The machinability of material

The machinability of a material usually defined in terms of four factors:

(1) Surface finish and integrity of the machined part;

(2) Tool life obtained;

(3) Force and power requirements;

(4) Chip control.

Thus, good machinability good surface finish and integrity, long tool life, and low force And power requirements. As for chip control, long and thin (stringy) cured chips, if not broken up, can severely interfere with the cutting operation by becoming entangled in the cutting zone.
Because of the complex nature of cutting operations, it is difficult to establish relationships that quantitatively define the machinability of a material. In manufacturing plants, tool life and surface roughness are generally considered to be the most important factors in machinability. Although not used much any more,approximate machinability ratings are available in the example below.

1 Machinability Of Steels

Because steels are among the most important engineering materials , their machinability has been studied extensively. The machinability of steels has been mainly improved by adding lead and sulfur to obtain so-called free-machining steels.

Resulfurized and Rephosphorized steels. Sulfur in steels forms manganese sulfide inclusions (second-phase particles), which act as stress raisers in the primary shear zone. As a result, the chips produced break up easily and are small; this improves machinability. The size, shape, distribution, and concentration of these inclusions significantly influence machinability. Elements such as tellurium and selenium, which are both chemically similar to sulfur, act as inclusion modifiers in resulfurized steels.

Phosphorus in steels has two major effects. It strengthens the ferrite, causing increased hardness. Harder steels result in better chip formation and surface finish.Note that soft steels can be difficult to machine, with built-up edge formation and poor surface finish. The second effect is that increased hardness causes the formation of short chips instead of continuous stringy ones, thereby improving machinability.

Leaded Steels. A high percentage of lead in steels solidifies at the tip of manganese sulfide inclusions. In non-resulfurized grades of steel, lead takes the form of dispersed fine particles. Lead is insoluble in iron, copper, and aluminum and their alloys. Because of its low shear strength, therefore, lead acts as a solid lubricant and is smeared over the tool-chip interface during cutting. This behavior has been verified by the presence of high concentrations of lead on the tool-side face of chips when machining leaded steels.

When the temperature is sufficiently high-for instance, at high cutting speeds and feeds —the lead melts directly in front of the tool, acting as a liquid lubricant. In addition to this effect, lead lowers the shear stress in the primary shear zone, reducing cutting forces and power consumption. Lead can be used in every grade of steel, such as 10xx, 11xx, 12xx, 41xx, etc. Leaded steels are identified by the letter L between the second and third numerals (for example, 10L45). (Note that in stainless steels, similar use of the letter L means "low carbon," a condition that improves their corrosion resistance.)

However, because lead is a well-known toxin and a pollutant, there are serious environmental concerns about its use in steels (estimated at 4500 tons of lead consumption every year in the production of steels). Consequently, there is a continuing trend toward eliminating the use of lead in steels (lead-free steels).Bismuth and tin are now being investigated as possible substitutes for lead in steels.

Calcium-Deoxidized Steels. An important development is calcium-deoxidized steels, in which oxide flakes of calcium silicates (CaSo) are formed. These flakes, in turn, reduce the strength of the secondary shear zone, decreasing tool-chip interface and wear. Temperature is correspondingly reduced. Consequently, these steels produce less crater wear, especially at high cutting speeds.

Stainless Steels. Austenitic (300 series) steels are generally difficult to machine.Chatter can be s problem, necessitating machine tools with high stiffness. However,ferritic stainless steels (also 300 series) have good machinability. Martensitic (400 series) steels are abrasive, tend to form a built-up edge, and require tool materials with high hot hardness and crater-wear resistance. Precipitation-hardening stainless steels are strong and abrasive, requiring hard and abrasion-resistant tool materials.

The Effects of Other Elements in Steels on Machinability. The presence of aluminum and silicon in steels is always harmful because these elements combine with oxygen to form aluminum oxide and silicates, which are hard and abrasive.These compounds increase tool wear and reduce machinability. It is essential to produce and use clean steels.

Carbon and manganese have various effects on the machinability of steels,depending on their composition. Plain low-carbon steels (less than 0.15% C) can produce poor surface finish by forming a built-up edge. Cast steels are more abrasive,although their machinability is similar to that of wrought steels. Tool and die steels are very difficult to machine and usually require annealing prior to machining.Machinability of most steels is improved by cold working, which hardens the material and reduces the tendency for built-up edge formation.

Other alloying elements, such as nickel, chromium, molybdenum, and vanadium,which improve the properties of steels, generally reduce machinability. The effect of boron is negligible. Gaseous elements such as hydrogen and nitrogen can have particularly detrimental effects on the properties of steel. Oxygen has been shown to have a strong effect on the aspect ratio of the manganese sulfide inclusions; the higher the oxygen content, the lower the aspect ratio and the higher the machinability.

