell hardness.-Rockwell "H" readings shall be taken on at least three points around the circumference of the band in accordance with Specification QQ-M-151 to determine compliance with 3.5.3.2.

4.7.3 Destructive method of inspecting rotating-band tightness.-The rotating band sample shot selected shall be tested as follows: Carefully cross-section the shot with a wet abrasion cut-off wheel so as to produce four segments of 90° each. Visual examination of the 16 pieces shall then be conducted to determine compliance with 3.5.3.3.

4.8 Proving-ground test (pilot-lot).-

4.8.1 Plate penetration.-Prior to firing pilot-lot penetration samples, the BL(P) of a reserve reference lot of the same caliber and model as the pilot lot, shall be determined. The BL(P) is defined as the mean of six velocities, to include three complete and three partial penetrations, the velocity spread of which shall not exceed 100 feet per second. Following determination of the BL(P) of the reference lot, the BL(P) of the pilot lot shall bedetermined as indicated above, utilizing samples selected in accordance with Table II of 4.2. All samples shall be fired from a gun for which the shot is standard, against homogeneous armor plate, placed approximately 300 feet from the muzzle of the gun. Thickness and obliquity of plate shall be as specified in Table III. A complete penetration shall be considered to have occurred if a fragment of the plate or core is thrown beyond the rear of the plate with sufficient energy to penetrate a 0.020-inch aluminum alloy (24 ST) sheet, or its equivalent, placed parallel to, and one foot behind the plate. When in the proof-officer's opinion, it is possible to observe that these conditions are being complied with, without the use of a sheet, as in testing against heavier plate, the sheet may be omitted. An impact that occurs under the following conditions shall be disregarded and another sample fired in its stead: (Cost of such additional samples and testing will be borne by the Government.) (See 6.4)

a. Any core that strikes within three core diameters of the edge of the plate.

b. Any core that strikes within two core diameters of a previous impact or whose path of penetration intersects a previous hole.

c. Any shot that strikes in the spalled area of a previous impact.

TABLE III

Caliber (Size)	Thickness (Inches)	Armor Plate Obliquity
76-MM		
Pilot Lot	2"	60°
	4"	30°
Production Lot	2"	60°
90-MM		
Pilot Lot	3"	55°
	6"	30°
Production Lot	3"	55°

4.8.2 Security test.-The sample shot, selected in accordance with Table II of 4.2, shall be assembled into complete rounds using propellant of a weight calculated to give a pressure equal to the rated maximum pressure of the shot in a new gun for the applicable combination of shot and gun. Five rounds shall be fired hot (125°F), and five rounds shall be fired cold (-40°F). The complete rounds of fixed ammunition shall be held at the proper temperature for a period of not less than 24 hours, and shall be fired within two minutes after removal from the conditioning chamber. The shot shall be fired through paper screens situated approximately 100 and 300 feet from the gun, into a target at approximately 1000 yards range. A gun in the last quarter of its service life shall be used. Observation shall be made for evidence of loss, or break-up of any shot component either in the gun or in flight to determine compliance with 3.6.2.2.

4.8.3 Velocity-accuracy test.-The sample shot, selected in accordance with Table II of 4.2, shall be fired from a gun, for which shot is standard, for comparison with a group of tenshot from a reference lot, utilizing the service charge. The sample shot and reference shot shall be fired alternately, and the velocity and accuracy measurement shall be obtained, for information only, at approximately 100-yard range. Accuracy shall be recorded in the firing record in terms of Probable Error (PE) horizontal and vertical. Accuracy data is for information only and will not be used to determine acceptance or rejection of the lot. (See 6.3).

4.8.4 Acceptance.-The pilot lot shall be considered acceptable provided the shot fired comply with the requirements of 3.6.2.1 and 3.6.2.2.

4.9 Proving-ground test (production lot). (See 6.5.)

4.9.1 Plate penetration.-The BL(P) of a reference lot and the BL(P) of the production lot shall be determined in the same manner as specified in 4.8.1, except that production-lot samples shall be used.

4.9.2 Security.-The sample shot, selected in accordance with Table II of 4.2, shall be fired in a gun for which standard, in the last quarter of its service life, with a propellant adjusted to obtain 112 percent of the rated maximum pressure in a new gun. The shot shall be fired through paper screens placed 100 feet and 300 feet from the gun, into a target at approximately 1000 yards range. Observation shall be made for evidence of loss, or break-up, of any shot component either in the gun bore or in flight, to determine compliance with 3.7.2.

