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Grinding

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Overview

Metal removal fluids (MRF) are used for both machining and grinding applications. As was discussed in the basic training, both applications are similar in that there is an interface between the cutting tool, the metal being cut (i.e. the workpiece) and the chip that is created. With grinding, the tool has hundreds to thousands of cutting edges instead of just a few or a single point of contact. There are attributes specific to the grinding process that impact the selection of the grinding wheel, the level of lubrication required and the fluid selection to meet these needs.

Definition

The grinding application involves a rotating cutting tool (in the shape of a wheel) that removes metal from a surface via the constant application of pressure against the workpiece by the wheel. While there are basically three different types of grinding (surface, external and internal), the application uses the same principles. Just like any other metal removal process, the tool (i.e. the abrasive grains in the wheel) must be harder than the workpiece or there will be no cutting. Grinding is similar to turning with a negative rake angle.

The two key things to remember with grinding are 1) the grit must be harder than the alloy you are grinding and 2) only sharp grit grinds the workpiece. The grinding process involves cutting, then plowing (i.e. the wheel plows through the metal), then rubbing at the end of the cut.

There are three stages of grinding:

1. Spark in – The grind wheel does not immediately cut the workpiece surface due to some flexibility in the machine tool and related devices involved in the process.
2. Steady state – When the grinding process actually occurs.
3. Spark out – Grinding may actually continue to take place because of the flexibility in the machine tool.

The main thing to remember is that stiff, rigid machines will produce improved finishes especially if the surface finish requirement calls for a very tight tolerance.

Calculations

There are many different types of calculations that can be used to describe specific aspects of the grinding process. However, the most common is related to determining the Grinding Ratio or "G ratio" for short. Simply put, the calculation for the G Ratio is Volume of Work Material Removed divided by the Volume of Wheel Wear. Of course the wheel must be of the type that can be dressed so this leaves out electroplated wheels. G Ratios range in value from 2 to 200 for conventional wheels (like aluminum oxide or silicon carbide). However, using super abrasive wheels (cubic boron nitride or diamond) can provide G Ratios of much higher values.

Another calculation that is commonly used compares one grinding application to another. This is accomplished by comparing the diameters of the work pieces and grinding wheels. This value is called the Equivalent Diameter and is represented as D_e. The calculation is:

$$D_e = \frac{D_w \times D_s}{D_w +/- D_s}$$

D_w is the diameter of work piece, and D_s is the diameter of the grinding wheel. The plus symbol (+) in the denominator is used for external grinding while the minus symbol (-) is used for internal grinding. This means that you can apply similar practices to similar operations to achieve the same result.

The metal removal rate is the last calculation and is called Q. However, by measuring the specific metal removal rate per width of grinding wheel, this parameter becomes Q Prime (Q'). The equation is $Q' = aBV_w$, where a is the depth of the cut (inches), B is the width of the grinding wheel contact (inches) and V_w is the work speed (inches/minute). The units

for Q′ are in.^{3}/min./in. of wheel. Q′ can be used in many charts and tables to predetermine important parameters like horsepower requirements, surface finish capability and others. In general, as Q′ increases the surface finish becomes rougher. Higher Q′s are achieved with deeper cuts. Recognize that the process, as well as size of the grit in the wheel, governs the surface finish! Increases in Q′ or work speed increases the chip thickness but an increase in the De or wheel speed reduces the chip thickness.

Types of Grinding

The three different types of grinding are surface, external and internal. The geometry of the contact zone (i.e. where the grinding wheel impacts the workpiece) is different for each. However, using the calculations from above permits comparisons. Internal diameter (ID for short) only has one type of application. Outer diameter (OD for short) can be broken down into cylindrical and centerless. Surface grinding, like ID grinding, stands alone.

Internal grinding is as its name implies. The grinding wheel tends to be smaller as it fits inside of the open workpiece. The grinding wheel grinds the inner diameter of the workpiece. One of the most important concerns is the rigidity of the shaft or arbor that holds the grinding wheel. If the shaft/arbor is too long and not rigid enough (i.e. sturdy), then there could be flexing that will create problems during the grinding process. A general rule of thumb is that the diameter of the grinding wheel should be about 80% of the workpiece ID.