In selecting various elements to improve machinability, we should consider the possible detrimental effects of these elements on the properties and strength of the machined part in service. At elevated temperatures, for example, lead causes embrittlement of steels (liquid-metal embrittlement, hot shortness), although at room temperature it has no effect on mechanical properties.

Sulfur can severely reduce the hot workability of steels, because of the formation of iron sulfide, unless sufficient manganese is present to prevent such formation. At room temperature, the mechanical properties of resulfurized steels depend on the orientation of the deformed manganese sulfide inclusions (anisotropy).Rephosphorized steels are significantly less ductile, and are produced solely to improve machinability.

2 Machinability of Various Other Metals

Aluminum is generally very easy to machine, although the softer grades tend to form a built-up edge, resulting in poor surface finish. High cutting speeds, high rake angles, and high relief angles are recommended. Wrought aluminum alloys with high silicon content and cast aluminum alloys may be abrasive; they require harder tool materials. Dimensional tolerance control may be a problem in machining aluminum,since it has a high thermal coefficient of expansion and a relatively low elastic modulus.

Beryllium is similar to cast irons. Because it is more abrasive and toxic, though,it requires machining in a controlled environment.

Cast gray irons are generally machinable but are. Free carbides in castings reduce their machinability and cause tool chipping or fracture, necessitating tools with high toughness. Nodular and malleable irons are machinable with hard tool materials.

Cobalt-based alloys are abrasive and highly work-hardening. They require sharp,abrasion-resistant tool materials and low feeds and speeds.

Wrought copper can be difficult to machine because of built-up edge formation,although cast copper alloys are easy to machine. Brasses are easy to machine,especially with the addition pf lead (leaded free-machining brass). Bronzes are more difficult to machine than brass.

Magnesium is very easy to machine, with good surface finish and prolonged tool life. However care should be exercised because of its high rate of oxidation and the danger of fire (the element is pyrophoric).

Molybdenum is ductile and work-hardening, so it can produce poor surface finish. Sharp tools are necessary.

Nickel-based alloys are work-hardening, abrasive, and strong at high temperatures. Their machinability is similar to that of stainless steels. Tantalum is very work-hardening, ductile, and soft. It produces a poor surface finish; tool wear is high.

Titanium and its alloys have poor thermal conductivity (indeed, the lowest of all metals), causing significant temperature rise and built-up edge; they can be difficult to machine.

Tungsten is brittle, strong, and very abrasive, so its machinability is low,although it greatly improves at elevated temperatures.

Zirconium has good machinability. It requires a coolant-type cutting fluid,however, because of the explosion and fire.

3 Machinability of Various Materials

Graphite is abrasive; it requires hard, abrasion-resistant, sharp tools.

Thermoplastics generally have low thermal conductivity, low elastic modulus,

and low softening temperature. Consequently, machining them requires tools with positive rake angles (to reduce cutting forces), large relief angles, small depths of cut and feed, relatively high speeds, and proper support of the workpiece. Tools should be sharp.

External cooling of the cutting zone may be necessary to keep the chips from becoming "gummy" and sticking to the tools. Cooling can usually be achieved with a jet of air, vapor mist, or water-soluble oils. Residual stresses may develop during machining. To relieve these stresses, machined parts can be annealed for a period of time at temperatures ranging from 80° C to 160° C (175° F to 315° F), and then cooled slowly and uniformly to room temperature.

Thermosetting plastics are brittle and sensitive to thermal gradients during cutting. Their machinability is generally similar to that of thermoplastics.

Because of the fibers present, reinforced plastics are very abrasive and are difficult to machine. Fiber tearing, pulling, and edge delamination are significant problems; they can lead to severe reduction in the load-carrying capacity of the component. Furthermore, machining of these materials requires careful removal of machining debris to avoid contact with and inhaling of the fibers.

The machinability of ceramics has improved steadily with the development of nanoceramics and with the selection of appropriate processing parameters, such as ductile-regime cutting .

Metal-matrix and ceramic-matrix composites can be difficult to machine,depending on the properties of the individual components, i.e., reinforcing or whiskers, as well as the matrix material.

4 Thermally Assisted Machining

Metals and alloys that are difficult to machine at room temperature can be machined more easily at elevated temperatures. In thermally assisted machining (hot machining), the source of heat — a torch, induction coil, high-energy beam (such as laser or electron beam), or plasma arc—is forces, (b) increased tool life , (c) use of inexpensive cutting-tool materials, (d) higher material-removal rates, and (e) reduced tendency for vibration and chatter.

It may be difficult to heat and maintain a uniform temperature distribution within the workpiece. Also, the original microstructure of the workpiece may be adversely affected by elevated temperatures. Most applications of hot machining are in the turning of high-strength metals and alloys, although experiments are in progress to machine ceramics such as silicon nitride.

5 Summary

Machinability is usually defined in terms of surface finish, tool life, force and power requirements, and chip control. Machinability of materials depends not only on their intrinsic properties and microstructure, but also on proper selection and control of process variables.