Grinding

Training Objectives

After watching the program and reviewing this printed material, the viewer will gain knowledge and understanding of the primary industrial grinding processes.

- cylindrical, internal, centerless and surface grinding are demonstrated
- types of abrasives and bonding methods are shown
- grinding wheel maintenance is explained
- specifics of workpiece surface finishing are detailed

The Grinding Process

Grinding is an abrasive material removal and surface generation process used to shape and finish components made of metals and other materials. The precision and surface finish obtained through grinding can be up to ten times better than with either turning or milling.

Grinding employs an abrasive product, usually a rotating wheel brought into controlled contact with a work surface. The grinding wheel is composed of abrasive grains held together in a binder. These abrasive grains act as cutting tools, removing tiny chips of material from the work. As these abrasive grains wear and become dull, the added resistance leads to fracture of the grains or weakening of their bond. The dull pieces break away, revealing sharp new grains that continue cutting. The requirements for efficient grinding include:

- abrasive components which are harder than the work
- shock- and heat-resistant abrasive wheels
- abrasives that are friable. That is, they are capable of controlled fracturing

Most abrasives used in industry are synthetic. Aluminum oxide is used in three quarters of all grinding operations, and is primarily used to grind ferrous metals. The next most common manufactured abrasive is ceramic, which is used for grinding hard brittle metals. Ceramic abrasive grains are commonly mixed with aluminum oxide in the manufacture of the wheel to produce better grinding characteristics. Silicon carbide is next, it is used for grinding softer, non-ferrous metals and high density materials, such as cemented carbide or ceramics. Superabrasives, namely cubic boron nitride or ‘CBN’ and diamond, are used in about five percent of grinding. Hard ferrous materials are ground with ‘CBN’, while non-ferrous materials and non-metals are best ground with diamond.

The grain size of abrasive materials is important to the process. Large, coarse grains remove material faster, while smaller grains produce a finer finish.

The binders that hold these abrasive grains together include:

- vitrified bonds, a glass-like bond formed of fused clay or feldspar
- organic bonds, from synthetic resins, rubber, or shellac
- metal bond, using powder metallurgy or single-layer bond systems

Wheels are graded according their strength and wear resistance. A ‘hard’ wheel is one that resists the separation of its individual grains. One that is too hard will wear slowly and present dulled grains to the work and overheat, affecting the final finish. If too soft a wheel is used, it will deteriorate quickly, requiring frequent replacement.

Another aspect of grinding wheels is their pore structure or density, which refers to the porosity between individual grains. This pore structure creates spaces between the grains that provide coolant retention and areas for the chips to form. Dense wheels are best for harder materials, while more open densities are better for the softer metals.

The three factors of grain size, bond type, and pore structure are closely related, and together determine how well a wheel will perform.

Grinding Safety

Damaged wheels or even wheels suspected of being damaged should not be used. Safety steps for proper use of grinding wheels include, but are not limited to:

- always having machine guards in place before turning on a grinding wheel
- running wheels for at least one minute before actual work begins
- always using eye protection
- properly balancing and dressing wheels before use

Wheel dressing is done with special tools designed for that purpose. Although wheel dressing is often done manually between work cycles, some grinding machines perform the dressing task automatically.

The application of coolants to the grinding process is important. Coolants reduce grinding machine power requirements, maintain work quality, stabilize part dimensions, and insure longer wheel life. Coolants are either emulsions, synthetic lubricants or special grinding oils. Coolants are applied by either flooding the work area or by high pressure jet streams.

Precision Grinding Methods

There are many forms of grinding, but the three primary categories of precision grinding operations are:

- cylindrical grinding, both external and internal
- centerless grinding
- surface grinding

In cylindrical grinding, the workpiece rotates about a fixed axis and the surfaces machined are concentric to that axis of rotation. ‘OD’ or outside diameter cylindrical grinding produces an external surface that may be either straight, tapered, or contoured. The basic components of a cylindrical grinder include a wheelhead, which incorporate the spindle and drive motor; a cross-slide, that moves the wheelhead to and from the workpiece; a headstock, which locates, holds, and drives the workpiece; and a tailstock, which holds the other end of the work.

