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TECHNICAL PROGRESS REPORT

CONTRACT DA-36-034-ORD-3296 RD

ORDNANCE CORPS PROJECT NUMBER—OMS 5010.1180 800.51.03

PREPARED FOR

U. S. ARMY ORDNANCE DISTRICT

PHILADELPHIA, PA.

UNDER

TECHNICAL SUPERVISION—FRANKFORD ARSENAL

CONTROL NO. A5180

DEVELOPMENT OF HIGH PERFORMANCE ROCKET MOTOR CASE

REPORT NUMBER 11

Period—May 1, 1961 to May 31, 1961

PRODUCT DEVELOPMENT DEPARTMENT

THE BUDD COMPANY

Philadelphia 32, Pennsylvania

FORM 3106
8/60

THE Budd COMPANY

PHILADELPHIA 32, PA.

PRODUCT DEVELOPMENT

ENGINEERING
PROGRESS REPORT NUMBER 11

Period: May 1, 1961 to May 31, 1961

Contract: DA-36-034-ORD-3296 RD

Ordnance Corps. Project Number:
OMS-5010-1180800-51-03

ROCKET MOTOR CASE DEVELOPMENT

Control Number A-5180

Prepared by:

[signature]

Reviewed by:

[signature]

Approved by: [signature]
Manager-Product Development Dept.

PREFACE

This progress report is submitted in conformance with the requirements of U.S. Army Ordnance Contract DA-36-034-ORD-3296 RD dated June 21, 1960, for the development of a high performance rocket motor case. The work to be performed by The Budd Company is to initiate and conduct a development program, the ultimate objective of which will result in a high performance rocket motor case, capable of being fabricated with reasonable ease, which will utilize the maximum strength potential of available materials. This will be accomplished through proper selection of materials, design of joints, and improvement of fabricating techniques.

Acknowledgment is made of the contribution to this report of Messrs. J. L. Herring and W. J. Hauck of The Budd Co., Product Development Dept.

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INTRODUCTION

This is the eleventh monthly progress report covering the work being conducted under Contract DA-36-034-ORD-3296RD by The Budd Company. The report covers the period May 1, 1961 to May 31, 1961.

Evaluation of materials selected for possible application to rocket motor cases is continuing. Data is included in this report for the following:

25% Nickel Steel - HEAT 23223-3 analysis covered in report number 9.

Heat treatment was revised to improve low mechanical properties and the material retested.

20% Nickel Steel - Heat 23222-1; Discussion of this alloy and test data is included.

JLS 300 - Data is reported on tests made to determine the effect of corrosion on spot welds of this alloy.

Center notch fracture energy testing is in process on JLS 300 alloy in the cold rolled and aged condition, and Ti-13V-11Cr-3Al in 3 conditions. The complete evaluation of Ti-6Al-6V-2Sn alloy is underway. Mechanical property evaluation of AM 359 for confirmation of Allegheny Ludlum results will be made. Data on these tests will be included in subsequent reports.

Extension of delivery times on material for evaluation is delaying and extending the Laboratory specimen fabrication and testing program. Mid-June delivery estimates have been received on the balance of materials ordered.

The status of work on uniaxial fusion butt welded joints is included in this report.

Plans to accelerate the materials portion of the program and testing of sub-scale chambers are discussed in the report.

MATERIALS EVALUATION

Materials ordered for evaluation, but not received are now scheduled for mid-June delivery based on latest estimates received. These include:

20% Nickel Steel, Heat IV890	Allegheny Ludlum Steel Corp.
25% Nickel Steel, Heat IV 891	Allegheny Ludlum Steel Corp.
PH 12-8-6 Steel	Armco Steel Corp.
Ti-8Al-10V-Alloy	Republic Steel Corp.
Low Alloy 'A' and 'B'	Republic Steel Corp.
AM 357	Allegheny Ludlum Steel Corp.

A preliminary draft of the sub-contract to Massachusetts Institute of Technology for research on controlled solidification of ingot castings was forwarded to M.I.T. for review and comments. It is expected that work on this project can be released within the next few weeks.

Discussion and Data on Reheat Treatment and Testing of 25% Nickel Steel. The specimen coding system is included in this report and is shown in Table 1.

In Report No. 9 the properties obtained from the

SPECIMEN IDENTIFICATION

Specimen number consists of a four letter group and one digit. The sequence is as follows:

Material Condition Specimen Type Direction No.in Group

Materials	Code Letter
AM - 357	A
AM - 359	B
25% Ni	C
20% Ni	D
Ti-13V-11Cr-3Al	E
JLS - 300	F
25% Ni (Mod.)	G
20% Ni (Mod.)	H
Armco 12-8-6	K
Ti-6Al-6V-2Sn	L
Ti-8Al-10V	M

Conditions	
Annealed	A
SCCRT	B
CRT	C
SCT	E
Ti, Single Age, 48 Hrs.	F
Ti, Single Age, 72 Hrs.	G
Cold Rolled & Aged, 200,000 psi	J
Cold Rolled & Aged, 230,000 psi	K
25% and 20% Ni, Stand. Heat Treat	L
Cold Rolled and Aged	N
PH 12-8-6, Stand. Heat Treat	P
20% Ni, Isothermal Heat Treat	R
25% Ni, Double Sub-Zero Cool	S
Cold Rolled 25%	T

	Code Letter
Sheet Tensile	A
Fracture Energy, Center Notched	B
Sheet Tensile, "As Welded"	C
Sheet Tensile, Weld Dep. Removed	D
Tensile Shear, Resist Weld	E
Bend Specimen, Base Metal	G
Bend Specimen, Welded, Weld Dep. Removed	H
Stress Corrosion, Resist Weld	K
Dimensional Change Specimen	L
Arc Welding Plates	M
Photomicrographic Mounts	N
Photomacrographic Mounts	O
Tensile Spec. Cleaning	P
Tensile, Resist Weld, Criss-Cross	S
Electron Beam, 90° Butt Weld Tensile	T

DIRECTION

Indicated as L (longitudinal) or T (transverse)

TABLE 1

initial testing of the 25% nickel steel were reported. These values are repeated for reference in this report in Table 2.

At that time we were concerned about the low yield strengths, although the ultimate strengths were satisfactory. The modulus of elasticity was also low for this alloy, being approximately 20 X 10^6 psi as compared to an expected value of about 25 X 10^6 psi.

In an attempt to correct these conditions additional material from the same heat was released for tensile testing. The material was first re-annealed at 1500°F and then subjected to two different heat treatments. One heat treatment was a repeat of the treatment originally used; the other consisted of a double sub-zero cool and aging cycle in an attempt to transform what appeared to be a retained austenite phase. Both heat treatments are outlined below

1. Heat treatment originally used (type L)
   Aus-age at 1100°F, 16 hours, air cool
   Cool at -100°F, 16 hours, air warm
   Mar-age at 800°F, 1 hour, air cool
2. Double Sub-zero Cool Treatment (Type S)
   Aus-age at 1200°F, 8 hours, air cool
   Cool at -100°F, 16 hours, air warm
   Mar-age at 800°F, 1 hour, air cool
   Cool at -100°F, 16 hours, air warm
   Mar-age at 850°F, 1 hour, air cool

MECHANICAL PROPERTIES OF 25% NICKEL STEEL

0.060" GAGE | HEAT NUMBER 23223-3

Condition	Spec. No.	Direct.	Yield Strength .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 Inches	Rockwell Hardness
Annealed 1500°F, 15 Min. A. C.	CAAL-1	L	57	129	22.5	B92
	-2	L	57	125	24.	
	-3	L	55	123	25	
	-4	L	54	123	24.5	
	CAAT-5	T	50	124	25	
	-6	T	52	122	25.5	
	-7	T	54	121	25.5	
	-8	T	50	122	25	
Heat Treated 1100°F, 16 Hrs. A.C. -100°F, 16 Hrs. 800°F, 1 hr., A.C.	CLAL-1	L	230	299	7	C56
	-2	L	232	298	7	
	-3	L	234	296	7	
	-4	L	231	294	2*	
	CLAT-5	T	245	295	2	
	-6	T	240	300	3	
	-7	T	236	292	1*	
	-8	T	234	292	1*	

* Broke outside of gage length

TABLE 2

The results of the testing of the re-annealed material and material heat treated to the two conditions are shown in Tables 3 and 4, respectively.

The annealed yield strengths shown in Table 3, using the same re-annealing procedure, are higher than the data shown in Table 2. Ultimate tensile strengths are slightly lower. There is no obvious reason for this difference. The second group of specimens (shown with X after the specimen number) were taken from another sheet of the same heat and shipment. Both groups of values are within what would be considered normal annealed tensile properties.

The heat treating to the same condition as previously used (Cond. L) produced both lower yield and ultimate strengths. The Condition L values, shown in Table 4 are not as consistent as one might expect from a normal, sound, homogenious material. The transverse yield strengths are especially poor in this respect, showing a variation from 202,000 psi to 225,000 psi. In addition, an unusually higher percentage of the specimens failed outside the gage length despite a carefully controlled testing procedure. As had been mentioned in the discussion of this material in Report No. 9 we experienced a banded structure with layers of what appeared to be retained austenite. This heterogenious condition could cause the low strength and erratic results.

