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Grinding—
Tools and Technique

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To remove stock, to produce a finer finish and to permit closer tolerance on jobs, grinding has superseded many types of machining. Sometimes a job may be done quicker as well as more accurately by grinding than by turning or shaping; plain bronze bearings may be finished quicker by grinding (thus producing a more economical job) and also produce a better finish and a smaller tolerance.

Plate glass is ground to produce a fine finish, billets are ground to remove imperfections, bearings are ground to conform to a specified size within close limits and cemented carbides are ground since it is the sole practical method of machining them.

A grinding wheel is a true self-sharpening tool since in "perfect use" the grains of abrasive will break off and new grains will come into contact with the work before the effectiveness of the grains is lost through dullness. On termination of the useful life of the grains they are ripped from the bond to present a new grain into contact with the work. The wheel stresses are the factors determining the above "perfect use". The stresses should be close to the shearing stress of both the bond and the grain. If a slight increase in the stress breaks the grain or tears it from the bond, the wheel is said to be "soft". If the grain stays in the wheel and grows dull, the wheel is said to be "hard".

The stresses are due to impact, shear and compression. They are governed by the physical properties of the work being ground, the contact area between the grinding wheel and the work, the wheel speed and the work speed, the rate of feeding the wheel into the work and the cross speed or traverse rate. For example, since copper offers much less resistance to penetration than chilled cast iron it produces lower stresses in the grinding wheel.

Compressive stresses are affected by the contact area between the wheel and the work. In surface or cylindrical grinding, a large wheel will have a larger area of contact than a small wheel on the same work. With work of the same diameter and the same wheel size, internal grinding has a larger arc of contact and a greater compressive strength.

The ratio of wheel speed to work speed partially determines the shearing stress in the wheel. If the wheel operates at a given peripheral speed the individual grains will remove chips of a certain size. If the peripheral speed of the work is increased a greater amount of metal is sheared off in each chip. This increases the stress on each grain. The grains then tend to break away from the wheel or the wheel acts "soft". If the peripheral speed of the work is decreased the wheel grains have less metal to remove in each chip. This produces a lower shearing stress and the grains tend to stay in the wheel until they become dull. Thus, the wheel acts "hard". This is a method of controlling the grinding action since a "soft" wheel may be made to act "hard" and vice versa.

The in-feed rate or the rate of moving the wheel directly into the work affects both the shear and compressive stresses. If the in-feed is large a large compression on the grain results, also the amount of metal contained in each chip is large which causes a large shearing stress. Plunge-cut grinding or grinding by moving the wheel in to the desired depth, backing out and repeating tends to cause high stresses. They are minimized by decreasing the work speed.

The cross speed or traverse rate causes lateral shear and forces the edges of the wheel to break down. This in turn affects the finish produced on the work. This may be partially compensated for by slowing the traverse speed to produce a good finish.

In deciding on the kind of abrasive wheel to be used the above factors plus the type of abrasive, grain size, structure, type of bond and hardness of bond or grade must be considered.

There are three important types of abrasive used in grinding wheels. They are aluminum oxide, silicon carbide and industrial diamonds or "bort".

Most aluminum oxide crystals are tough and not easily broken. It is best suited for grinding a high tensile strength or hard material which can break the crystals before they get too dull to do effective work. This places new, sharp cutting grains in contact with the work. This grain is effective on such material as annealed malleable iron, tough bronze, high speed steel, high silicon steel, alloy steel and high carbon steel.

Silicon carbide is harder than aluminum oxide, more brittle and not as tough. Since it is not broken until it begins to dull it is suited to two extremes of materials; those of low tensile strength and those of very hard materials from aluminum, rubber, leather, copper, soft bronze, lead and brass to cemented carbides, cobalt and chromium alloys, gray and chilled iron, marble and granite.

Diamond wheels were first manufactured to grind extremely hard materials which could not be ground in any other manner. They are composed of industrial diamonds or "bort" set in a matrix, usually an alloy. Recently, a metal bonded diamond wheel has been developed for off-hand grinding of cemented carbide tools. It is made of industrial diamonds from the Belgian Congo embedded in an alloy under high pressure. This gives the wheel a high heat conductivity, small bond disintegration, low wheel wear and a reasonably high cutting rate. In placing one of these diamond wheels on the grinder, it is first indicated before truing since the cost of the wheel is so high.

For other grades of work the "special" aluminum oxide has been developed. This special grade breaks easier than the regular aluminum oxide. In the case of internal grinding a "soft" wheel is required. If an operator were to grind a hole in some high speed steel he would like to have a wheel made of "regular" aluminum oxide but since he is to grind internally the wheel should also have the characteristics of silicon carbide. In internal grinding of a material of high tensile strength a small wheel could be used; this would provide a small arc of contact but the stresses would be great, therefore, a wheel of aluminum oxide would have to be used. Since it would not be economical to use small wheels, large wheels are used which increase the arc of contact and lower the stresses. This may lower the stresses so much that the regular wheel would not be self-sharpening but would become dull and refuse to cut or "load". Here the special aluminum oxide would work effectively.

In selecting grain sizes the amount of material to be removed and the finish desired are of paramount importance. If the amount of material to be removed is large, or if the material is soft, coarse-grained wheels should be used. This is particularly applicable to hand grinding operations such as snagging castings, where finish is of little importance and rapid stock removal is essential. However, in cylindrical grinding with coarse wheels there is a strong tendency to spring the work. The use of fine-grained wheels to produce a fine finish is desirable since large grains do not penetrate well. This is also the reason for using fine-grained wheels on hard materials.

