Machinability of Steel

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Free-machining steels are an important component of the U.S. steel industry—over two million tons per year have been consumed during peak periods. From an economic perspective, the total cost of machining alone is estimated at $125 billion. Thus, any improvement in a steel's machinability will significantly impact the cost of manufacture. Not surprisingly, free-machining steels and machinability are areas to which recent insights are being applied for the development of a better product. This article reviews the characteristics of machinability, measurement and analytical techniques, methods for improving machinability, and ways of improving free-machining steels.

INTRODUCTION

Machinability depends upon the dynamic reactions which occur among the workpiece material, the machine tool, the tool's geometry, the lubricant employed, operating conditions, and so forth. In other words, machinability is not a unique material property which can be clearly defined and measured. Although there is no clear-cut meaning, the machining operator engaged in a particular set of operations understands that the most machinable product is the one with the greatest commercial potential. The problem in easily labeling machinability revolves around the many different sets of operations involved. As a result, there are many different criteria of machinability. The same material may have different degrees of machinability as the operations (and hence the criteria) change.

To deal with this complex situation, the commonly adopted approach is a separate examination of several machinability aspects. Improvements in machinability are characterized by one or more of the following:

- **Increasing tool life.** Tool life relates to the amount of material removed by a tool, under standardized cutting conditions, before the tool performance becomes unacceptable or the tool is worn by a standard amount.
- **Raising the rate of metal removal.** The maximum metal removal rate is the fastest speed at which the material can be machined for a standard tool life.
- **Improving surface finish.** The quality of the surface finish depends on the specified cutting conditions applied.
- **Promoting easier chip removal.** Chip morphology is important as it influences the removal of the chips from around the tool, under standardized cutting conditions.
- **Reducing cutting forces.** The cutting forces affect both the tool or power consumption. Metallurgical factors influence most of the preceding aspects.

MEASUREMENT OF MACHINABILITY

Recently established to develop and characterize improved machining steels, the Inland Steel Machinability Test Center is using multiple testing with different machining operations to fully characterize machinability.

ASTM has developed a standardized machinability test, designated as ASTM E 618, which uses the automatic screw machine. The part manufactured during a test is illustrated in Figure 1, along with the relative position of the rough-form and finish-form tools. As parts are manufactured, the part growth (increase in diameter) of the rough-formed and finish-formed surfaces are monitored. The surface roughness is measured by a surface profilometer. Drill wear is evaluated by monitoring the decrease in drilled hole diameter, and drill eccentricity is measured to determine the degree of off-center drilling commonly encountered in part manufacture. Representative chip samples are taken and photographed to document chip morphology. Finally, the tools are microscopically examined and photographed to document tool wear and built-up edge formation.

A modified form of the ASTM test is used at Inland by which the rough-form part growth (limit 0.005 in.) or rough-form tool failure is considered the primary criterion for termination of the test, while the surface roughness of the finished-form surface is considered a secondary criterion. Drill wear and eccentricity are monitored but are not causes for the end of a test. A typical part growth curve and surface roughness curve, as a function of the machine time or number of parts produced, are shown in Figure 2.

The machinability of a steel is characterized by: the highest speed at which a nominal eight-hour rough-form tool life is obtained, the tool life obtained at a certain speed, and the surface finish of the machined part. The advantage of the screw machine test is that it most closely resembles the machining operations performed by users of low-carbon resulfurized AISI 1200 series steels—the large bulk of the free-machining steel market.

A computer numerically controlled (CNC) lathe is used to carry out two kinds of tests. The first is a standardized turning test using either carbide or high speed steel (HSS) tools in which tool life is obtained as a function of cutting speed. A typical Taylor curve, as these results are usually called, is shown in Figure 3. In addition, the forces used during the machining operation in all three directions—known as the cutting force, the thrust force, and the turning force—are all mea-
Figure 2. Typical part growth and surface roughness curves for the rough formed and finish formed surfaces obtained in the screw machine test.

Figure 3. A typical Taylor tool life curve obtained in a single point turning test.

Figure 4. Typical cutting forces obtained in the CNC lathe plunge machinability test, as a function of cutting speed.

Figure 5. Typical drill torque curves obtained in the drill test, as a function of cutting speed.

SURED CONTINUOUSLY BY A PIEZOELECTRIC DYNAMOMETER ATTACHED TO THE CUTTING TOOL HOLDER. THE DATA ARE ACQUIRED, ANALYZED, AND PLOTTED WITH THE AID OF A PERSONAL COMPUTER. THIS INFORMATION IS ULTIMATELY TRANSFERRED TO A MAINFRAME COMPUTER FOR STORAGE AND FURTHER ANALYSIS.

A PLUNGE TEST HAS BEEN DEVELOPED AT INLAND BY WHICH A SIMPLE PARTING TOOL (CARBIDE OR HSS) IS PLUNGED INTO A BAR BEING ROTATED AT A CONSTANT SURFACE SPEED. TOOL FORCES IN TWO DIRECTIONS ARE MEASURED AND ANALYZED. TOOL FAILURE CAN ALSO BE USED AS A CRITERION, AND TOOLS ARE MICROSCOPICALLY EXAMINED TO STUDY WEAR AND BUILT-UP EDGE BEHAVIOR. TYPICAL PLUNGE TEST RESULTS ARE SHOWN IN FIGURE 4.

CNC LATHE TESTS ARE USEFUL IN THAT THE TURNING TEST IS SIMILAR TO THE MACHINING OF FORGING GRADE CARBON OR ALLOY STEELS, AS WELL AS MANY COLD DRAWN STEELS. THE PLUNGE TEST CAN BE USED TO STUDY AND DEVELOP BETTER FREE-MACHINING STEELS.

SINCE DRILLING IS ONE OF THE MOST IMPORTANT—OFTEN RATE-CONTROLLING—MACHINING OPERATIONS, A SPECIAL DRILL TEST, WAS ALSO DEVELOPED AT INLAND STEEL. THE TEST EMPLOYS A MULTIPLE SPINDLE DRILL PRESS, WITH INFINITELY VARIABLE FEED RATES, AND IS EQUIPPED WITH DYNAMOMETERS TO MEASURE THE DRILL FORCE AND DRILL TORQUE. BOTH DRILL LIFE, AS WELL AS DRILL FORCE (OR TORQUE) CAN BE USED TO CHARACTERIZE A MATERIAL'S DRILLABILITY. TYPICAL DRILL TORQUE RESULTS FOR 1215 AND 12L14 ARE SHOWN IN FIGURE 5. AGAIN, THE DATA IS ACQUIRED, ANALYZED, AND PLOTTED BY A PERSONAL COMPUTER AND STORED IN THE MAINFRAME COMPUTER.

THE AFOREMENTIONED BATTERY OF TESTS CAN BE USED NOT ONLY TO STUDY AND DEVELOP IMPROVED WORK MATERIALS, BUT TO ALSO STUDY OTHER INTERACTIVE PROPERTIES SUCH AS THE EFFECT OF NEW TOOL MATERIALS, IMPROVED LUBRICANTS, AND MACHINING CONDITIONS.

IMPROVEMENT OF MACHINABILITY


THE BASE STEEL CHEMISTRY IS DETERMINED BY ENGINEERING REQUIREMENTS AND THEN OPTIMIZED TO YIELD THE BEST MACHINABILITY. Thus, in applications where strength...