The elastic moduli as determined from the load

MECHANICAL PROPERTIES OF 25% NICKEL STEEL

0.060 GAGE — HEAT NUMBER 23223-3

Condition	Spec. No.	Direct.	Yield Strength .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 inches	Rockwell Hardness
Annealed 1500°F, 15 min. Air Cooled	CAAL-1X	L	69	120	25	B92
	-2X	L	68.5	115	27	
	-3X	L	68	113	26	
	-4X	L	70.5	118	26	
	CAAT-5X	T	71	116	27	
	-6X	T	72	119	25	
	-7X	T	72	122	25	
	-8X	T	71	120	29	

TABLE 3

X - signifies repeat tests of condition previously reported

MECHANICAL PROPERTIES OF 25% NICKEL STEEL

0.060 GAGE HEAT NUMBER 23223-3

Condition	Spec. No.	Direct.	Yield Strength .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 inches	Rockwell Hardness
Heat Treated	CLAL-1X	L	211	271	2.5	C55
1100°F, 16 Hrs. A.C.	-2X	L	212	278	3	
-100°F, 16 Hrs.	-3X	L	223	278	2*	
800°F, 1 Hr. A.C.	-4X	L	220	274	2*	
(Type L)	CLAT-5X	T	225	282	7	
	-6X	T	210	276	5*	
	-7X	T	212	280	7.5*	
	-8X	T	202	277	3	
Heat Treated	CSAL-1	L	238	253	5.5	C53
1200°F, 8 Hrs. A.C.	-2	L	245	259	6.5	
-100°F, 16 Hrs.	-3	L	248	264	6	
800°F, 1 Hr. A.C.	-4	L	247	262	6	
-100°F, 16 Hrs.	CSAT-5	T	250	264	6.5	
850°F, 1 Hr. A.C.	-6	T	248	264	6	
	-7	T	250	264	6	
	-8	T	250	267	7	

X - signifies repeat tests of condition previously reported

* Broke outside of gage length

TABLE 4

deformation diagrams showed values from 23.1 to 25.3 X 10^6 psi. The previously tested specimens which had been similarly treated had developed moduli values from 19.5 to 20.3 psi.

In an effort to reduce or eliminate the suspected retained austenite another heat treatment (Type S) was used. This treatment consisted of a double sub-zero cool and age, which was expected to encourage the transformation of the sluggish austenite. The complete heat treating cycle is outlined above and the tensile testing data are shown in Table 4.

The improvement in the yield strength and the increase in the yield strength to tensile strength ratio indicates that additional transformation did occur after the double sub-zero cool and age. However, the ultimate tensile strength was reduced below that of the other treatments (type L both groups of specimens). More carefully selected aging temperatures and times at temperature would possibly improve both the yield and tensile strengths and preserve the higher yield to tensile strength ratio.

The modulus of elasticity averaged 24.1 X 10^6 psi for the eight specimens tested.

As a result of the generally unsatisfactory values obtained with this heat of 25% Ni steel we are eliminating any additional processing or testing. Within the next week or two we expect to receive a modified analysis of the basic 25% Ni steel which was melted and processed at our request. This material has an analysis designed to develop higher strengths and was both vacuum induction melted and vacuum consumable electrode remelted. Preliminary test data received from Allegheny-Ludlum Steel Corporation indicate excellent tensile properties in both the standard heat treated condition and in a cold rolled, sub-zero cooled, and aged condition. Our own evaluation of this material will be reported as soon as possible.

Discussion and Data on 20% Nickel Steel in Various Heat Treat Conditions. The 20% nickel steel received for evaluation has the following composition as reported by the Allegheny-Ludlum Steel Corporation for their heat number 23222-1. This was supplied as 0.060 inch sheet stock in the annealed condition.

Carbon	- 0.007	Columbium	- 0.52
Manganese	- 0.105	Nickel	- 20.04
Phos.	- 0.007	Titanium	- 1.27
Sulphur	- 0.002	Aluminum	- 0.22
Silicon	- 0.15	Iron	- Balance

This heat of 20% nickel steel, similar to the 25% nickel steel previously reported, was air induction melted and re-melted under vacuum using the consumable electrode re-melt process.

All material was received in the annealed state. However, to insure a uniform condition the test material was re-annealed before use. This consisted of the following:

Anneal at 1500°F, 15 minutes, air cool

Initial testing was done with the material in the standard heat treated condition. This treatment, suggested by the International Nickel Company (Type L)

Material in the 1500°F annealed condition

Cool at -100°F, 16 hours, air warm

Mar-age at 850 F, 1 hour, air cool

As will be discussed in a later section of this report the tensile properties resulting from the above heat treatment were not as high as had been anticipated. Additional material was heat treated using an isothermal treatment. The 20% nickel steel is martensitic as annealed and, therefore, cannot respond to an austenite aging treatment after transformation has occurred. If aging of the austenite to produce more instability and consequently more complete transformation to martensite is required, it must be done by cooling from the annealing temperature isothermally and holding for a prescribed period of time. The aus-aging also improves the hardness and strength of the alloy by the precipitation hardening mechanism.

The complete isothermal heat treatment of the 20% nickel steel is as follows: (Type R)

Anneal at 1500°F, 15 minutes, cool to 1100°F (by transferring material to 1100°F furnace), hold 16 hours and air cool.

Cool at -100°F, 16 hours, air warm

Mar-age at 850°F, 1 hour, air cool

After heat treatment, all specimens were pickled to remove scale and oxide. The solution used consisted of 10% H_2SO_4 and H_2O at 140°F followed by 5% HCl and H_2O at 125°F. Specimens were thoroughly rinsed in hot water after pickling. The oxide was apparently more easy to remove from the 20% nickel steel than from the 25% nickel composition. A more conclusive study of the pickling procedures required for these alloys is planned for a later date.

Tensile Properties. Two groups of specimens which are from different sheets of the same heat and delivery and which were separately annealed developed the tensile properties as shown in Table 5. This alloy is martensitic in the annealed condition and will usually be in the hardness range of 31 to 34 RC. The test results were reasonably consistent and exhibited the high annealed strengths and relatively low ductility characteristic of this low carbon martensitic structure.

The load deformation curves produced by the autographic recorder showed no straight-line or proportional region. Typical curves converted to stress-strain diagrams are shown in Figures 1 and 2. An arbitrary modulus line equivalent to 25 X 10^6 psi was used to determine the 0.2% offset yield strength.

MECHANICAL PROPERTIES OF 20% NICKEL STEEL

0.060 GAGE

HEAT NUMBER 23222-1

Condition	Spec. No.	Direct	Yield Strength .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 Inches	Rockwell Hardness
Annealed 1500°F, 15 min. Air Cooled (Type A)	DAAL-1	L	101	147	6	C33
	-2	L	101	153	7	
	-3	L	101	145	7	
	-4	L	106	149	7.5	
	DAAT-5	T	107	146	5.5	
	-6	T	111	150	6	
	-7	T	107	150	6.5	
	-8	T	107	149	6	
	DAAL-1X	L	107	149	7	C33
	-2X	L	106	151	7.5	
	-3X	L	107	151	7	
	-4X	L	105	151	7.5	
	DAAT-5X	T	110	155	7	
	-6X	T	108	155	7	
	-7X	T	108	155	7	
	-8X	T	103	153	7	

TABLE 5

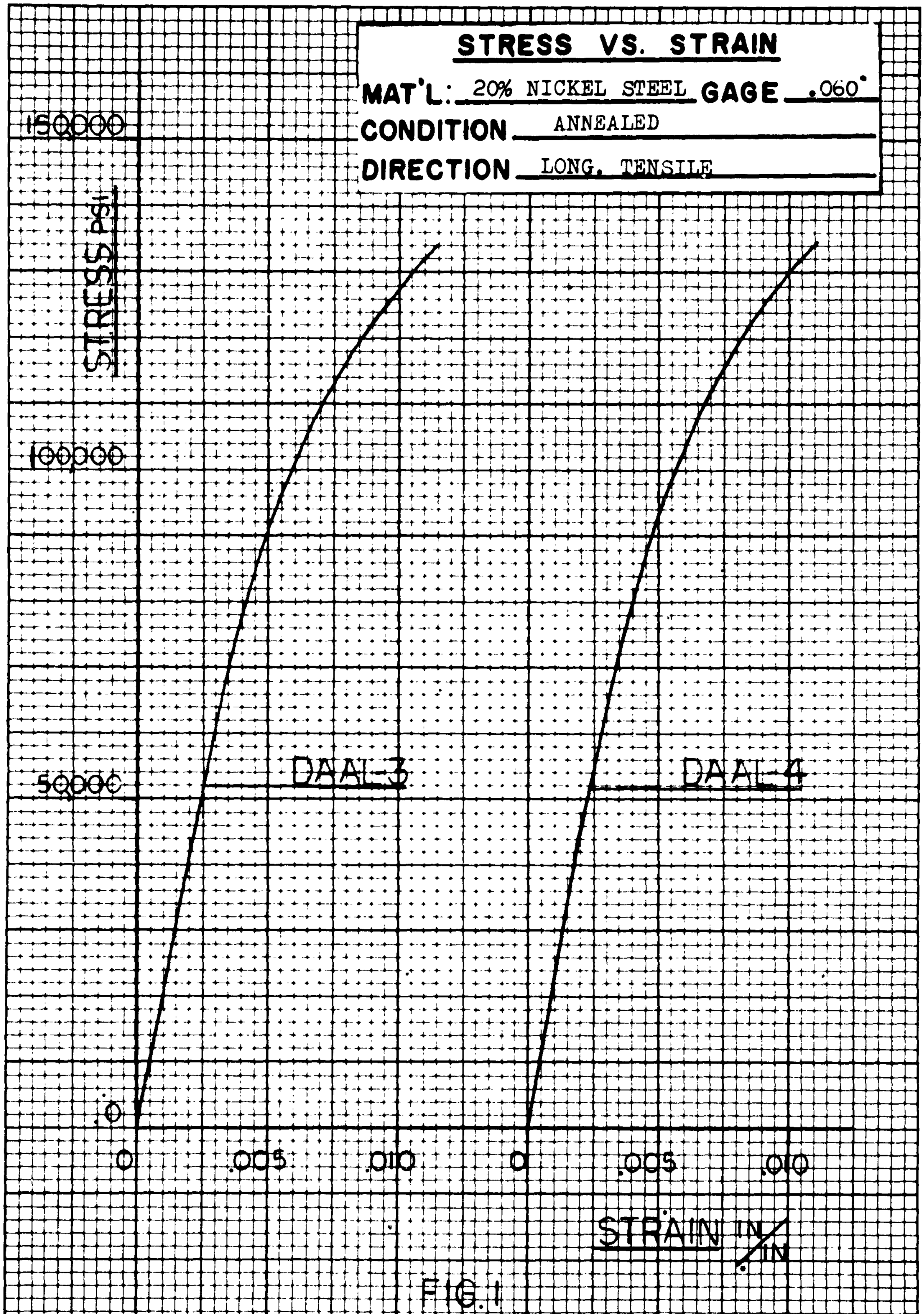

STRESS VS. STRAIN
MAT'L: 20% NICKEL STEEL GAGE .060"
CONDITION ANNEALED
DIRECTION LONG. TENSILE
150000
100000
50000
0
STRESS PSI
DAAL-3
DAAL-4
0
.005
.010
0
.005
.010
STRAIN IN/IN