4.9.3 Velocity-accuracy.-The procedure for tests shall be conducted in the same manner as specified in 4.8.3, except that production-lot samples shall be used.

4.9.4 Acceptance.-The lot shall be considered acceptable provided the shot fired complies with the requirements of 3.7.1 and 3.7.2. The lot shall be considered eligible for retest under the provisions of 4.9.5 provided:

a. The BL(P) of the production lot is greater than 100 f/s of the BL(P) of the reference lot or

b. not more than one shot shows a loss, or breakup, of its component parts in the gun bore or in flight.

The shot shall be rejected if the limits for eligibility for retest are exceeded.

4.9.5 Retest.-The retest shall be limited to the phase in which failures occur, i.e. plate penetration, or security.

4.9.5.1 Plate penetration.-A retest as provided for in 4.9.4 may be made if requested by the contractor by using eighteen sample shot. The BL(P) shall be determined twice, independently. The lot shall be considered acceptable on retest provided the BL(P) of each of the two groups is not greater than 100 f/s above the BL(P) of the reference lot.

4.9.5.2 Security.-A retest as provided for in 4.9.4 may be made if requested by the contractor by using double the number of samples. The lot shall be considered acceptable on retest provided the shot fired complies with the requirement of 3.7.2.

4.10 Reprocessing.-In the event of failure attributable to cores, the manufacturer may reprocess the cores in a lot by re-sintering, repressing, or re-inspecting and submit the lot for retest. A lot of shot may be reprocessed not more than twice, and after each reprocessing submitted but once to the proving ground for test.

5. PREPARATION FOR DELIVERY

5.1 Packing, labeling, and marking.-Packing, labeling, and marking shall be as specified in Specification MIL-P-10025.

5.2 Data cards.-Data-card information shall be as specified in MIL-G-2550. In addition the data cards shall contain on the reserve side the following information:

1. Name of core manufacturer.
2. Name of carrier manufacturer.
3. Chemical composition of core. (See 6.2.)
4. Hardness of cores in range of two points Rockwell "A".
5. Method of core manufacture (hot-press, cold-press, or specify other means.)
6. Details of reprocessing, when applicable.
7. Category, in accordance with 4.2, when applicable.

6. NOTES

6.1 Ordering data.-Procurement documents should specify the title, number and date of this specification.

6.2 Chemical composition.-While the chemical composition given on the applicable drawing is advisory rather than mandatory, a complete analysis will be included on the data card for informational purposes only. The composition given on the drawing represents that with which past experience indicates best results are obtainable.

6.3 Velocity and accuracy requirements.-Proving-ground tests for velocity and dispersion, are not acceptance tests. Firing of shot from each of the test lots will be interspersed with one of a reference lot, continuing until test is completed.

6.4 Replacement samples.-To cover the possibility of unfair impacts in the armor-plate penetration test, the necessity of obtaining replacement samples, and the consequent delay in obtaining ballistic test results, additional samples for the plate penetration test may be shipped to the proving ground with the original sample. Unused sample will be returned to the contractor, or the contractor will be reimbursed for the cost of samples used to replace those that impacted unfairly.

6.5 Defective cores.-Cores rejected for minor defects not affecting dimensions or weight may be supplied for security and velocity tests of production lots. Shot so assembled will be suitably marked.

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APPENDIX B

DEFINITIONS OF TERMS USED IN BALLISTIC TESTING OF ARMOR AT NAVAL PROVING GROUND

(Taken from Naval Proving Ground Report 10-46, Jun 1946)

DEFINITIONS OF TERMS USED IN BALLISTIC TESTING OF ARMOR AT NAVAL PROVING GROUND

Description of Projectile after Impact

In the following are defined terms in general use at the Naval Proving Ground for the description of the projectile condition after impact against armor. The definitions are listed under four headings according to whether the term applies to:

(a) The projectile as a whole;
(b) The nose of the projectile;
(c) The body of the projectile;
(d) The base of the projectile.

1. Projectile Condition (as a whole)

(a) Effective - A projectile is called effective when its cavity is capable of holding water up to a pressure of 50 pounds per square inch without leaking. In most cases visual inspection reveals whether the projectile could pass this test. An effective projectile is considered capable of being detonated high-order under service conditions.

(b) Not effective - A projectile which is unable to meet the above requirements is called not effective. It is believed that such projectiles would not detonate with satisfactory fragmentation characteristics after impact under service conditions.

(c) Undeformed - The projectile shows no bulging, cracks, or breaks. Undeformed projectiles are expected to lose windshields, caps, and rotating bands during impact. Synonymous terms are "excellent" and "intact."

