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REPORT NO. 681/1

SHOP NO. 1

PERMANIBILITY OF METALS

By

James Kirk
Lt. Col., Ord. Dept.

January 10, 1938

**WATERTOWN ARSENAL
WATERTOWN, MASS.**

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Chief of Ordnance	✓	-	2	2	-
Technical Staff	-	-	1	1	-
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Watervliet Arsenal	-	-	1	1	-
Rock Island Arsenal	-	-	1	1	-
Frankford Arsenal	-	-	1	1	-
Picatinny Arsenal	-	-	1	1	-
Aberdeen Proving Ground	-	-	1	1	-
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Private Parties paying for work	-	-	-	-	2

as directed in each case

welding and as directed

January 10, 1938

SHOP NOTE

PRESENTATION BY LT. COL. JAMES KIRK, ORD. DEPT.
PAPER DELIVERED BEFORE JOINT MEETING OF ARMY ORDNANCE
ASSOCIATION AND AMERICAN SOCIETY OF METALS AT WATERTOWN
ARSENAL, DECEMBER 3, 1937, FROM DATA PREPARED BY W.C. NEWCOMB

MACHINABILITY OF METALS

The Watertown Arsenal is a jobbing shop devoted to the manufacture of proto-types of artillery carriages and cannon. The design requirements of ordnance are mandatory in demanding high strength and great emphasis is placed on the saving of weight. Maintenance features such as resistance to corrosion and wear must be given careful consideration. Extreme precision in the fabrication and fitting of parts is essential for accuracy in operation. The severe requirements of design do not generally permit the selection of those metals known to the trade as "free machining". The metal prescribed, with the physical requirements clearly specified, must be used by the shop. The problem of how to work this metal to the best advantage with the machine tools available is one that must be solved by the production department.

Under the conditions cited machinability may be defined as "that quality of a metal which permits it to be formed by selected cutting tools into a shape suitable for the purpose intended". The quality is controlled by the purpose for which the part is to be used.

In all probability Watertown Arsenal has a greater variety of problems in "Machinability" than any commercial plant would ever be called upon to solve. Frequently it takes considerable time to solve a given machining problem and the solution might not be considered efficient from a commercial manufacturer's viewpoint. Nevertheless, a solution is generally found without changing the material prescribed.

Experience at the arsenal has shown that selections of combinations of speeds, feeds, depth of cut, tool material, tool shape, clearance and rake angle of tools, position of tools in respect to work, method of supporting work, rigidity of tool mounting and machines, kind of coolant and lubricant used, method of applying coolant,

type of chip and amount of burnishing all have a definite bearing on machining. At times it has proved advantageous to change from milling to planing or from an engine lathe to a turret lathe, vertical turret or boring mill. A change in the type of machine tool may offer more advantageous means of mounting the work and tools and the way in which they are applied one to the other.

It has been observed that machinability of materials is affected by -

Composition of the Metal

Yellow brass and ordinary grades of bronze require negative rake tools which prevent tendency to dig into the work. High tensile (110,000 lb.) bronze requires tool form which has slightly more rake than is generally used for steel similar to SAE 1035 to 1055.

Addition of Molybdenum to alloy steels seems to affect the grain boundaries so as to improve machining quality.

Method of Processing

Castings - Poor foundry practice will cause hard spots, slag and chilled sections, all of which cause difficult machining.

Forgings - Forgings which are not properly annealed are not uniform. They will cause trouble with cutting tools and will distort as internal strains are relieved by machining.

Rolled Material - Bar shapes and plates formed by the rolling method, either hot or cold, generally have a worked surface. Removing this surface in whole or part releases strains which cause distortion.

Welded Structures - Welded structures will have hard zones and be subject to distortion from internal strains if not properly stress relieved.

Heat Treating

Heat treatments of metal to produce stability, refinement of structure and physical properties all bear a definite relation to machining. Here at the arsenal physical properties are determined by the requirements of

ordnance design. For machining purposes we resort to heat treatments where permissible to obtain the most satisfactory degree of hardness and to stabilize the material. We stress relieve all welded structures to gain uniformity between the hardness of the base metal and the weld metal and to relieve all stresses which will cause distortion. We have found that "K" Monel resisted all attempts to hob gear teeth until it was heat treated to higher physical properties.