FIG. 1

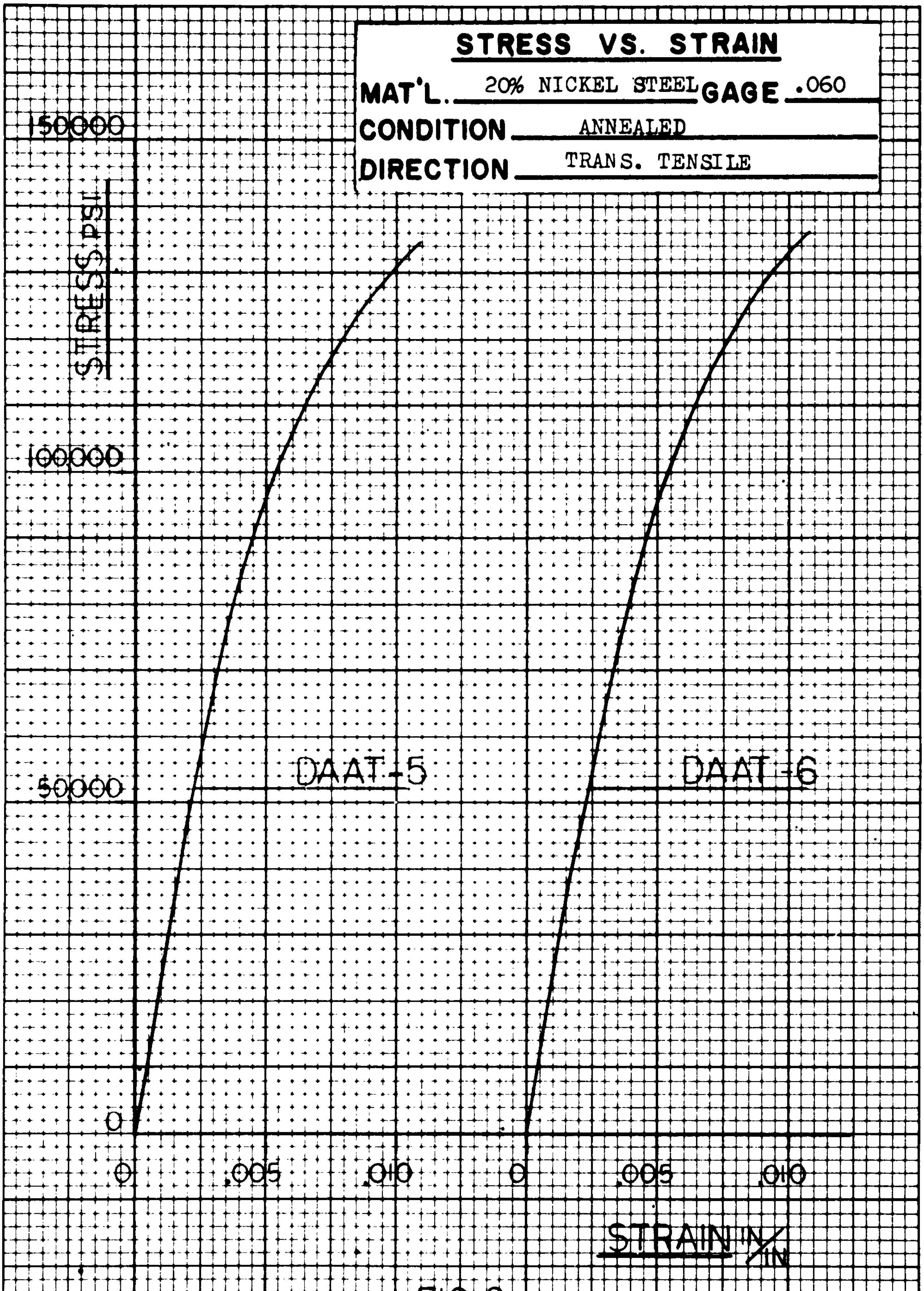

STRESS VS. STRAIN
MAT'L. 20% NICKEL STEEL GAGE .060
CONDITION ANNEALED
DIRECTION TRANS. TENSILE
150000
100000
50000
0
STRESS PSI
DAAT-5
DAAT-6
0
.005
.010
0
.005
.010
STRAIN IN/IN

FIG. 2

The standard heat treatment, as previously described (Type L) produced the tensile values shown in Table 6. The first group of values are very much lower than had been anticipated for this grade of 20% nickel steel. The ultimate strengths in the transverse direction are low and erratic. Although the specimen preparation was excellent and the specimens were carefully tested to insure uniaxial loading, all failed outside the gage marks.

The re-heat treatment of new material from the same sheet produced improved properties as shown by specimens DLAL-5 to DLAL-8 in Table 6. Two of the specimens were pickled before testing to evaluate the effect the acid attack may have had on the properties. No effect was apparent.

The heat treating is carefully controlled and verified by recorded charts which leaves little explanation for the difference in properties obtained. with the same treatments.

A new heat treatment was authorized to improve the low strengths. This was the isothermal cycle described previously (type R). In conjunction with this treatment the effect of pickling was observed by the testing of material as heat treated only and after heat treating and pickling. The pickling procedure was the same as outlined above. The results obtained from the tensile testing of these specimens are shown in Table 7.

MECHANICAL PROPERTIES OF 20% NICKEL STEEL

0.060 GAGE

HEAT NUMBER 23222-1

Condition	Spec. No.	Direct	Yield Strength .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 Inches	Rockwell Hardness
Heat Treated -100°F, 16 hrs. 850°F, 1 hr. Air Cooled (Type L)	DLAL-1	L	209	222	9.5	C47-C49
	-2	L	210	222	8	
	-3	L	-	223	7	
	-4	L	209	222	7.5	
	DLAT-5	T	200	212	1.0 *	
	-6	T	195	206	1.0 *	
	-7	T	194	207	2.5 *	
	-8	T	202	214	1.5 *	
Heat Treated -100°F, 16 hrs. 850°F, 1 hr. Air Cooled (Type L)	DLAL-5	L	240	251	4.5	C50-C52
	-6	L	238	250	5	
	DLAL-7 **	L	244	254	4.5	
	-8 **	L	236	248	5	

* Broke Outside of Gage Length

** Specimens Pickled Before Testing

TABLE 6

The isothermal heat treatment developed significantly higher yield and ultimate strengths in the first group tested as may be seen in Table 7. The yield strength improved approximately 75,000 psi over the values originally obtained from the standard heat treatment. The high ultimate strength (over 300,000 psi) was accompanied by fair ductility. The elongation was 2 1/2% percent despite the fact that the specimens broke outside of the gage length. Material in this condition was also not affected by the pickling procedure.

The second group, heat treated isothermally using the same procedure, developed reasonably good properties but not as high as the first group similarly treated. The high ratio of yield to ultimate strength was retained. However, the results were not consistent and all specimens failed outside of the gage length of the tensile test specimens.

The stress-strain diagrams of typical tensile tests of both the standard heat treatment (type L) and the isothermal heat treatment (type R) are shown in Figures 3, 4, 5 and 6.

On the basis of the erratic behavior of this heat and analysis of 20% nickel steel no additional testing is planned. As was stated in the discussion of the 25% nickel steel we expect to receive material of a modified composition which has been made at our request. The new heat of steel was both vacuum induction melted and vacuum

MECHANICAL PROPERTIES OF 20% NICKEL STEEL

0.060 GAGE

HEAT NUMBER 23222-1

Condition	Spec. No.	Direct.	Yield Strength .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 Inches	Rockwell Hardness
Heat Treated Isothermally as shown on page (Type R)	DRAL-1X	L	284	303	2.5 **	C56
	-2X	L	283	303	2.5 **	
	DRAL-3X *	L	286	307	3.5	
	-4X *	L	289	308	2.5	
Heat Treated Isothermally as shown on page (Type R)	DRAL-1	L	260	275	0.5 **	C55
	-2	L	270	299	1.5 **	
	-3	L	270	296	1.0 **	
	-4	L	273	299	1.5 **	
	DRAT-5	T	266	272	0.5 **	
	-6	T	270	296	1.5 **	
	-7	T	270	270	0.5 **	
	-8	T	263	277	0.5 **	