(d) Split - The projectile is split into two or more parts along its longitudinal axis (Figure 15.B-1 A).

(e) Broken - The projectile is broken transversely across its middle, between the forward bourrelet and the band score, into a nose piece and a base piece (Figure 15.B-1 B).

(f) Shattered - Projectile broken into many small pieces (Figure 15.B-1 C).

Neg. #30748
R-915

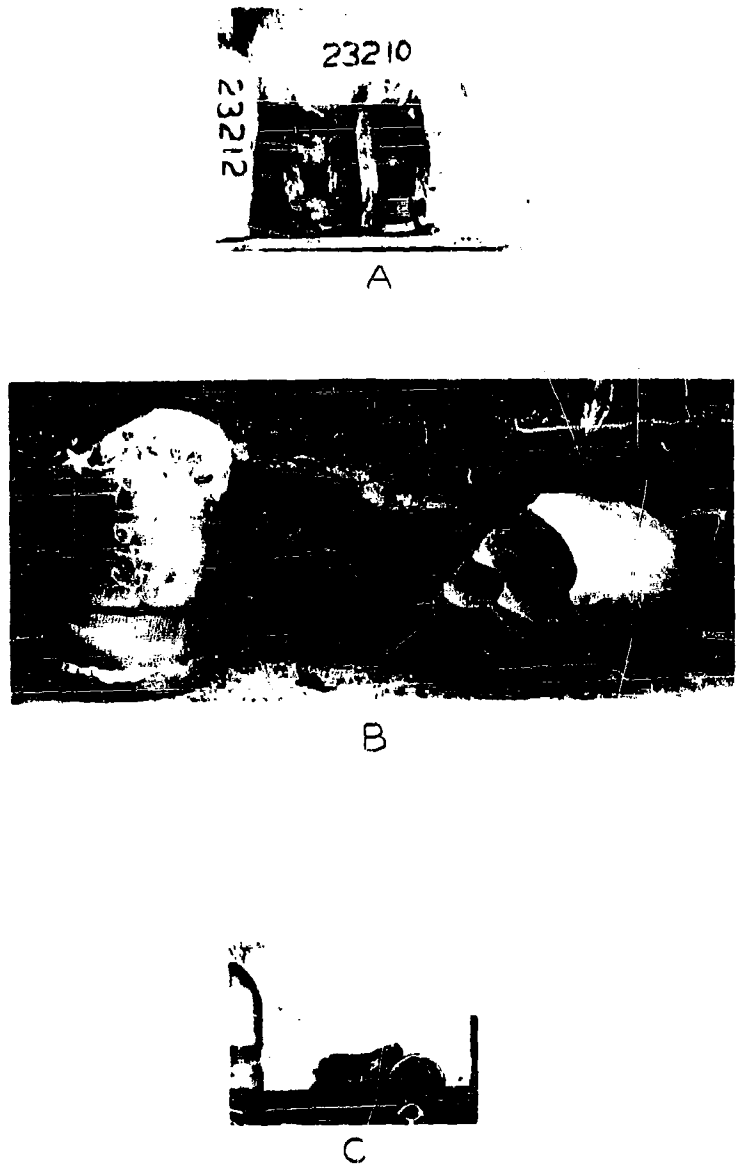

Figure 15.B-1. Projectile condition

A - Split
B - Broken
C - Shattered

(g) Not recovered - As the name implies, the projectile could not be found.

2. Nose Condition

(a) Nose cracked off - The nose breaks off, usually nearly perpendicular to the projectile axis, leaving a smooth regular surface with no appearance of shearing or abrading. Cracking may occur immediately after or hours after the impact (Figure 15.B-2 A).

(b) Nose shattered - The nose of the projectile is shattered, leaving a rough, jagged pattern. The fractured surface has a crystalline appearance (Figure 15.B-2 B).

(c) Nose chewed off - The nose of the projectile is lost during impact and has a rough, crumbled appearance. This failure differs from the "nose shattered" appearance in that the jagged edges are rounded, as if fused (Figure 15.B-2 C).

(d) Nose sheared off - The nose of the projectile is sheared off leaving a relatively smooth and regular surface of fracture, which is usually inclined approximately at 45° with the axis of the projectile (Figure 15.B-2 D).

(e) Nose cracked - Well developed cracks are evident on the nose of the projectile (Figure 15.B-2 E).

(f) Nose flattened - The projectile is plastically deformed to produce a flat area on the nose of the projectile (Figure 15.B-2 F).

(g) Nose upset - The nose is compressed, which results in an over-all swelling of the nose (Figure 15.B-2 G).