Exterior grinding occurs on the outer diameter (OD) of a workpiece. OD tends to describe cylindrical workpieces, as flat pieces are generally surface ground. Parts like shafts, bearing rings and other cylindrical shapes are OD ground. One of the main concerns with OD grinding is maintain concentricity. Concentricity has to do with making sure that parts remain round and lobes are not produced. For example, long cylindrical pieces can easily become tapered if the forces are not controlled properly.

Technically speaking, one can even further segment this type of grinding into cylindrical and centerless. Cylindrical means that the workpiece rotates about a fixed axis and the surface ground is concentric to that axis. Centerless means that the workpiece rotates between a grinding wheel and a regulating wheel. A fixed, steady rest blade supports the workpiece. Parts can be placed into the operation via the thru-feed process or an in-feed process. Thru-feed means that multiple parts are fed through the narrowing gap that exists between the grinding and the regulating wheels. The in-feed process is used for parts that cannot continually "flow through" the gap. Parts are placed in the process one at a time and the grinding wheel moves in to grind the part and then retracts.

Surface grinding is used to produce flat surfaces, typically with requirements to maintain parallel surfaces. Most often this is achieved via a double disk grinder. This type of grinding is prone to foaming because of the manner in which the fluid gets aerated.

Terms like micro-centric and centertype describe the relationship between the wheel and the workpiece. Micro-centric is a term that indicates the grinding wheel is smaller than the workpiece and is generally centered or used in some type of preformatted form. Centertype means that the grinding takes place where the part rotates around a fixed centerline as defined by the chuck or other holding devices.

Grinding Wheel Identification

There are many grinding wheel manufacturers but there is generally commonality regarding the naming convention of wheel types. Unfortunately, this convention is not always the same outside the United States. It is a combination of alpha and numeric designations as described in the following example: W A 54 M 5 V 18 and the following table.

Quaker Knowledge Network

Grinding Cont.

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Grinding Wheel Identifications		
Value	**Parameter**	**Definitions**
W	**Optional prefix to describe wheel**	Manufacturer's proposal
A	**Abrasive**	A = Al2O3, B = CBN, C = SiC, D = diamond
54	**Abrasive grain size**	Two-three digits; larger value = fine grit
M	**Wheel grade (i.e. hardness)**	Alpha designation where higher letter is the strongest; described as soft, medium or hard
5	**Grain Structure**	Numeric value where low value is dense and high value is open
V	**Bond type**	V = vitrified, B = resinoid, R = rubber, E = shellac, M = metal, and S = silicate
18	**Optional suffix to describe wheel**	Manufacturer's proposal

Grinding Wheel Types

A grinding wheel is a combination of abrasive grains and a bonding agent. It is pressed into a shape with a certain density and porosity. It becomes a tool after it has been cured or hardened through specific processes controlling temperature and pressure. Grinding wheels are defined by their abrasive type, the size of the abrasive, the grade/hardness, and the structure/porosity.

There are natural and man-made abrasives. The majority of the metalworking industry uses man-made abrasives. The natural grains are sandstone, emery/quartz and diamond dust. As described in the table above the man-made abrasives are aluminum oxide (Al_2O_3), cubic boron nitride (CBN or Borazon), silicon carbide (SiC) and natural or synthetic diamond. Aluminum oxide is used for general-purpose applications on steel while silicon carbide is used for tool steels and very hard non-metallic surfaces. Diamond is used on hard, non-metallic surface. It is not used on metallic surfaces because the carbon in the diamond will react with the carbon in the metal. CBN is used on very hard steels, tool steels and super alloys (i.e. those containing nickel and chrome).

In ranking their hardness (from softest to hardest) Al_2O_3 is softest, then SiC, then CBN and finally diamond. Remember that diamond is the hardest substance on earth. Softer grades are used for large stock removal, as in a roughing operation, on hard materials. Soft wheels are used where constant breakdown (via dressing the wheel) is desired. Hard grades are used for low stock removal, as in finishing operations, on softer materials.

Hardness, size and friability are used to define abrasive grains. As listed in the table above, the larger the value, the smaller the grain. A very fine abrasive could be 600 grit while a roughing operation might employ a 60-grit grain size. Friability is the fracturing property of the grain under pressure. A wheel that is more open cuts more and usually contains a larger grain size. There is a condition known as "induced porosity" wheels that actually have very large openings. Larger grain size and larger porosity does permit the coolant greater access to the grinding zone.