* Specimens Pickled Before Testing

** Broke Outside of Gage Length

TABLE 7

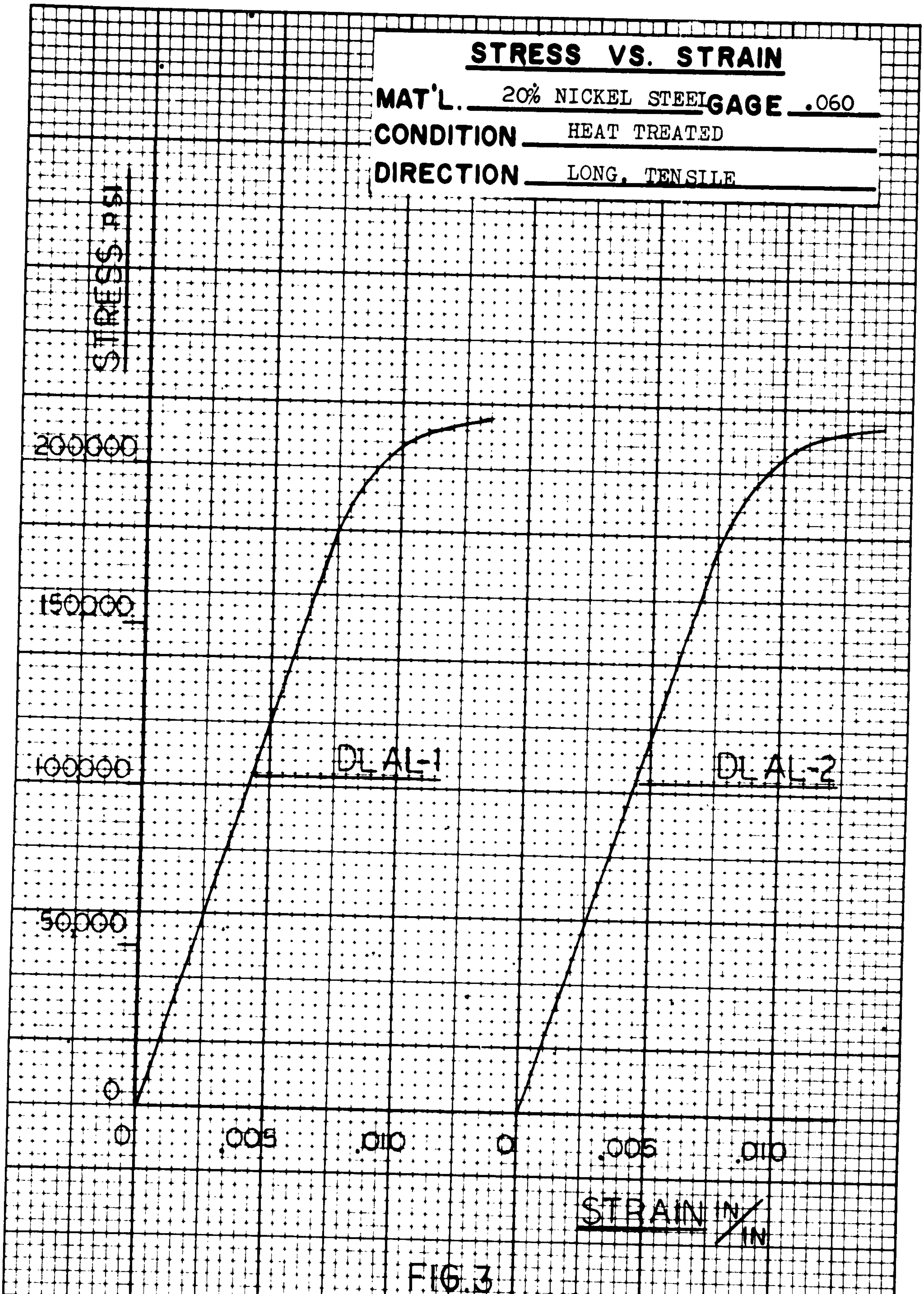
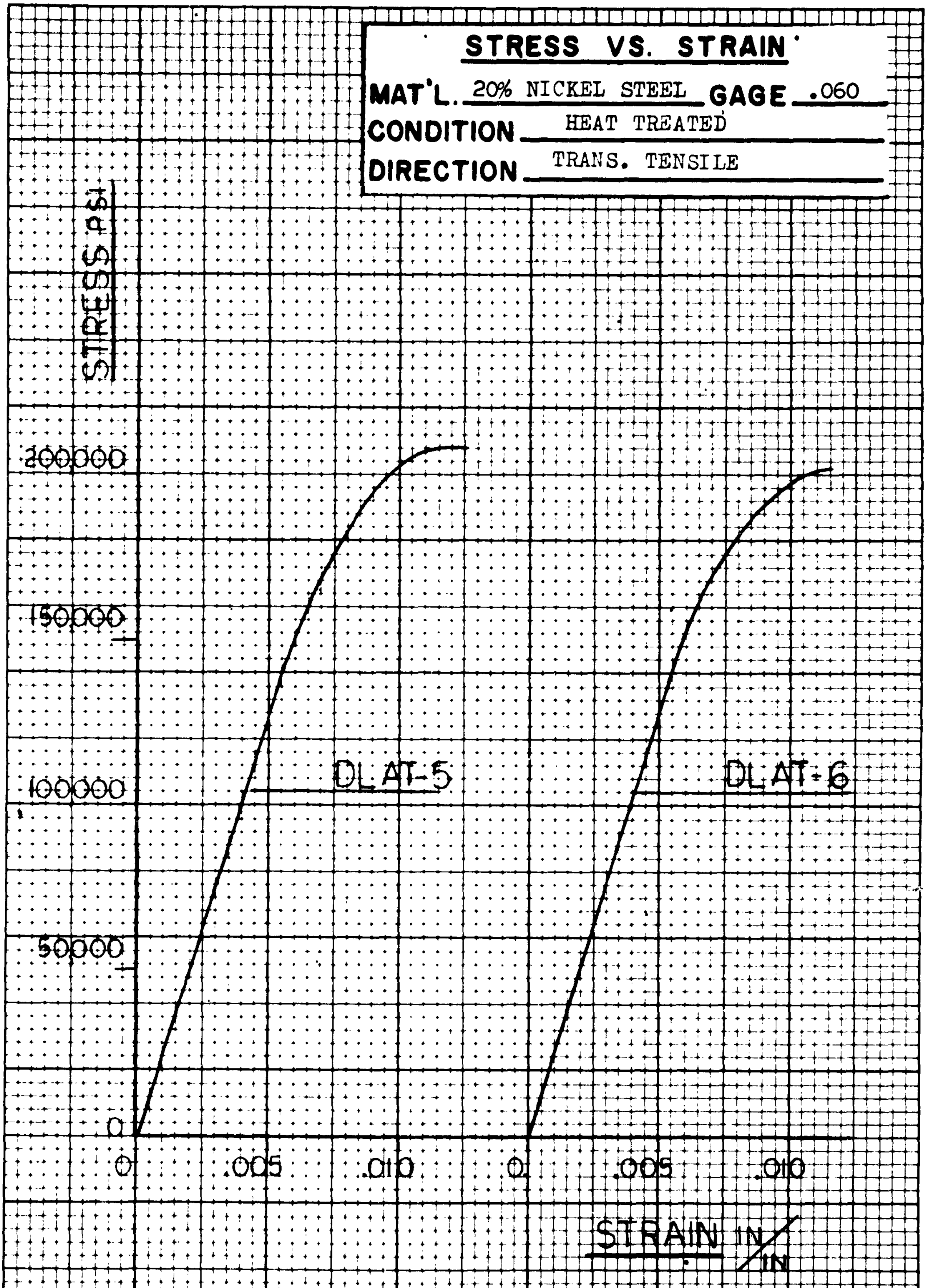

STRESS VS. STRAIN
MAT'L. 20% NICKEL STEEL GAGE .060
CONDITION HEAT TREATED
DIRECTION LONG. TENSILE
STRESS PSI
200000
150000
100000
50000
0
DLAL-1
DLAL-2
0
.005
.010
0
.005
.010
STRAIN IN/IN

FIG. 3


STRESS VS. STRAIN
MAT'L. 20% NICKEL STEEL GAGE .060
CONDITION HEAT TREATED
DIRECTION TRANS. TENSILE
STRESS PSI
200,000
150,000
100000
50,000
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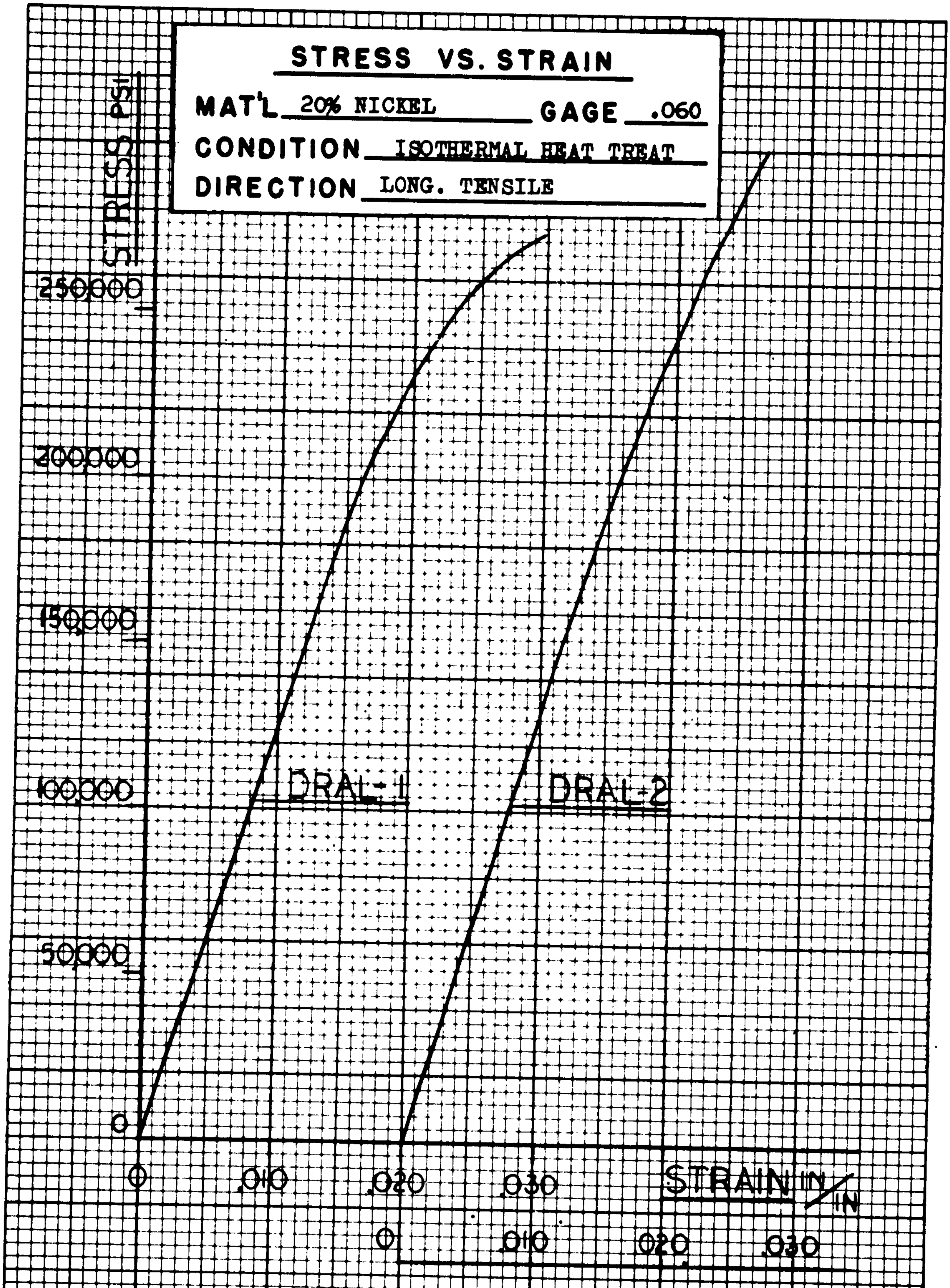
0
.005
.010
0
.005
.010
DLAT-5
DLAT-6
STRAIN IN/IN