Internal diameter or ‘ID’ cylindrical grinders finish the inside of a previously drilled, reamed, or bored hole, using small grinding wheels run at high RPM. The principle elements of a internal grinding machine are the workhead, which holds the work and has its own drive; and the wheelhead, which is the internal grinding spindle. In addition to the rotary motions of work and wheel, an internal grinder has a traverse movement to bring the wheel to and from the work zone, and a reciprocating spindle movement for both the wheel's approach to the work surface and for the feed movement of the wheel during grinding. Several different internal contours can be produced within a workpiece using ‘ID’ grinding.

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In centerless grinding, the workpiece rotates between a grinding wheel and a regulating wheel. The regulating wheel is slower than the grinding wheel, and causes the workpiece to rotate at a desired peripheral speed for grinding. As the gap between the two wheels is reduced, the diameter of the rotating workpiece is ground to a uniform outside diameter. The change in the workpiece diameter is equal to the distance by which one of the wheels is advanced. The work is supported from below by a fixed work-rest blade.

The two basic modes of centerless grinding are ‘thru-feed’ and ‘infeed’ or ‘plunge’ mode. In the thru-feed mode, the work proceeds in the axial direction through the slowly narrowing gap between the grinding wheel and the regulating wheel. Work is advanced by the axial force exerted on it by the rotating surface of the regulating wheel. This is a highly productive form of grinding in that a number of workpieces can be ground simultaneously and in a continuous stream. The ‘infeed’ mode is used for work with projecting heads that would prohibit ‘thru-feeding’, the work is placed on the work-rest blade while one wheel is retracted and fed to an end stop. The wheel is then brought back, reducing the gap between the wheels, grinding the work.

Surface grinding produces flat, angular, or contoured surfaces by feeding the workpiece in a horizontal plane beneath a rotating wheel. Work is most often magnetically attached to the table, and a flat surface may be ground by either a traversing movement of the table using the periphery of a grinding wheel, or by a rotating movement of the workpiece or workpieces using the grinding wheel face.

Workpiece surfaces produced by grinding are influenced by the following factors:

- workpiece material - harder materials allow finer finishes
- type of wheel - fine grains yield finer finishes
- wheel condition - clogged wheels cannot produce a good finish
- dressing procedure - improperly dressed wheels will mar the work surface
- feed rate - finer finishes are obtained with slower feed rates
- machine rigidity - a machine in poor condition is prone to produce chatter and poor quality parts.
- lubricant cleanliness - coolant filtration removes waste that could damage workpiece surface

Surface integrity is the condition of the surface below the apparently smooth finish. Micro-cracking, microstructural changes, or other damage, typically due to excess heat or excess force in the process, may be hidden under a clean, smooth-looking surface. Careful finish grinding can sometimes remove damage to surface integrity created by too-vigorous rough grinding.

Grinding

Review Questions

1. Friable means:
   a. capable of resisting heat buildup
   b. extremely porous
   c. capable of controlled fracturing
   d. tendency to clog wheel

2. The most commonly used grinding abrasive is:
   a. ceramic
   b. aluminum oxide
   c. diamond
   d. silicon carbide

3. Coolant retention is affected by the grinding wheel's:
   a. hardness
   b. bond type
   c. grain size
   d. porosity

4. 'OD' cylindrical grinding finishes:
   a. internal diameter surfaces
   b. horizontal surfaces
   c. external surfaces
   d. protruding surfaces

5. Internal grinding requires the grinding wheel to move:
   a. vertically up and down
   b. transversely
   c. longitudinally
   d. transversely and reciprocally

6. Workpiece movement in centerless grinding is accomplished using:
   a. a conveyor system
   b. air or hydraulic pressure
   c. the rotating regulating wheel
   d. the rotating grinding wheel

7. Most surface grinding machines have spindles that are:
   a. vertical
   b. horizontal
   c. stationary
   d. orbiting

8. The most important aspect of grinding coolant is:
   a. cleanliness through filtration
   b. temperature control
   c. high pressure application
   d. compatibility with work material