Machining

The type of machining has considerable effect upon the apparent machinability:

In planing a good shearing condition is possible with a minimum of tool contact. The resistance to the cut is in a straight line parallel to the direction of work movement. This condition gives an advantage over milling.

In milling the cutter shape limits the amount of shear and increases tool pressure. The resultant line of resistance between the cutter and the work is a combination of a pressure against a concave surface as the cutter rotates and a pressure parallel to the longitudinal direction of work movement. Cutter pressure in milling increases power requirements and very often distorts the work.

In turning resistance to the tool is from a rotating convex surface with the lines of force tangent away from work surface. This condition allows unrestricted flow of metal away from both the tool and the work. Turning operations probably offer the best condition for machining.

In boring resistance to the tool is from a rotating concave surface with the lines of force tangent to but against the work surface. This condition leads to high compression in the chip, and a direct pressure against the work, which may cause the tool to dig in. Combination of speeds, feeds, cutting tool shape and rigidity have much to do with successful boring.

In drilling our experience has shown that rigidity and drill point shape are very often the key to success. This was clearly demonstrated by attempting to drill armor plate having a Brinell hardness of 450 to 475. Standard length tungsten high speed drills 3/8" diameter and with

standard point grinding failed completely. The same drill was successfully used by making it as short as possible, changing the point angle from 118° to 140° , thinning the web at the point and providing a minimum of lip clearance. A short flat drill made from molybdenum high speed steel with the same point grinding was also successfully used. It is interesting to note that equal results were gained using either a twist drill having a positive lip rake or a flat drill having a very slight negative lip rake. The type of coolant used was not important.

Materials that Distort

Great difficulty in machining comes from materials which are subject to excessive expansion from heat generated by the cutting tools and the supporting rest and center friction. Materials which cannot be successfully stress relieved and constantly change during machining operations and after finishing are a serious problem. Stainless steel and monel metal are typical examples.

If any of the conditions affecting established shop practice are changed without advising the machine section, the difference will be discovered very quickly, but it will require a process of elimination to determine the correction in machining practice. If the machining section is notified in advance what changes have been made, selection of machining technique can almost always be applied immediately. This point is brought out to show the necessity of close co-ordination between all departments if economical results are to be achieved.

General

1. Tools and Chips. a. Machining of metals by the cutting process can best be described as a shearing and tearing of the metal by a wedging action which is applied and controlled to produce the size and shape desired.

b. Size and shape are controlled by the type and shape of the wedge or tool and the manner in which the tool is applied to the work. Surplus metal removed by a tool is scrap, generally termed chips. Considered in connection with the machinability of metals, chips become very important in determining the shape of the cutting tool.

c. To remove chips, cutting tools must be forced into action and the amount of pressure required for this forcing is determined by the resistance of the material and the shape of the tool. The best tool condition can readily be determined by observing the condition of the chip being produced:

(1) A heavy chip showing evidence of excessive compression indicates insufficient top rake or shear. It shows that excessive power is required to force the tool into the metal being cut, and that the chip is being torn away by a wedging action which creates a built-up tool edge and a cavity well in advance of the tool cutting edge. With this type of chip there is no metal contact between the cutting edge of the tool and the material being worked. This type of chip causes excessive wear on the top face of the tool some distance from the cutting edge.

(2) The other extreme to this heavy chip is the string or ribbon type of chip which is removed in the shape of a thin flat strip with little or no tendency to spiral or curl. A chip of this type is evidence of excessive top rake or shear which causes the chip to flow. The tool edge built up with this type of chip is very slight, and the tool edge is very nearly in contact with the metal being worked.