FIG. 4



STRESS VS. STRAIN
MAT'L 20% NICKEL
GAGE .060
CONDITION ISOTHERMAL HEAT TREAT
DIRECTION LONG. TENSILE
STRESS PSI
250,000
200,000
150,000
100,000
50,000
0
DRAL-1
DRAL-2
0
.010
.020
.030
STRAIN IN/IN
0
.010
.020
.030

FIG.5

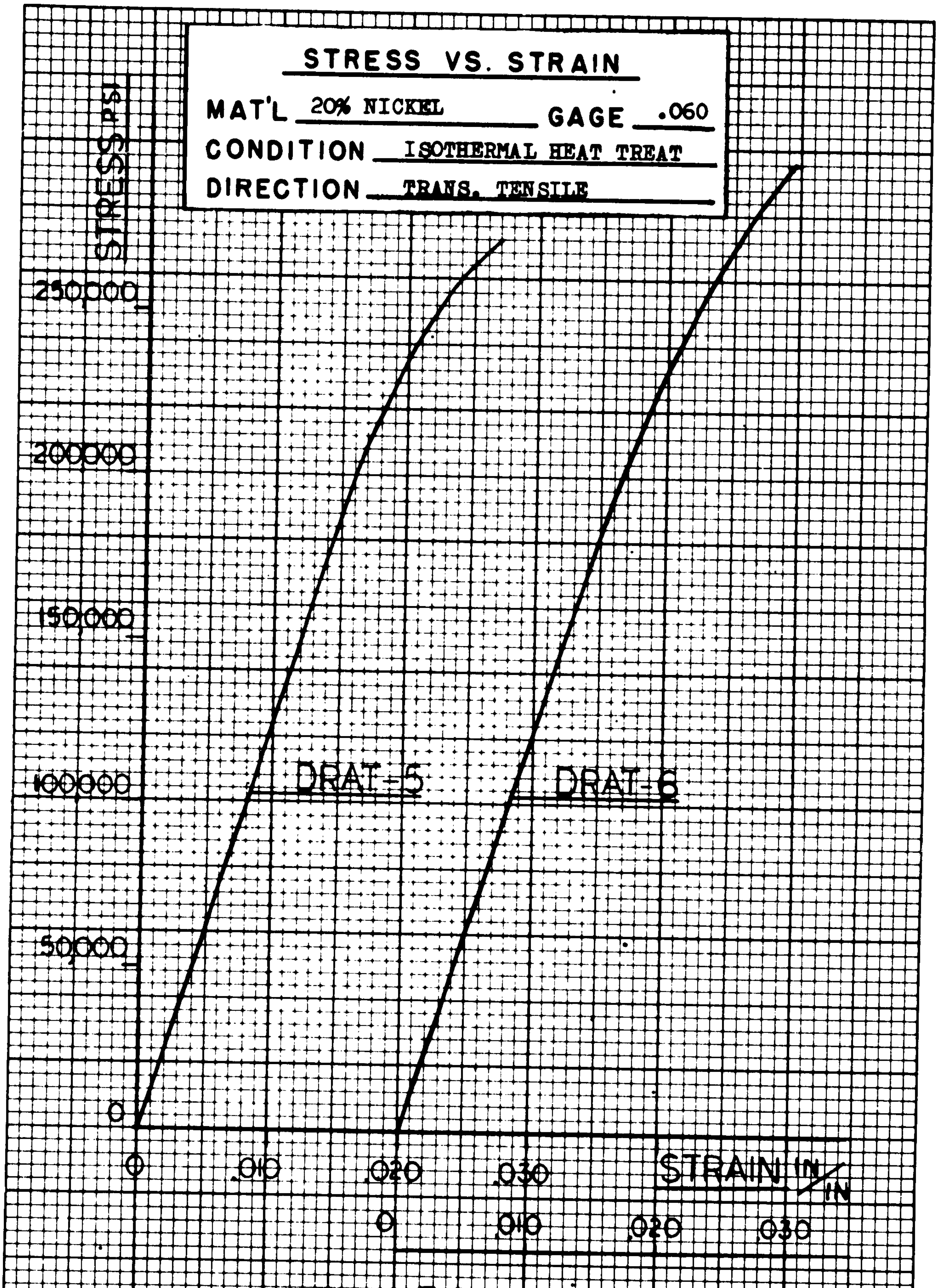
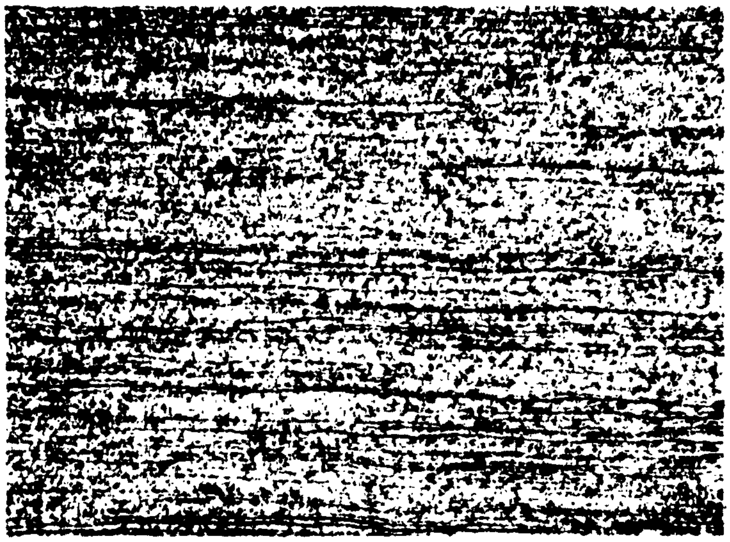

STRESS VS. STRAIN
MAT'L 20% NICKEL GAGE .060
CONDITION ISOTHERMAL HEAT TREAT
DIRECTION TRANS. TENSILE
STRESS PSI
250,000
200,000
150,000
100,000
50,000
0
DRAT-5
DRAT-6
0
.010
.020
.030
STRAIN IN/IN
0
.010
.020
.030

FIG. 6

consumable electrode remelted by the Allegheny-Ludlum Steel Corporation. Preliminary test data have indicated very promising properties.

Photomicrographs. Typical photomicrographs of the 20% nickel steel are shown in Figures 7 and 8. The annealed material in both the longitudinal and transverse direction is shown in Figure 7. The structure is a fine grained untempered martensite at approximately 33 RC hardness. A banded structure similar to that found with the 25% nickel steel (as shown in Report No. 9) is evident, but to a lesser degree. The response to heat treatment was better with the 20% than the 25% nickel heats tested. The very close similarity between these two photo-micrographs leads one to believe that they are both taken in the longitudinal direction. However, a re-check was made by preparing the longitudinal and transverse edges of the same sample. The results substantiated the photo-micrographs as shown.

Figure 8 shows the photomicrographs of a typically heat treated condition in both directions to rolling. It would be expected that little difference could be detected with material in the various modified heat treated conditions. The structure is primarily tempered martensite. Some retained austenite is most likely present, although it is not apparent in these photomicrographs.



20% Nickel Ht.No.23222-1 Annealed

Specimen DANL

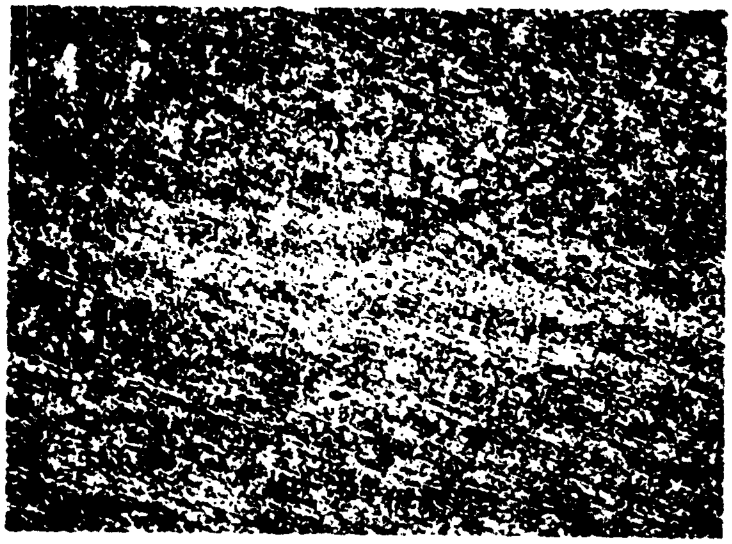
250X Etchant: 5gm.$FeCl_3$,50ml.HCl,100ml.H_2O