Grinding

Answer Key

1. c
2. b
3. d
4. c
5. d
6. c
7. b
8. a

Grinding

Grinding Glossary

abrasive	Natural (sandstone, emery, corundum, diamonds) or artificial (silicon carbide, aluminum oxide) material used for making grinding wheels, sandpaper, abrasive cloth, and lapping compounds.
abrasive cutoff	A process related to grinding, which uses a thin, bonded abrasive wheel to cut materials for further processing.
abrasive disc	Disc wheel. A grinding wheel shaped like a straight wheel, but usually mounted on a plate for grinding on the side of the wheel.
abrasive finishing	Any of several processes for removing scale and other surface contaminants using bonded grinding wheels, coated abrasives, honing stones or bonded abrasive sticks. Abrasive finishing leaves a surface with a controlled pattern of fine scratches- usually exhibiting a specific lay characteristic of the abrasive grit size and form, and type of equipment used.
abrasive flow machining	A process for finishing holes, inaccessible areas or restricted passages by clamping the part in a fixture, then extruding semisolid abrasive media through the passage. Often, multiple parts are loaded into a single fixture and finished simultaneously.
abrasive wheels	Wheels of a hard abrasive, such as Carborundum, used for grinding.
abrasive-wire bandsawing	A variation of bandsawing that uses a small-diameter wire with diamond, cubic boron nitride or aluminum oxide abrasives bonded to the surface as the cutting blade. Abrasive-wire bandsawing is an alternative to electrical discharge machining for producing dies, stripper plates, electrodes and cams from difficult-to-machine conductive and nonconductive materials.
arbor	The spindle of a grinding machine on which the wheel is mounted.
arc of contact	The portion of the circumference of a grinding wheel in contact with the work.
back-off stop	An adjustable stop that determines the amount of wheel withdrawal for dressing. Also called back-off stop.

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Balance (dynamic)	A wheel in static balance is also in dynamic balance if, upon rotating, there is no vibration or whip due to unequal distribution of weight throughout its mass.
balance (static)	A grinding wheel is in static balance when, centered on a frictionless horizontal arbor, it remains at rest in any position.
bench grinder	A small grinding machine for shaping and sharpening the cutting edges of tools.
blotter	A pliable, compressible paper disc used between a grinding wheel and its mounting flanges.
bond	The material which cements the grains together making up the wheel. Bond may be rubber, shellac, resin, silicate, vitreous material, or metal, depending upon the abrasive material.
burn	Visible discoloration or subsurface damage from excessively high temperature produced by grinding.
carborundum	A trade name for an abrasive compounded of silicon and carbon (silicon carbide).
centerless grinding	Grinding in which the workpiece is supported on its OD and rotated around an axis created by this reference surface. The workpiece is free to shift, and if the support surface is the one being ground, the axis of rotation also shifts.
center-type grinding	Grinding by rotating the workpiece around a fixed centerline established by the chuck or centers in which it is held.
compensator	The device that advances (crossfeeds) the grinding wheel to compensate for wear and dressing.
coping	Shaping stone or other hard nonmetallic material with a grinding wheel.
corner wear	The tendency of a grinding wheel to wear on its corner so that it does not grind up to a shoulder without leaving a fillet.
corundum	A natural abrasive of the aluminum oxide type.
creep-feed grinding	A technique of plunge grinding with special design in which the table speeds are kept very low and the wheel is fed down to full depth of cut in one or two passes.

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critical speed	1. That rotating speed beyond which the vibration of a spindle carrying an abrasive wheel or point would be hazardous. 2. A characteristic speed such that the predominant response of the system or rotor occurs at a resonance.
crossfeed (grinding)	In surface grinding, the amount of horizontal feed of the wheel across the table, or of the table across the wheel.
crush dressing	The process of using rolls or special forms to form or dress the face of a grinding wheel to a specific contour.
cubic boron nitride (CBN)	A form of boron nitride (BN), is a superabrasive crystal, second in hardness and abrasion resistance only to diamond. It is produced by a high-pressure/high-temperature process similar to that used to make synthetic diamonds. CBN crystals are used most commonly in superabrasive wheels for precision grinding of steels and superalloys. The crystals are also compacted to produce polycrystalline cutting tools.
cup wheel	A grinding wheel shaped like a cup or bowl.
cutoff wheel	A thin abrasive wheel used to cut off or slot any material or part; usually made with an organic bond.
cutter sweep	The section removed by the milling cutter or grinding wheel in entering or leaving a flute.
cutting fluid	1. A substance, generally liquid, used to enhance workpiece characteristics and reduce costs in a metalcutting operation. Cutting fluids may be oil-based fluids, water-oil emulsions, or chemicals in water solution. 2. Fluid used during grinding or dressing to cool, lubricate, and clean the work, wheel, and diamond. Sometimes called grinding fluid.
cylindrical grinding	Grinding the outer surface of a part that rotates on centers or in a chuck.
DAF (dressing after finishing)	Cycle in which dressing comes after finish grinding.
DBF (dressing before finishing)	Cycle in which dressing is done before finish grinding.
disc grinder	A machine on which abrasive discs are used.