(3) A third type of chip is called the shear chip. This is generally considered the most satisfactory from a shop standpoint. The tool producing this chip has a top rake or shear which penetrates the work without excessive pressure and causes the chip to roll into a spiral coil and break up into small sections suitable for disposal without interference with machining operations. With this type of chip there is a small build-up at the tool edge. The chip contact on the tool is back from the edge sufficiently to locate wear on the tool at a point which allows reasonable tool life.

2. a. This brief description of chips shows that the mechanic has a fundamental knowledge as a starting point for the machining of metals and knows the tool condition which should be applied in the majority of cases. When conditions prevent these general results, there is seldom any need to abandon best chip form principle - chip form is still his best guide.

b. Failing to get desired chip condition, the mechanic considers the material - has it changed from what he is used to working, and how? Again the chip acts as a guide to determine if the material has large, open grain or fine, close grain. It shows the degree of resistance to tool penetration and whether the material is tough and hard or soft and ductile. Having determined the probable change in the material, the mechanic resorts to combinations of speeds, feeds, depths of cut, tool shape, etc., so as to produce the approximate type of chip which indicates best machinability. Realizing now that coolant is also an important factor in machinability, he will try dry and wet machining. If the dry condition permits an excess of cutting edge build-up and a rapid tool wear from chip friction, he resorts to wet machining to control heat and wear.

c. The type of coolant he selects is governed by its cooling and lubricating properties and its effect on quality of finish desired. Coolant is a subject for special discussion. It is very important to machinability. When a mechanic resorts to it, he wants a liquid which he can apply with desired pressure and volume. It should not obscure vision. It must dissipate heat rapidly. It must furnish the necessary amount of lubrication. It must penetrate and keep wet all points of friction. Coolant must not wash out machine lubrication or cause damage to the machine being used. It must not cause corrosion and when required, must wash away chips. Why some coolants are successfully used on some materials and fail on others is often a mystery. The results obtained govern the choice.

An interesting coolant problem recently arose at the arsenal. We had a piece of work made from monel metal which it was necessary to finish by broaching. Sulphurized oil is the recommended coolant for broaching operations on monel metal, but was an absolute failure on this job. All other generally used coolants were equally unsuccessful. The work was finally accomplished

with excellent results using carbon tetrachloride as a coolant. (The action of carbon tetrachloride and the inclusion of the beneficial properties in cutting oils appear to present a very good research problem.)

3. Materials for Cutting Tools. a. Carbon tool steel, tungsten high speed steel, molybdenum high speed steel form the general kind of materials used for cutting tool manufacture. There are times when a change appears advantageous and such materials as stellite, cobalt and sintered carbides are resorted to, mainly for the purpose of gaining an increase in cutting speed.

b. Except for the gain in speed by using cobalt, stellite and carbide tools, there is a question of their value over the material in general use. In most cases, tungsten or molybdenum steels can be prepared to do equal or better work. An example of this is shown by experience at the arsenal machining heat treated armor plate with Brinell hardness of 450. The first attempt with general purpose tools failed and cobalt tools were procured, resulting in successful machining. It was known that the quantity of cobalt tools purchased would not complete the work, yet we had no request for replacement tools. Investigation brought out that as the cobalt tools were used up they had been replaced by tungsten high speed tools. It had been found that by using short stiff tools with less clearance and rake the work could be done just as efficiently.

4. Conclusions. a. Machinability of metals is influenced by two factors - time and the requirement for a given material. Here at the arsenal we have found when no change can be made in materials and the time element is not a governing factor, conditions of machines and tooling can be modified to complete the article required. This method is not economical. Perhaps greater efficiency in machining would obtain if the designer of ordnance could be provided with a table showing the relative machinability of the metals he must employ.

b. Efficiency, in terms of time and cost, is what is sought. It is a problem which can be largely solved in the design section by a more careful selection of metals. From a production viewpoint the requirements imposed by design should be as simple as possible and the physical requirements of the material selected should not exceed those necessary. The material should lend itself

to the simplest fabricating or forming practice with the machine tools available.

c. Machinability is a relative term. Each case demands its own solution as an answer to a quality requirement at a cost which is justifiable for the product.