20% Nickel Ht.No.23222-1 Annealed

Specimen DANT

250X Etchant: 5gm.$FeCl_3$,50ml.HCl,100ml.H_2O

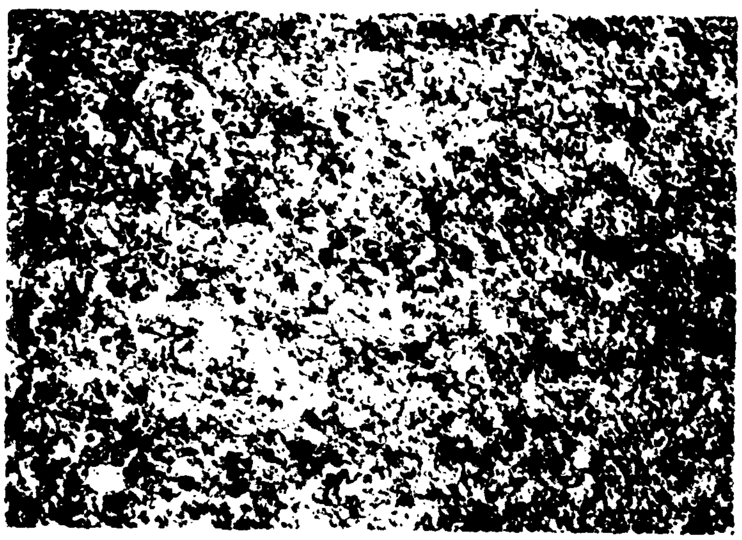
FIG. 7



20% Nickel Ht.No.23222-1 Heat Treated

Specimen DLNL

250X Etchant: 5gm.$FeCl_3$,50ml.HCl,100ml.H_2O



20% Nickel Ht.No.23222-1 Heat Treated

Specimen DLNT

250X Etchant: 5gm.$FeCl_3$,50ml.HCl,100ml.H_2O

FIG. 8

The transverse specimen contains large and numerous inclusions of unknown composition.

Discussion of Stress-Corrosion of Resistance Spot Welds. In the evaluation of the materials in this program, we have included a stress-corrosion test of resistance spot welded specimens. In past experiences with high strength sheet alloys, especially with the cold rolled and aged stainless steels such as AISI 301 and others, there has been a tendency for cracking to occur in the weld area when the material was exposed to a corrosive medium. The cracks usually developed in the area immediately outside the heat affected zone of the resistance spot weld. These cracks vary from a hardly visible length to an arc as much as 50% greater in length than the diameter of the weld.

It is assumed that the highly stressed area is the result of both the thermal shrinkage of the weld nugget in cooling and the reduction in volume when the cold rolled stainless steels are returned from the partly martensitic condition to the completely austenitic condition. No attempt has been made to measure the value of the stress concentration. There undoubtedly is also an interweld effect due to the restraint of adjacent welds. The stresses may be highly irregular around the periphery of the weld, especially when other welds are present.

The specimen designed for this stress-corrosion test consists of two 1" X 2" sections which are placed in an aligning fixture for welding. The welds are located on the longitudinal centerline and are placed 1" apart. The drawing of the specimen is shown as Figure 9.

In many fabricated resistance spot welded structures the faying surfaces would not be exposed to the potentially corrosive atmosphere which may be encountered. For this reason and because it was felt that a non-uniform penetration may occur, the edges of the specimen were sealed to exclude the solution from the opening between the specimen halves.

An investigation was made to find a suitable edge sealant. The sealant had to be stable at 250°F, chemically inert, retain its adhesive characteristics over the operating temperature range, and be relatively easy to apply. An epoxy resin was used on four preliminary test specimens and these were given a trial run using distilled water. The specimens were kept in the boiling water and after inspection at 1,3,5 and 24 hours it was found that the epoxy resin peeled away from the surfaces.

A coating called Maintz produced by West Chester Chemical Company, West Chester, Pa. was used. This sealant is based upon duPont's Hypalon synthetic rubber in combination with silicone and other resins. It has an operating range up to 315°F. A primer coating was applied to the specimens which were heated to 115°F so that entrapped air would be driven from between the

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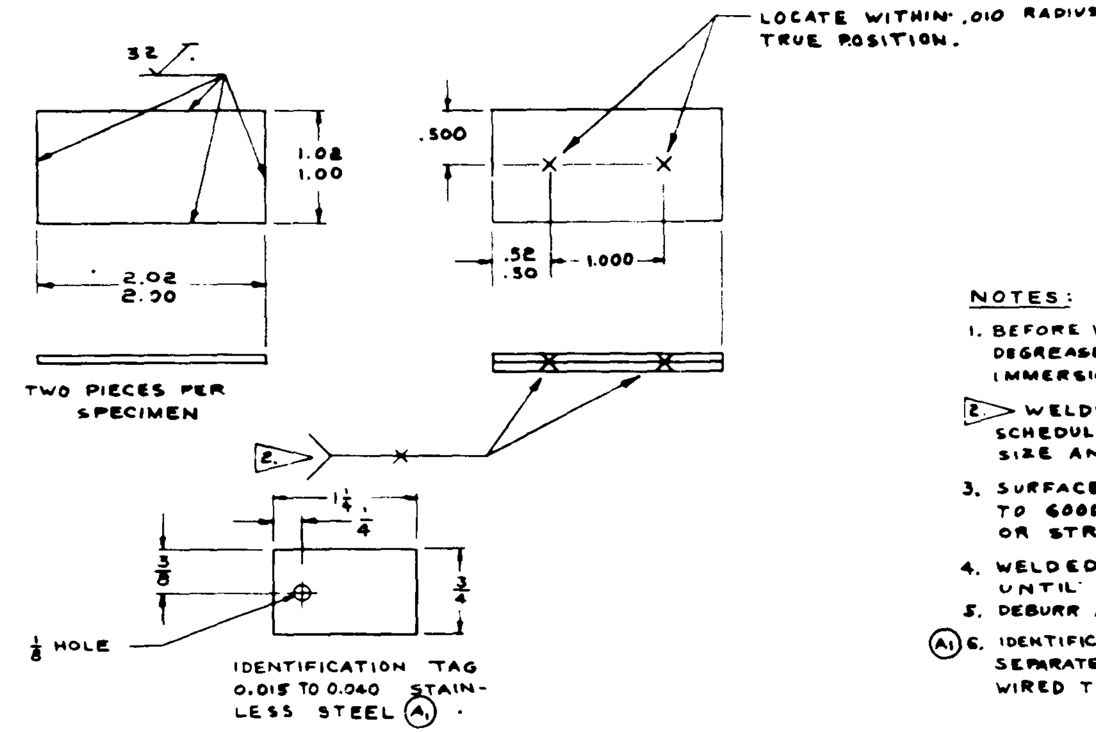


NOTES:

1. BEFORE WELDING, PIECES ARE TO BE THOROUGHLY DEGREASED IN TRICHLORETHYLENE, FOLLOWED BY IMMERSION AND AGITATION IN ACETONE OR ALCOHOL.
2. WELDS ARE TO BE MADE ACCORDING TO SCHEDULE DEVELOPED FOR OPTIMUM NUGGET SIZE AND MECHANICAL PROPERTIES.
3. SURFACE OF MATERIAL MUST BE COMPARABLE TO GOOD NORMAL MILL DELIVERY OF SHEET OR STRIP WITH A 2D (ASTM) FINISH.
4. WELDED SPECIMEN MUST BE KEPT CLEAN UNTIL EXPOSED TO CORROSIVE ENVIRONMENT.
5. DEBURR ALL EDGES AND CORNERS.
6. (A1) IDENTIFICATION CODE NUMBER SHALL BE STAMPED ON SEPARATE STAINLESS STEEL TAG WHICH SHALL BE WIRED TO THE SPECIMEN.

DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED TOLERANCES ARE AS FOLLOWS
DECIMAL
FRACTION
ANGLES
SURF FIN

USED ON	JOB	PIECE NO	QTY	PIECE NO	QTY	DESCRIPTION	MATERIAL	MTL'S. SPECS.	ITEM	REV.
	8600-255-2434	NO		NO						

THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.

TITLE: STRESS CORROSION SPECIMEN RESISTANCE SPOT WELDED TYPE K

DRAWING NO: E2434-0011 REV. A

DRAWN	CHECKED	APPROVED STRESS	APPROVED MTL'S	APPROVED WELDING	APPROVED	APPROVED	SCALE
agd 7 DEC. '60	12-13-60						FULL SIZE