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disc wheel	A grinding wheel shaped like a straight wheel, but usually mounted on a plate for grinding on the side of the wheel. Also referred to as abrasive disc.
dish wheel	A grinding wheel shaped like a dish.
downfeed	In surface grinding, the rate at which the grinding wheel is fed into the work.
dress lead	The distance between successive diamond cuts for each revolution of the wheel; usually given in thousandths of an inch or millimeters.
dress pass	One dressing traverse of the diamond across the wheel.
dress rate	Time it takes to dress the length of the wheel.
dress stop	An adjustable stop that determines the amount of wheel withdrawal for dressing. Also called back-off stop.
dresser	Device for manually or automatically dressing or trueing the grinding wheel. Also referred to as wheel dresser.
dresser arm	Arm that carries the diamond holder.
dresser stop	Stop pads or stop screws on the dresser to limit its travel relative to the wheel.
dressing	Resharpening and renewing the cutting face of the wheel by removing or severing dull grains with a diamond or other type of dressing tool. Also referred to as trueing.
dressing after finish (DAF)	Cycle in which dressing comes after finish grinding.
dressing before finish (DBF)	Cycle in which dressing is done before finish grinding.
driver	In shoe centerless grinding, usually a flat plate attached to the work spindle and against which the part is held. It drives, but does not actually support the workpiece.
driver contact	Area in which driver and work touch each other.
edging	A method for deburring or chamfering sheet stock, tubing or rod ends, or workpiece edges by passing the stock across small grinding wheels or rotating angled cutters, or between pinch rolls.

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EDM grinding	This is done with an EDM power supply connected to a machine that resembles a surface grinder, but uses a wheel made from electrode material, usually graphite.
electrical discharge grinding (EDG)	A process similar to electrical discharge machining except that the electrode is a rotating wheel, generally graphite but sometimes brass.
electrochemical discharge grinding (ECDG)	A nontraditional machining process in which a-c or pulsating d-c current is passed from a conductive grinding wheel made of bonded graphite to a positively charged workpiece through an electrolyte. There is no mechanical contact between wheel and workpiece. Rather, workpiece material is removed by the action of electrochemical grinding, and oxides formed by the electrochemical action are removed by intermittent random-spark discharges as in electrical discharge grinding.
electrochemical grinding (ECG)	A special form of electrochemical machining that uses the combined actions of electrochemical attack and abrasion to rapidly remove material; only 2 to 5% is done by the grinding wheel.
electrochemical honing (ECH)	A process similar to electrochemical grinding in which nonconductive honing stones rather than a grinding wheel provide the abrasive action. Electrochemical action removes about 90% of the workpiece metal; the honing stones cut most aggressively on high or tight areas to maintain size and surface finish.
emery	A natural abrasive of the aluminum oxide type.
extreme pressure (EP) lubricant	A compound (usually containing chlorine, sulfur, or phosphorus) which reacts with the surface of the metal or tool to form compounds (chlorides, sulfides, or phosphates) which have a low shear strength. These compounds can help provide longer tool and grinding wheel life in the moderate to heavy-duty operations.
feed lines	An objectionable spiral pattern produced on the work during grinding.
feed reversal	A slow feed of the wheel away from the work. Used to improve the finish.
feed, down	In surface grinding, the rate at which the grinding wheel is fed into the work.

