Abrasive machining uses tools that are made of tiny, hard particles of crystalline materials.

Abrasive particles have irregular shape and sharp edges. The workpiece surface is machined by removing very tiny amounts of material at random points where a particle contacts it.

By using a large number of particles, the effect is averaged over the entire surface, resulting in very good surface finish and excellent dimension control, even for hard, brittle workpieces.

Abrasive machining is also used to machine brittle materials. Such materials cannot be machined easily by conventional cutting processes since they would fracture and crack in random fashion.
The main uses of grinding and abrasive machining

1. To improve the surface finish of a part manufactured by other processes.

Examples:

(a) A steel injection molding die is machined by milling. The surface finish must be improved for better plastic flow, either by manual grinding using shaped grinding tools, or by electro-grinding.

(b) The internal surface of the cylinders of a car engine are turned on a lathe. The surface is then made smooth by grinding, followed by honing and lapping to get an extremely good, mirror-like finish.

(c) Sand-paper is used to smooth a rough cut piece of wood.

2. To improve the dimensional tolerance of a part manufactured by other processes

Examples:

(a) Ball-bearings are formed into initial round shape by a forging process; this is followed by a grinding process in a specially formed grinding die to get extremely good diameter control ($\leq 15\mu m$).

(b) Knives are made from forged steel; the steel is then hardened; finally, a grinding operation is used to give a sharp cutting edge.
The main uses of grinding and abrasive machining

3. To remove unwanted materials of a cutting process

*Examples:*

(a) Drilling and milling often leave tiny, sharp chips along the outer edges of the surface created by the tool – these are called burrs. Tapered grinding wheels are used to remove the burr (the process is called deburring).

The main uses of grinding and abrasive machining

4. To cut hard brittle materials

*Examples:*

(a) Most semiconductor IC chips are made from silicon; the starting point is a long bar of a crystal of silicon (the diameter is usually 8cm, 15cm or 30cm, and length up to 200 cm). This rod must by sliced into thin circular slices; each slice is used to make a large number of ICs. A diamond abrasive wheel is used to cut the rod into slices.
Common abrasive materials are **Aluminum Oxide** and **Silicon Carbide**. For harder materials and high precision applications, superabrasives (Cubic Boron Nitride and diamond powder), which are extremely hard materials, are used.

Abrasive materials have **two properties**: **high hardness, and high friability**. Friability means that the abrasive particles are brittle, and fracture after some amount of use, creating new sharp edges that will again perform more abrasion.

Several types of abrasive tools. They all contain abrasive grains that are glued together using resin or hardened rubber. Sometimes, the abrasive particles may be embedded in metal or ceramic.
**A Abrasive Tools**

It is important for the bonding material to be softer than the abrasive. Also, the bonding material is selected to release the abrasive particles and wear away after some amount of use – this keeps exposing fresh abrasive particles to the workpiece continuously.

The mean size of abrasive particle used in each tool determines the rate at which it will cut, and the quality of surface finish it will provide. **Low material removal rate leads to better surface, which is achieved by using very fine grains.** Grain size is expressed using numbers, small numbers like 10 mean large grains, and large numbers, e.g. 100 mean fine grain. You can see this in the grades of sand-paper.

**Physical Model of a Grinding Wheel**

Schematic illustration of a physical model of a grinding wheel, showing its structure and wear and fracture patterns.
Some common types of grinding wheels made with conventional abrasives. Note that each wheel has a specific grinding face. Grinding on other surfaces is improper and unsafe.

Variables in surface grinding. In actual grinding, the wheel depth of cut $d$, and contact length, $l$, are much smaller than the wheel diameter, $D$. The dimension $t$ is called the grain depth of cut.
There are several types of grinding machines. The main ones are surface or flat grinders, grinding wheels, cylindrical grinders and centerless grinders. The figure below shows examples of a few of these.

Surface or flat grinders produce flat surfaces. The part is held on the flat table (steel parts can be held by a magnetic force – this is called magnetic chucking). The table moves in a reciprocating motion (±X-axis), and the rotating wheel is lowered (Z-axis) so that it just scrapes along the surface. After each reciprocating cycle, the part is fed by a small amount along the Y-axis.
Schematic illustration of a horizontal-spindle surface grinder. The majority of grinding operations are done on such machines.
Schematic illustration of surface-grinding operations:

- (a) Traverse grinding with a horizontal-spindle surface grinder.
- (b) Plunge grinding with a horizontal-spindle surface grinder, producing a groove in the workpiece.
- (c) Vertical-spindle rotary-table grinder
To improve dimension control on cylindrical parts, centerless grinders, which use long cylindrical wheels, are employed. The axis of the regulating wheel and grinding wheel are slightly misaligned, causing the part to travel slowly in the axial direction, and after some time, the part automatically moves beyond the length of the wheel. Controlling the angle of misalignment can control the time that the part is subjected to grinding.
- Schematic illustration of centerless-grinding operations.

Rounded external grinding machine
Rounded external grinding machining

Grinding Operations for various workpiece geometries

(a) cylindrical surfaces, (b) conical surfaces, (c) fillets on a shaft, (d) helical profiles, (e) concave shape, (f) cutting off or slotting with thin wheels, and (g) internal grinding.
**Honing**

Honing is a finishing operation used to improve the form tolerance of an internal cylindrical surface – in particular, it is used to improve the cylindricity. The honing tool is a metal bar holding a set of grinding stones arranged in a circular pattern. The tool brushes along the cylindrical part surface by rotating, and moving up-and-down along its axis. You can identify a honed surface by looking for the helical cross-hatched scratch marks on the part surface.

**Honing Tool**

- Schematic illustration of a honing tool to improve the surface finish of bored or ground holes.
Honing machining

Schematic illustration of the superfinishing process for a cylindrical part: (a) cylindrical microhoning; (b) centerless microhoning.
Lapping is a finishing operation. The lapping tool is made of metal, leather, or cloth, impregnated with very fine abrasive particles. For preparing the surface of silicon wafers, lapping operations use a flat metal disc that rotates a small distance above the part. The gap is filled with a slurry containing fine abrasive grains. The rotation of the disc causes the slurry to flow relative to the part surface, resulting in very fine surface finish. This process gives dimensional tolerances of $\geq 0.5\mu m$, and surface finish of up to $0.1 \mu m$.

- (a) Schematic illustration of the lapping process.
- (b) Production lapping on flat surfaces.
- (c) Production lapping on cylindrical surfaces.