1-13-61	ADDED IDENTIFICATION TAG & NOTE 6	A1	

DRAWING NO. E2434-0011 REV A

FIG. 9

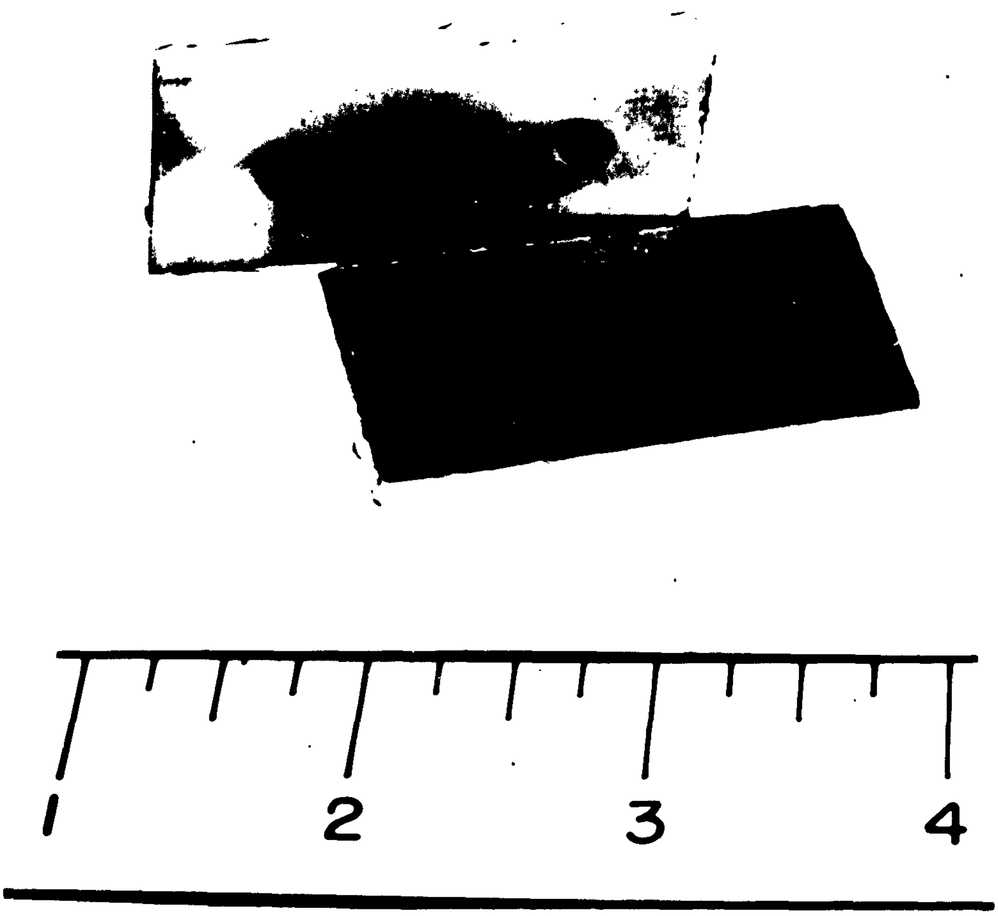
faying surfaces. An eight hour period was required for the material to dry. Some small bubbles formed due to the entrapment of gases and due to the volatile fluids in the coating vehicle. A second coat was applied to the warm (115°F) specimens to seal the existing capillaries. After exposure to boiling distilled water up to 24 hours the sealant was intact and resilient enough to accommodate the linear expansion. A specimen exposed for the 24 hour period was separated and only a negligible amount of staining had occurred.

All test specimens were sealed with the Maintz product as described above. A photograph of the specimens with the edge sealant is shown in Figure 10.

The testing of the stress corrosion specimens was done according to the procedure outlined on page 101, Report No. 9. A photograph of the specimens shown suspended in the boiling corrosive reagent is shown in Figure 11.

<u>Stress Corrosion - JLS 300, Resistance Spot Welded.</u> This is a limited corrosion study designed to develop comparison data for the alloys in the program. We used two concentrations of aqueous solutions of magnesium chloride and have exposed all specimens for a 120 hour period.

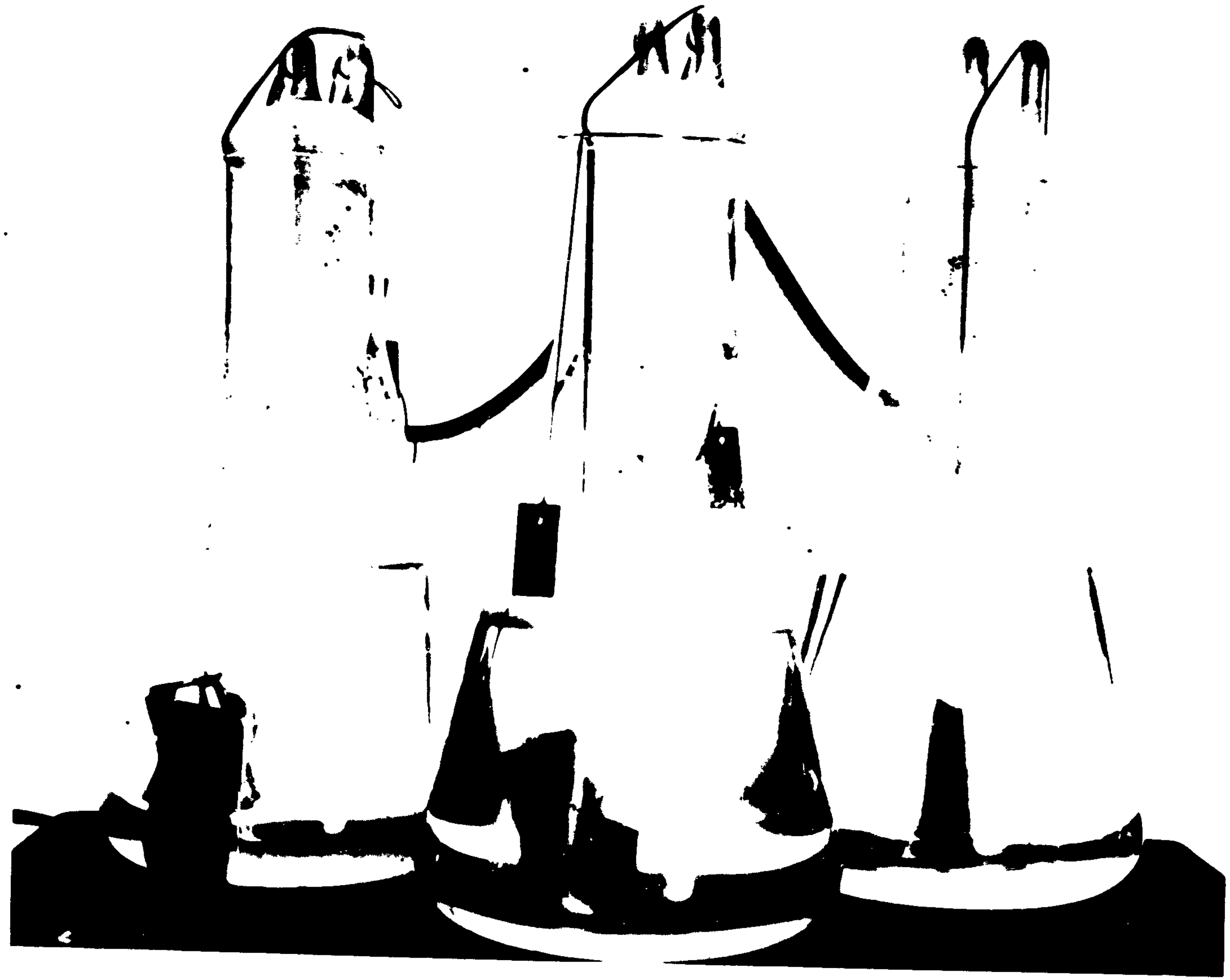
The JLS-300 stainless steel in the cold rolled and aged condition with a 345,000 psi tensile strength (as previously reported) was exposed to both a 5 percent



STRESS-CORROSION SPECIMENS, TYPE K

Resistance Spot Welded
Edges Sealed to Exclude Corrosive Solution

FIG. 10



STRESS CORROSION TEST OF RESISTANCE SPOT WELDED SPECIMENS, TYPE K

Specimens Hung in Boiling Corrosive Medium
2000 ml. Erlenmeyer Flasks with Water Cooled Condensers

FIG. 11

and a 20 percent boiling $MgCl_2$ solution. Specimens were inspected after 1/2 hour, 1 hour, 2 hours, 4 hours, 8 hours, 14 hours, and each 24 hour period up to five days. Inspection was made of both sides of the welds using a low magnification binocularscope. The results of the tests are shown in Table 8.

As may be seen in the data only one specimen responded unfavorably to the corrosive medium and this one was in the 5% solution. The crack was approximately 3/32 inch long and was located slightly outside of the heat affected zone. It is well to note that no failures occurred in the 20% $MgCl_2$ solution although pitting was observed in the area of the electrode indentation.

These results are very encouraging for this material. It is difficult to justify such excellent resistance to the chloride ion, especially in the 20% concentration. We expect to re-test additional samples of the JLS-300 without sealing up the edges. Previous work with similar alloys, which usually produced many cracked specimens in relatively short time, was done with un-sealed specimens.

UNIAXIAL WELD JOINT EVALUATION

The AM 355-PH 15-7 Mo head to shell and shell to shell joint designs shown on Drawings B480-SK-0007 through 0015 were tested. The analysis of the data obtained is being developed and results of the tests plus conclusions will be included in the next report.

STRESS-CORROSION TESTING DATA OF JLS STAINLESS STEEL

0.040" GAGE — Resistance Spot Welded Specimens, Type K — HEAT NUMBER 61616

Condition	Spec. No.	Type of Solution	Specific Gravity Start	Specific Gravity Finish	Total Hours	Results
Cold Rolled and Aged	FNK-1	5%M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
	-2	5%M_gCl_2	1.020@83°F	1.023@73°F	116	OK
	-3	5%M_gCl_2	1.020@83°F	1.023@73°F	116	OK
	-4	5%M_gCl_2	1.020@83°F	1.023@73°F	116	Crack developed after 116 hours
Cold Rolled and Aged	FNK-5	20%M_gCl_2*	1.075@89°F	1.073@90°F	126	All specimens OK after 126 hrs. except for pitting in the area of the electrode indentation
	-6	20%M_gCl_2	1.075@89°F	1.073@90°F	126	
	-7	20%M_gCl_2	1.075@89°F	1.073@90°F	126	
	-8	20%M_gCl_2	1.075@89°F	1.073@90°F	126	

* Boiling aqueous solutions. See Page 101 of Report No. 9 for complete test procedure.

TABLE 8

Electron beam welding of 90°, 20°, and 40° angle butt joint specimens is in process at Bristol Machine Co. using JLS 300 steel and Ti-13Al-11Cr-3Al alloys. The JLS 300 alloy, cold rolled and tempered condition to a 340 KSI yield strength, has been electron beam welded. Radiographic examination of the welds indicate excessive oxide type inclusions and porosity in some areas. This condition has been associated with pre-existing micro cracks and some of the impurities appeared to diffuse into the fusion zone during welding. Where these micro-cracks were absent the welds were radiographically sound. Six weldments are in process of evaluation and results will be included in the next progress report. Electron beam welding ofthe Ti-13Al-11Cr-3Al alloy is in process and evaluation will be made during June. Additional alloys will be electron beam welded when material is received from suppliers.