(h) Nose bent - The tip of the nose is displaced relative to the body. A synonym is "nose offset" (Figure 15.B-2 H).

3. Body Condition

(a) Body cracked - Well developed cracks appear on the body of the projectile (Figure 15.B-3 A).

(b) Body upset - The body of the projectile is swelled.

(c) Body bent - The body of the projectile is bent (Figure 15.B-3 B).

(d) Body dented - A dent is produced in the body of the projectile (Figure 15.B-3 C).

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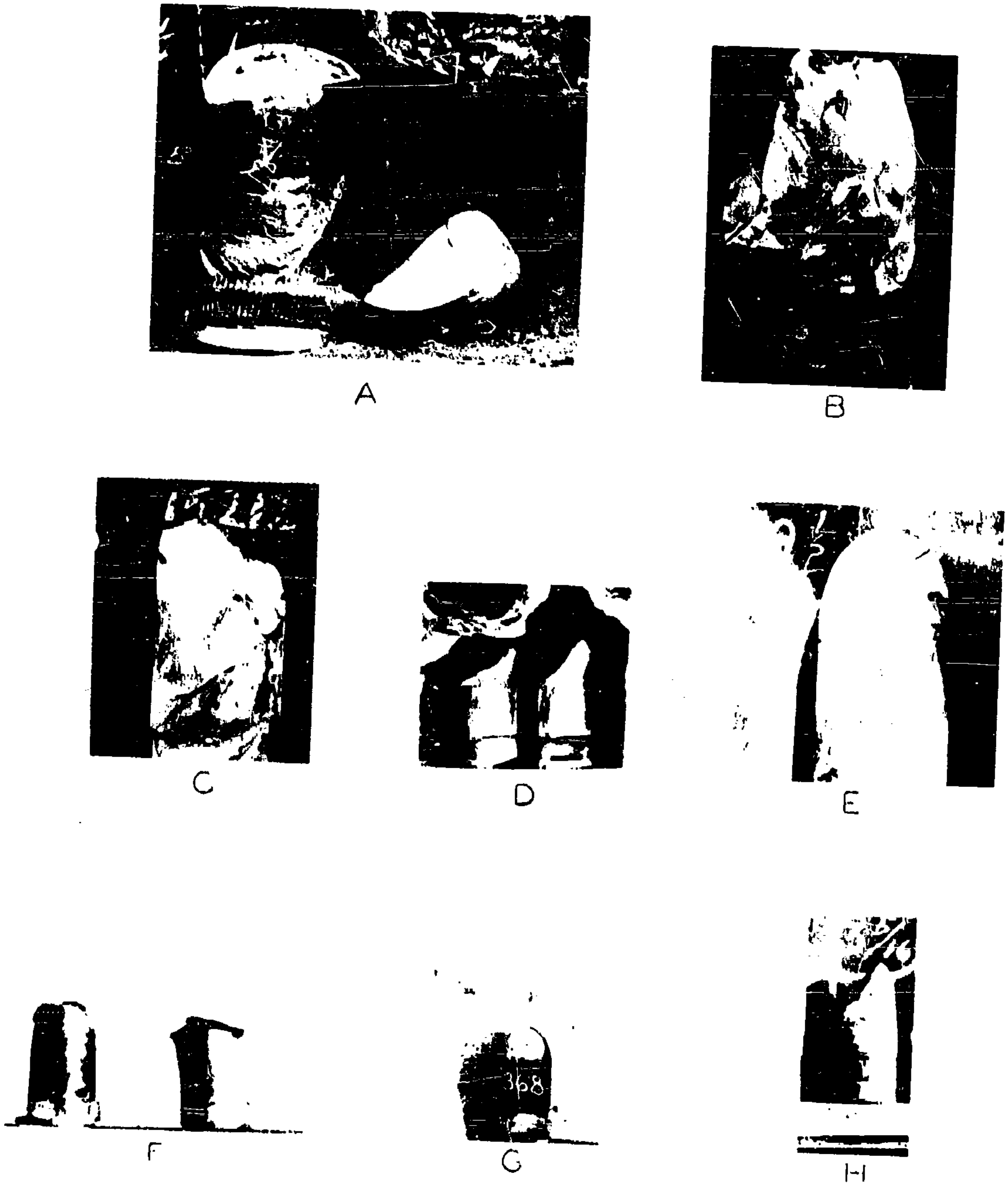

Figure 15.B-2. Nose condition

A - Nose cracked off
B - Nose shattered
C - Nose chewed off
D - Nose sheared off
E - Nose cracked
F - Nose flattened
G - Nose upset
H - Nose bent

