Machinability

Dura-Bar cast iron pricing competes very favorably against carbon steel bars and even net-shape castings because it can be machined much faster and with less scrap due to foundry defects.

The machinability advantage comes from the graphite flakes in gray iron and the nodules in ductile iron. These tiny particles, not visible unless viewed under a microscope, make Dura-Bar free machining meaning it has natural chip breaking abilities. As the cutting tool moves across the work piece, the material being removed will either come off in long stringers or small chips. When it breaks into small chips, the material is classified as free machining.

Free machining steels are manufactured by adding elements that are not soluble in iron and therefore precipitate as small particles or inclusions. When sulfur is added, it combines with manganese to form manganese sulfides. Phosphorus causes the formation of phosphides. Lead is completely insoluble and, when added to steel, are present in the structure. Manganese sulfides, phosphides and lead make steel “free machining”.

The grades of plain carbon steel are identified by a 4-digit number. The first two digits identify whether sulfur or phosphorus has been added to improve machinability. They can also represent other elements that may have been added to improve heat treat response or other properties. The second two digits are the carbon content, multiplied by 100%. A 1010 steel is plain carbon steel with 0.10% carbon. A 1212 steel is a grade that has been *resulfurized* and *rephosphorized* to improve machinability and has 0.12% carbon. A 4140 steel contains nickel, chrome and molybdenum and has 0.40% carbon.

When lead is added to steel, the grade designation has an “L” between the first and second set of digits. For example, a 12L14 steel has been resulfurized and rephosphorized and has additions of lead. The carbon content is 0.14%.

It is important to understand the modifications that are commonly done to steel to illustrate how machinability is improved. Cast iron, both gray and ductile, is free machining because carbon is added in excess of its solubility limit in iron. Excess carbon precipitates to form graphite, flakes in gray iron and nodules in ductile iron. Graphite also acts as a lubricant to reduce friction between the work piece and the insert. This reduces heat and tool wear during cutting.

The metal matrix of Dura-Bar also influences machinability. One grade of ductile iron will have different machinability characteristics than another grade and the same is true for gray iron, therefore machinability ratings and machining processes have been established for each Dura-Bar grade same as with steel.

Machinability is not a property of the material but is an attribute. With this attribute, there are 3 factors to consider:

1. Tool life and cutting speed
2. Surface finish and accuracy
3. Power requirements and tool forces.

Cutting speed and tool life directly affect productivity, which relates to cost. Optimizing either factor will lower a customer's cost of production. The relationship between tool life and cutting speed is inversely proportional meaning that as cutting speed increases tool life decreases. No one customer has the same requirements for tool life. One may want to maximize the life of the tool and another may decide it wants to cut as fast as possible and not worry about how many times the tool has to be changed.

Cutting speed is commonly expressed in Surface Feet per Minute or SFM. Imagine the edge of a cutting tool traveling across the surface of a long flat plate. The speed in feet per minute of the cutting tool is the SFM. The amount of metal being removed depends on the depth of cut.

The speed and depth of cut determine an extremely important outcome:
If either the speed or the depth of cut is increased, the number of parts being produced every hour is increased. That is why it is important to be able to specify machining recommendations for Dura-Bar.

Production Rate or PCS Per Hour

If the speed and depth of cut are too high, the inserts will not last very long and the costs to change them frequently may outweigh the faster production times. It is necessary to optimize the speed and depth of cut to provide an acceptable tool life for the customer. Most machinability ratings are based on the feed and speed of different materials providing a constant tool life.

For example, if the feeds and speeds for material “A” produces 100 parts per hour before the insert fails and the settings for material “B” produces 150 parts in one hour, and the insert fails at one hour for both materials, material “B” has 150% machinability rating compared to material “A”.

The standard material for comparing machinability ratings in steel is 1212 (a resulfurized, rephosphorized carbon steel having 0.12% carbon). 1212 steel has a rating of 100%. Steels that machine better, or allow more parts produced per hour with the same tool life in time, have higher machinability ratings. Steels that are less machinable than 1212 have ratings less than 100%.

Unfortunately, there are no standardized machinability ratings for cast iron. Part of the problem is that machining characteristics are so dependent on a large number of variables (i.e. size of the graphite flake or nodule, graphite density, lamellar pearlite spacing, intercellular carbides and other impurities, etc.) that it is virtually impossible to establish one rating for one particular grade of metal.