A Tungsten Inert Gas welded joint program is being initiated employing similar design configuration to the electron beam weldments. Titanium, 6Al-6V 2Sn alloy and Titanium 13V-11Cr-3Al alloy are currently being welded and other alloys will be included when they are received.

Table 9 is a summary schedule showing the tentative timing of fusion welding program based on current estimates of material availability. It is expected that data from this program will be covered in the August progress report.

Schedule

Fusion Welded Joint Evaluation
TIG and Electron Beam Processes

Rocket Motor Case Alloys

Type Work and Locale	Week Work is Scheduled for Initiation (1961)								
	13-11-3 Ti	6-6-2 Ti	8-10 Ti	25% Ni	20% Ni	HI-C Ausroll	M-C Ausroll	JLS 300	ARMCO 12-8-6
TIG-Budd Co. Res.Lab.	Completed	5/29	6/19	7/3	7/3	7/3	7/3	Completed	7-10
TIG-Budd Co. Prod.Develop.	6/5	6/19	7/3	7/17	7/17	7/17	7/17	None	7-10
Elect.Beam BM&T Co.	Completed	None	6/26	6/26	None	7/17	7/17	Completed	None

Note: Above Schedule is based on current estimated delivery of materials from suppliers.

Table 9

PROGRAM REVIEW

A recent review of the program with the Technical Supervisor at Frankford Arsenal resulted in the following decisions:

1. Accelerate the materials evaluation work as much as possible. However, delays in receipt of materials for evaluation are currently effecting this effort.
2. The uniaxial fusion weld joint program is, where possible, being run concurrently with the laboratory evaluation program. This includes T.I.G. welding techniques in Budd Co. Product Development Shop and Electron Beam welding at Bristol Machine and Tool Co.
3. A qualitative study of various designs for chamber cylindrical sections comparing the eight alloys and various processes was made. Data on material characteristics was taken from available sources. Confirmation from results of material evaluation will be used to support conclusions reached.
4. The new Budd Co. development of a high speed free state method for machine welding helical fusion butt welded cylindrical sections will be completed. Design of a welding fixture capable of welding 20" dia. sub-scale and 40" dia. full scale sections will be initiated.

Cylindrical sections 10" in dia. by approximately 36" lg. have been welded with gratifying results using a "rig up" fixture.

5. Manufacture and test 20" dia. sub scale chambers using materials, design and welding techniques developed in the foregoing program. Our aim is to test subscale 20" chambers by December, 1961.

DESIGN OF CYLINDRICAL SECTION

A qualitative evaluation was made of designs of cylindrical sections utilizing materials selected for possible application to rocket motor cases where a strength to density ratio in excess of 1×10^6 is attained. Materials data was primarily taken from information obtained through contacts with suppliers. Revisions in these estimates may be required based on actual test data taken from the material evaluation work. Eight different materials in various cold worked or heat treat combinations and eleven different process combinations were studied. From these studies it became evident that a cylindrical section which would attain a strength to weight ratio of 1×10^6 or better must have at least the following:

1. The base material must have a strength weight ratio in excess of 1×10^6, probably 1.2 or 1.3 to offset production process variables, notch sensitivity and design discontinuities.

2. The material must have high annealed weld strength to reduce the need for severe post weld heat treatments or strain hardening of weld areas, or reinforcement in weld area by means of doublers or local upsetting.

3. The material must have good notch sensitivity factors at high strength levels.

4. Dimensional discontinuities must be kept to a minimum.

Several different designs of cylindrical sections were studied for the qualitative comparison. These included: longitudinal butt welded wrapped sheet, helical butt welded strip, Chevron butt welded sections joint by butt circumferential girth joints, overlapping resistance welded Chevron pattern at longitudinal joint, shear spun with no welding, staggered double helical wrap with resistance seam. Welds and composite single thickness inner case reinforced with a series of narrow hoops helical butt welded.

From these studies, it was evident that a cylindrical section having a preferentially oriented helical butt weld offered one of the best possibilities of attaining the objective of an overall chamber strength to density ratio of 1×10^6 or better. Some reasons for this selection are noted below:

1. Strip materials are available which have strength to density ratios in excess of 1×10^6.

2. The penalties imposed by discontinuities resulting from lap joints on doubler reinforcements are reduced.
3. The connection of the head to cylindrical section is simplified by eliminated the necessity of joining a multi-layer section to the head.
4. Preferential orientation of the weld line reduces the normal stress sustained across the weld line.
5. Weld strength improvement can be made by either mechanical means or by a mild aging heat treatment. If necessary, weld strengths can approach those of base materials.
6. Proven and available process techniques can be employed in the fabrication of this design of cylindrical section.

The choice of helix angle will be made based on test results on uniaxial weld joint tests being conducted on this program utilizing T.I.G. and Electron Beam welding processes. From the tests we plan to determine the yielding characteristics of a narrow weld by comparing the relationship of the normal stress perpendicular to the weld, with the shear stress along the weld line at various angles. From this data an optimum helix angle will be chosen.

It is planned to fabricate and test subscale chambers using a preferentially oriented helical butt welded design. Based on present data available, a titanium alloy and high nickel alloy steel will be used in these subscale chambers. A typical test assembly for subscale cylindrical section is shown in Fig. 12 Dwg. B2434-0135.

WORK CONTEMPLATED FOR NEXT PERIOD

Evaluation of materials being considered for rocket cases will continue during the next period.

Fracture energy test results will be reported on JLS 300, and Ti-13V-11Cr-3Al alloys. Completion of testing of the Ti-13V-11Cr-3Al will be accomplished during the period plus mechanical tests on AM 359 and Ti-6Al-6V-2Sn.

We expect delivery of the AM 357, new analysis 20% and 25% Ni steel, PH 12-8-6 alloy, Ausrolled low alloy steel and Ti-8Al-10V during the period.

Design work for a helical butt welding fixture is underway for welding 20" diameter subscale and 40" dia. full scale chambers.

Details will be released for manufacture of a test assembly to burst test 20" diameter subscale chamber.

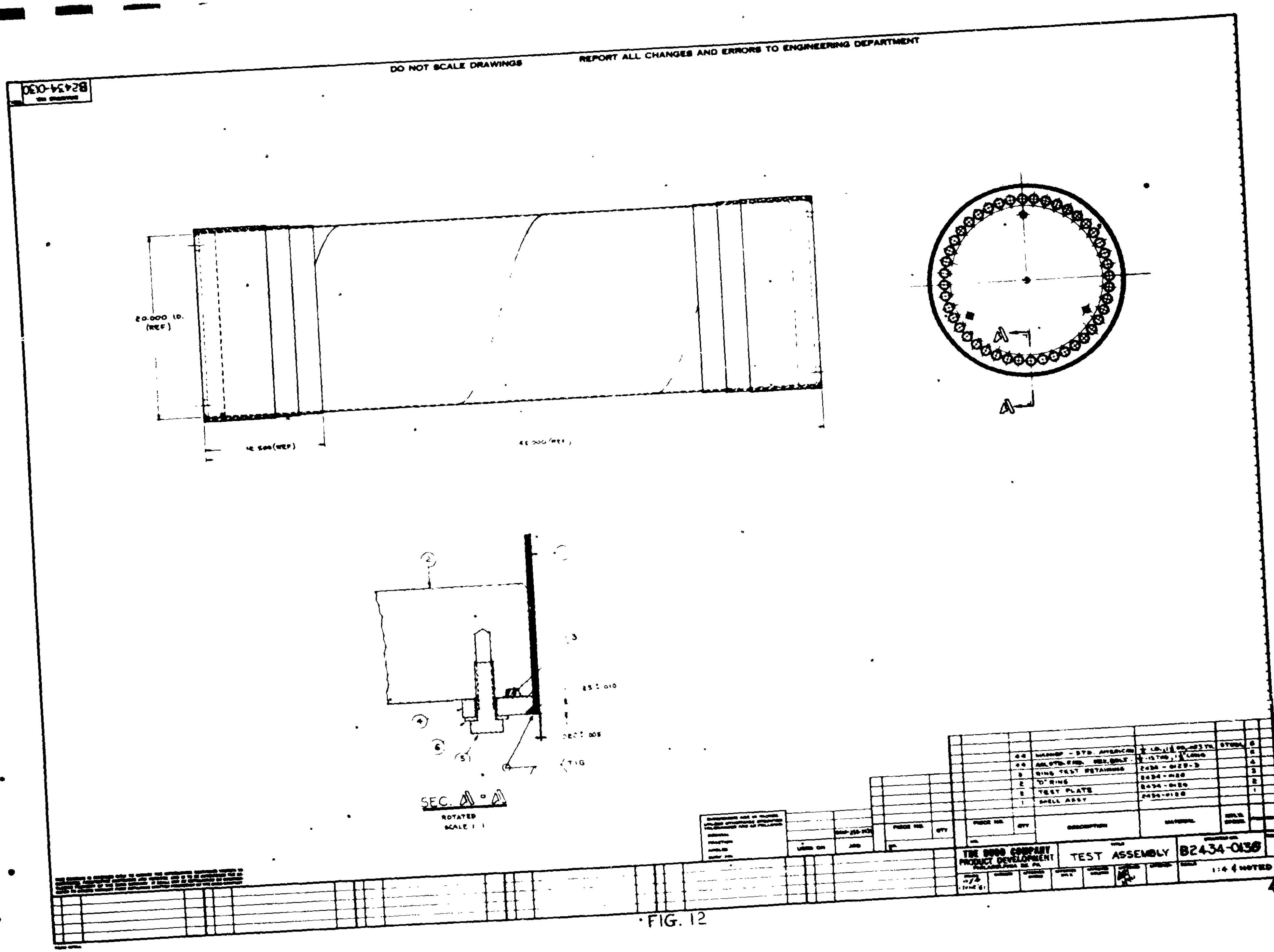

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FIG. 12

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