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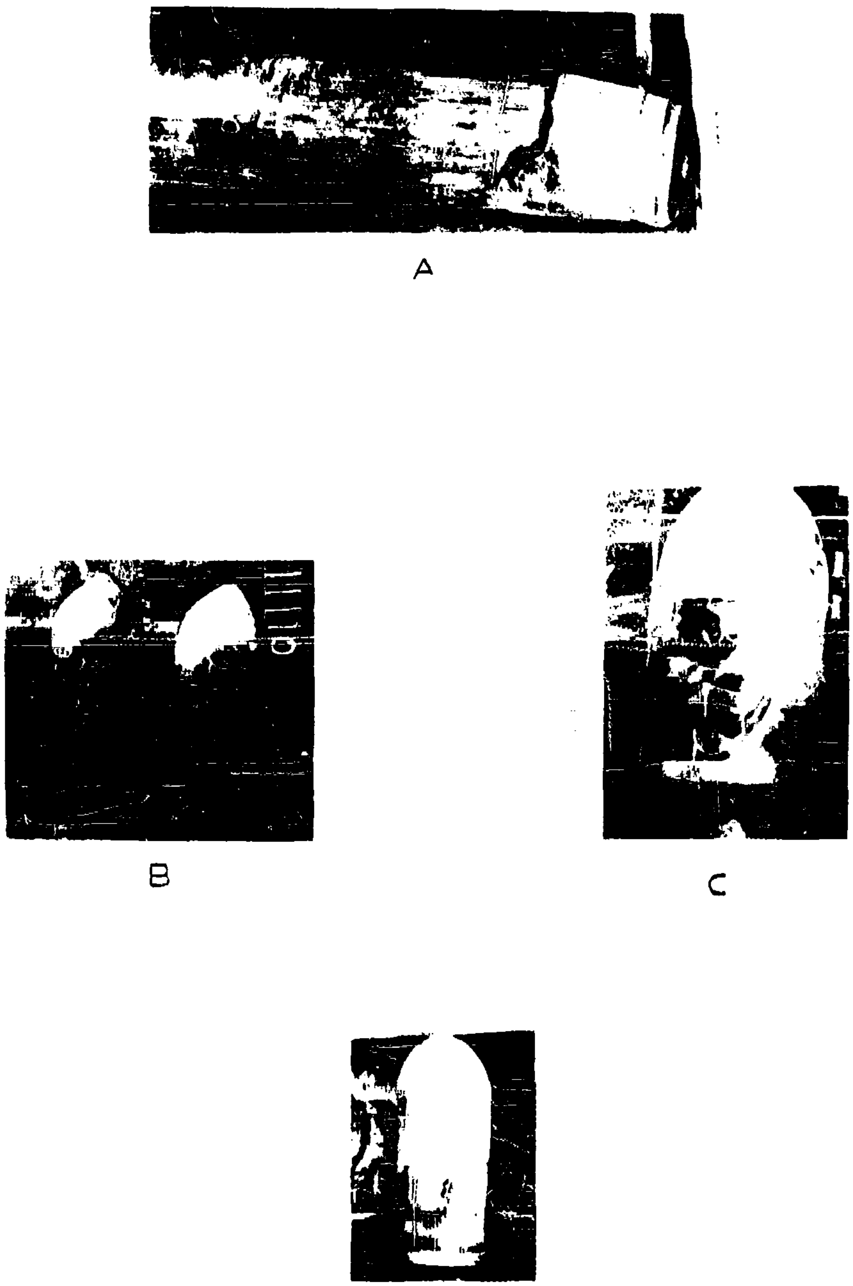

Figure 15.B-3. Body condition

A - Body cracked
B - Body bent
C - Body dented
D - Body gouged

(e) Body gouged - A deep gash is made in the side of the projectile. As a rule, some of the material of the projectile is removed (Figure 15.B-3 D).

4. Base Condition

(a) Base ring torn - Part of the base of the projectile is pulled off in penetrating the plate. This break often exposes the cavity or the base plug comes out, either of which renders the projectile ineffective (Figure 15.B-4 A).

(b) Base slapped (or flattened) - The base is flattened as the result of a slap against the plate during a ricochet or against the side of the impact hole during complete penetration (Figure 15.B-4 B).

(c) Base gouged - The base is scarred longitudinally. As a rule, some of the material of the projectile is removed (Figure 15.B-4 C).

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A

B

C

Figure 15.B-4. Base condition

A - Base ring torn
B - Base slapped
C - Base gouged

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