The structure of the wheel or spacing between grains is dependent on the material to be ground. Wide grain spacing is required for soft work since the chips are larger and this gives each chip more clearance and lowers the tendency to "load". Close grains are needed for hard materials, formed wheels and good finishes. Highly variable pressures such as cup wheels and snagging wheels endure need wide spacing of the grains to permit each grain to carry its share of the load.

The type of bond partially determines how long the cutting particles will be retained in the wheel. The bond must release the cutting particles when they grow dull but it must be strong enough to prevent centrifugal force from destroying the wheel. There are five major types of bonds: vitrified, silicate, shellac, resinoid and rubber.

The vitrified bond is composed of ceramic clays burned at high temperatures. It is virtually unchanged by heat or cold and can be made in a greater range of hardness than any other type of bond. It does not completely fill the void between grains, and, therefore, has more grain clearance than any other. Wheels with this type of bond are adaptable to all types of grinding except where the wheel is not thick enough to withstand lateral pressure. There is no elasticity in this bond. The wheels are strong enough to do structure and also heavy work, can remove stock quickly and produce fine finishes and close accuracy. Grinding wheels with this type of bond have a maximum peripheral speed of 6500 feet per minute and are used in greater quantities and for more purposes than a wheel with any other bond.

The silicate bond is composed of clays using silicate of soda and fired at low temperatures. It is more sensitive to changes of the moisture content of the air than the vitrified bond, gives less grain clearance and is softer than most vitrified bonds. It also has no elasticity and is not safe to use for thin wheels. This bond cuts with a lower temperature than vitrified and is used for grinding thin edges as required on knives and tools.

The shellac bond or elastic bond is composed of shellac and other gums. It completely fills the interstices between grains, has a high tensile strength and elasticity and is used in making very thin wheels. Wheels made with shellac bonds are used for grinding chilled iron mill rolls and hardened parts such as cams.

Resinoid bonded wheels are tough and resilient. They can withstand severe lateral pressure and shocks as are found in snagging. They produce fine finishes. Cut-off wheels have a maximum surface speed of 1600 feet per minute, whereas, snagging wheels are successfully operating at 9500 feet per minute. They are often used for billet and ingot grinding.

Rubber bonds have many of the characteristics of the shellac bonds but they cannot be manufactured in the same grades of hardness. Rubber wheels produce exceptionally fine finishes and almost all regulating wheels on centerless grinders are rubber bonded.

The grade of a wheel is the degree of resistance the bond presents to prevent the grains from being torn out. The ideal grade would hold the grains until they have become dulled through use and then release them. A hard grade holds the grains strongly. Hard grades are used when grinding soft materials since it

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takes a long period to dull the grains with soft material. A soft grade is used when grinding hard materials since the grains are quickly dulled and should then be released.

In cylindrical grinding, the work is supported on centers and driven by a grinder dog. To prevent the piece from being tapered at the ends the grinding wheel is allowed to run off only half of the width of the wheel. Tapered, straight or form grinding is easily performed on this machine. If a great amount of stock is to be removed it can be most easily accomplished by in-feeding or plunge cutting. The final size can then be ground with the conventional transverse feed. Often the grinder operator will put his hand up to the wheel and let it grind off a bit of skin in the feeling of the wheel to determine whether or not the wheel is rough or loaded.

German manufacturers have developed several methods of grinding threads that have not been very widely adopted in this country yet. They use the thin "V" shaped wheel that moves axially just as a threading tool in a lathe moves. This method is also used here. It is good for grinding threads in a hardened shaft of steel. It requires moving the wheel in and taking a new cut after each pass. Two grinding methods, very little use here, were developed to speed up the process. The wide, tapered wheel has multiple "V's" "trued" into its face. This wheel is axially fed into the work the same as the single "V" wheel but with the tapered wheel the full depth of cut can be taken in one pass. This is possible since the first "V" of the wheel takes part of the cut and each succeeding "V" takes more of the cut with the last "V" grinding the final size of the thread. With this method the wheel must be able to travel a distance equal to the width of the wheel farther than the desired length of thread. To remove this difficulty and still decrease machining time the straight-faced, multiple "V" wheel was developed. With this wheel a thread the full width of the wheel face may be cut in one revolution of the work. This is accomplished by plunging the wheel directly into the work and withdrawing it after a complete revolution. This has the added advantage of giving a precise location of the start of the thread with respect to the rest of the threaded piece. Its biggest disadvantage is the difficulty of holding close tolerance by this method.

Centerless grinding is on the increase because it eliminates the operation of centering both ends of the piece; the work is completely supported in the grinding zone which permits a higher efficiency for the grinding wheel; idle or non-grinding time is reduced in the grinding cycle; and work may be "trued" up with approximately half the grinding stock requirement of a cylindrical grinder, thus reducing the wheel cost per piece.

The centerless grinder also sizes on the diameter of the piece, and not on the radius as is done by the cylindrical grinder. The grinder design also lends itself to automatic and hopper feeds.

Essentially, a centerless grinder consists of a slowly moving regulating wheel and opposed, high speed grinding wheel forming a grinding throat. A work rest of cemented carbide is placed between the wheels for the work to ride upon. The grinding action of the large wheel forces the work against the regulating wheel which drives the work at the same peripheral speed.

Recent developments in grinding machinery include the grinding jig borer. It is nearly the same as the conventional jig borer except the spindle has higher speeds and is equipped to take a grinding wheel instead of a flybar or boring tool. With this machine distances between holes in hardened pieces can be maintained within close limits. Formerly, the piece was jig bored and hardened. During hardening the work often warped and destroyed both the distance between holes and the hole sizes. The toolmaker then had to laboriously stone the hole back into shape and position. This new machine eliminates this waste time. Grinding methods are constantly being improved to save machining time; in present times this assumes paramount importance.