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feed, index	In cylindrical grinding. an arrangement by which the amount of infeed is indicated on a dial. On most machines, the reference is to the diameter of the work; on a few machines, the reference is to the radius.
finish grind stop	Stop which limits crossfeed of wheel into work.
finishing	The final cuts taken with a grinding wheel to obtain the accuracy and surface finish desired.
flanges	The circular metal plates which retain and drive a grinding wheel.
friability	The tendency of abrasive grains to shatter under pressure.
glazed wheel	A wheel with a cutting surface too smooth (or dull) to grind efficiently. Glazing is caused by worn or improperly dressed grains.
grade	The strength of bonding of a grinding wheel; sometimes referred to as hardness.
grain	The tiny particles of abrasive which, with the bond, make up the wheel. Grains do the actual cutting. Also referred to as grit.
grain spacing	The relative density of the abrasive particles in a grinding wheel. Usually referred to as structure and designated by a numeral in the wheel marking.
G-ratio	A measure of grinding performance defined as the volume of metal removed divided by the volume of grinding wheel worn away in the process.
grinding	Removing material from a workpiece with a grinding wheel or coated abrasives.
grinding fluid	Cutting fluid used in a grinding operation to cool, lubricate and clean the work and grinding wheel.
hard-acting wheel	Grinding wheel that retains its dull abrasive grains or is less friable.
index feed	In cylindrical grinding. an arrangement by which the amount of infeed is indicated on a dial. On most machines, the reference is to the diameter of the work; on a few machines, the reference is to the radius.
inserted nut	Designating disc, segmental, or cylindrical wheels with nuts embedded in the back to facilitate mounting on the grinding machine.

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internal grinding	Grinding the surface of a hole in the workpiece.
loading	A condition caused by grinding the wrong material with a grinding wheel or using too heavy a grinding action.
magnetic chuck	A flat, smooth-surfaced work holding device which operates by magnetism to hold ferrous metal workpieces for grinding.
metal bond	Metal bond is used for diamond abrasives commonly used in the grinding of ceramics. There is also a trend to use metal-bonded wheels in the grinding of carbide with a technique known as single-pass, heavy-infeed grinding. Metal bonds are also used with aluminum oxide or diamond abrasive to provide conductive wheels for electrolytic grinding.
necking	Machining a groove or undercut in a shaft to permit mating parts to be screwed tightly against a shoulder or to provide clearance for the edge of a grinding wheel.
pawl	A pivoted lever or sliding bolt that secures an automatic directional table control on a grinder.
resinoid bond	This is a synthetic-resin, organic bond mixed in powdered or liquid form with the abrasive grains. Resinoid-bonded wheels generally find their use in rough grinding and cutoff operations. They are also used in generating very fine finishes in roll grinding. Resin bonds are likely to be softened by prolonged exposure to water or water-based grinding fluids.
rubber bond	Rubber-bond wheels are widely used in cutoff, centerless grinding, and polishing of drill flutes.
shellac bond	Shellac is another organic bond used for wheels to produce high finishes on rolls, and for cutlery grinding.
silicate bond	This bond is used to a very limited extent, primarily in operations in which the heat generated by grinding must be kept to a minimum, as in grinding edged tools.
specific metal removal rate (q')	The volume of metal removed per unit of time per unit of effective grinding wheel width.
surface grinding	The process of grinding flat surfaces on a surface grinding machine. With special setups, angular and form surfaces may also be ground.

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swarf	Metal fines and grinding wheel particles generated during grinding.
trueing (truing)	The act of centering or aligning a workpiece or cutting tool so that an operation may be performed accurately. Also, correcting the eccentricity or out of round condition when dressing a grinding wheel.
universal grinder	A versatile grinding machine designed to perform both internal and external grinding operations, including straight and tapered surfaces on tools and cutters.
vitrified bond	The chief ingredients of vitrified, or ceramic, bonds are clay and flux. The majority of grinding wheels in use today are vitrified wheels. They are strong and rigid and retain high strength at elevated temperatures, with the capability to remove stock, generate accurate geometry, and produce smooth finishes. Vitrified bonds are practically unaffected by water, oils, or ordinary temperature conditions. Poor shock resistance, however, inhibits their application when mechanical impact or large temperature differentials are likely to occur.
wheel bonds (grinding)	The purpose of the bond is to hold the abrasive grains together to form a grinding wheel. Ideally, as the abrasive grains become dull and used, the bonding material breaks away, thus permitting the dull grains either to fracture or to be torn out so that, at all times, new, sharp abrasive grains are available for grinding the workpiece. Standard grinding-wheel bonds are vitrified bond, silicate, resinoid, rubber, shellac, oxychloride, and metal.
wheel dresser	A tool or device for dressing or trueing a grinding wheel.