As explained above, the bond type is the material that holds the abrasive in place. There are pros and cons for the different types of bonds depending upon the application. V stands for vitrified, B stands for resinoid, R for rubber, E for shellac, M for metal and S for silicate. E and S are rarely used anymore. Vitrified bond is polymeric. The polymer used behaves like plastic in the grinding wheel. There is also metal bonding, which is really plated or sintered.

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Dressing and Truing

As a grinding wheel is used, the sharp edges break down and become dull. In order to make fresh grain available for more grinding the wheel is dressed. Dressing is the process whereby a diamond tool (the most common dressing implement) is exposed to the surface of the grinding wheel and a very tiny layer of the grinding wheel and bond are removed. Only electroplated CBN wheels are not dressed because the layer of CBN is typically too thin. Dressing would remove the layer of CBN abrasive.

There are other mechanisms that cause a grinding wheel to require dressing. Wheel "loading" can occur when grinding chips and swarf impact the wheel and will not easily flush out under the normal coolant conditions. Tramp oil can also load the wheel, causing it to not be very abrasive. Of course, tramp oil can also decrease the natural detergency of the coolant. "Glazing" of a wheel is typically referred to when the metal being ground off gets in the grain.

Truing is similar to dressing but deals more with just keeping the wheel properly aligned in terms of round and straight. The diamond tooling is the most common tool used to perform the truing of grinding wheels. The diamond is held in a holder called a nib and is typically canted at 10-15o on the approach to the wheel. The diamond is rotated in the nib every 10-12 truings to keep the diamond sharp. There are nibs that will hold multiple diamonds. Another common truing device is the aluminum oxide stick, which is porous like pumice.

Recognize that there is a balance between dressing and truing versus the wheel life. Many customers equate process performance to the number of parts obtained prior to dressing. It makes sense that the longer you go before dressing (i.e. the number of parts you produce), the longer the wheel should last. A grinding wheel with high friability will have a tendency to self-dress. This will happen, because the natural grinding forces will create the friability and the wheel will gradually lose grains to expose fresh sharpened surfaces.

Metal Removal Fluids

Cooling, detergency, lubrication and fine settling capabilities are the main objectives in choosing a metal removal fluid for grinding. The use of CBN generally requires higher lubrication to protect the layer of CBN crystals while lubricating the surface of the workpiece. This is why straight oils are used more often with CBN.

True solution synthetics provide the best cooling and fine settling capabilities. This would be the QUAKERCOOL 2700 and QUAKERCOOL 2800 Series of products. The 2700 Series contains higher levels of lubrication versus the 2800 Series. True solution synthetics provide good detergency as well as semi-synthetics. In general, solution synthetic fluids tend to make wheels run 1.0 - 1.5 times softer than they would with other fluids. The QUAKERCOOL 3000 Series of products are the semi-synthetics. Vitrified CBN wheels typically use water-soluble fluids but straight oil fluids are used for many electroplated CBN applications, as long as the oil is chilled. Chilling is used to keep the process temperatures under control. The QUAKERCUT Series of straight oils would apply to these processes. In some cases we have fluids that are already OEM approved for specific grinding processes.

Fluid application is critical in grinding. It is easy for the grinding wheel, with high surface speeds, to create forces that do not permit the coolant to make it to the point of contact. You must make sure that the nozzle is as close as it can be to the wheel/part interface. It is also important to make sure that the coolant velocity is close to the wheel velocity. The coolant must carry the heat away from the application otherwise the workpiece may become burned. In CBN grinding, the coolant is typically applied under higher pressures because of the high surface speeds typically employed with CBN. Special nozzles exist that permit most fluid applications to run efficiently but it is a good idea to ask and/or examine the application.

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Grinding Cont.

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When investigating some troubleshooting issues, fluids provide impact in the following areas:

- Burn marks – insufficient cooling and/or lubrication
- Erratic sizing – overheating due to insufficient coolant
- Bad finish – dirty coolant
- "Fish tails" (a.k.a. scratches) – dirty coolant
- Pick-up on steady rest blade – insufficient lubrication at steady rest blade
- Straightness – insufficient coolant causing the part to heat up which relieves stresses
- Sub-surface cracking – the entire grinding process as impacted by the coolant performance

Summary

Like any MRF application, understanding the parameters that impact performance are important. The MRF is only one part of the process but plays a key role. Don't be afraid to ask questions to make sure that the operation runs smoothly and correctly.

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