There are three processing variables that a Process Engineer needs to know. These parameters help determine the cost of making a part:

1. Depth of cut: (DOC)
2. The speed of the bar relative to the insert (Surface Footage per Minute: SFM)
3. How fast the insert is being fed along the material being cut (Inches of travel in one direction each time the bar makes one revolution: IPR)

Depth of Cut

The depth of cut defines the amount of material that is being removed by the insert during the machining process. If a 0.050" depth of cut is specified on a 2.0" diameter bar, then each time the bar makes one revolution, the diameter is reduced by 0.100". Likewise, a 0.125" depth of cut reduces the diameter by 0.250". The greater the depth of cut, the faster the machining cycle.

Dura-Bar can be machined with depth of cuts as much as 0.125" because the graphite acts as a chip breaker and is considered to be "free machining". Steel bars that are not free machining have to be machined with relatively shallow depth of cuts because the long stringy chip creates friction on the insert which in turn, creates heat and premature failure of the cutting surface.

Surface Footage Per Minute (SFM)

Round bars are chucked and turned at some revolutions per minute (RPM) that is used to calculate the surface footage. When a large diameter bar, say 6.0" makes one revolution, the insert travels a greater distance than when a 1.0" diameter bars makes a revolution. The surface footage is calculated by taking the circumference of the bar (Pi x diameter) and multiplying that by the number of revolutions the bar is rotating every minute:

$$\text{Surface Footage/Minute (SFM)} = (3.14)\text{x}(\text{Bar Diameter})\text{x}(\text{RPM})$$

At 1000 RPM, an insert is traveling 262 surface feet per minute along the surface of a 1.00" diameter bar. If a 6.0" diameter bar is rotating at the same RPM, the insert is moving at a rate of 1570 surface feet per minute. Machine tools are programmed to speed up as material on the outside diameter of the bar is removed so that the surface footage stays constant.

Dura-Bar grades can be machined at SFM in excess of 1200. The limit on most steel bar stock and some foreign continuous cast bars is 650 to 800 SFM. The ability to machine Dura-Bar at twice the speeds of other materials equates to substantial cost savings from increased productivity.

When specifying the cutting speed, it is necessary to express it in terms of surface footage per minute because just stating the revolutions per minute is completely meaningless. But, in order to figure out how fast to turn the bar, surface footage per minute is meaningless without knowing the diameter. It is important to know the relationship between RPM and SFM and how to convert back and forth from each.

Feed (IPR)

If the insert just sat there and didn't move with the bar rotating, it would take an infinitely long time to machine the part. So the insert travels along the bar at a certain rate, which is the feed; usually expressed in terms of "***inches per revolution***". As the feed rate goes up, the appearance of the machined surface starts to look rough, sort of like the threaded surface of a bolt. The lower the feed rate, the longer the time required to machine the part but the better the surface finish. It is usually best to specify the feed necessary to obtain the required surface finish and increase the speed to optimize productivity.

Suppose your feed is .015" and the length of the cut is to be 2.0". The number of revolutions required to make the cut is: 2.0"/.015 inches per revolution = 133.3 revolutions

Machinability data changes quickly. Most of the information published is a good starting point but may not be the "best" set of conditions. Usually, the starting point is conservative.

Microstructure has a very large influence on machinability, especially within the ductile and gray iron grades. Machining processes are conservative (low speeds and feeds and shallow depth of cuts) because of potential disasters that can occur if the insert hits an inclusion or area having a heavy concentration of carbides. Tooling "crashes" can cause more than just a broken insert, tool holders can become damaged and the machine tool spindle can be knocked out of alignment causing down time and substantial expense to repair.

The process controls and constant monitoring of chemistry, microstructure and all significant variables that influence machinability allows customers that are machining Dura-Bar to machine at very high surface footages and make relatively large depth of cuts. Customers report tool life improvements of over 45% and productivity increases of 50% when converting to Dura-Bar from carbon steel. Much higher tool life and productivity gains are realized when Dura-Bar is compared to continuous cast iron producers supplying commodity (non-engineered) bar stock.