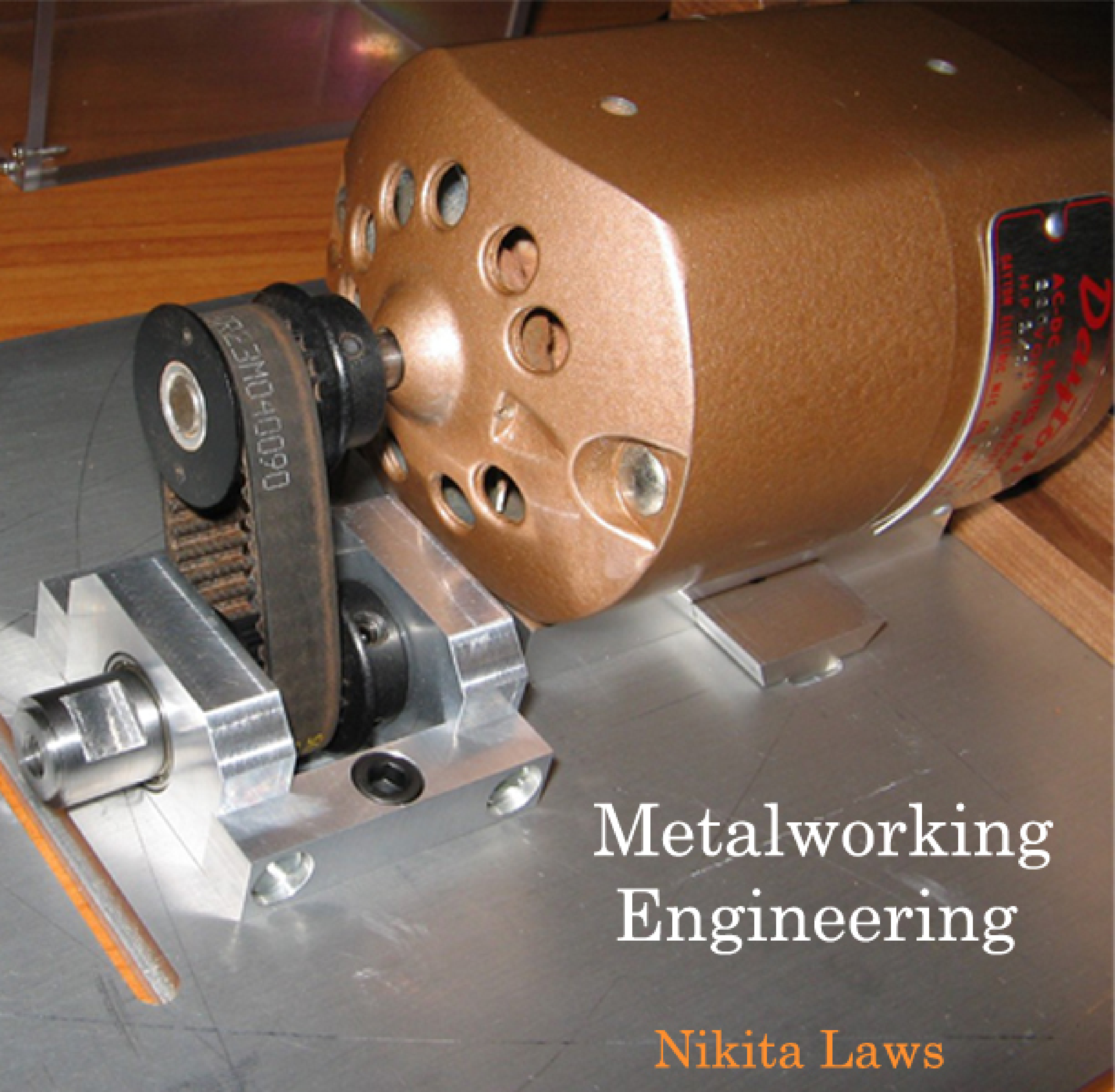

Metalworking Engineering

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First Edition, 2012

ISBN 978-81-323-3490-3

Published by:
Research World
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter-1

Metalworking

Machining a bar of metal on a lathe.

Metalworking is the process of working with metals to create individual parts, assemblies, or large scale structures. The term covers a wide range of work from large ships and bridges to precise engine parts and delicate jewelry. It therefore includes a correspondingly wide range of skills, processes, and tools.

Metalworking is a science, art, hobby, industry and trade. Its historical roots span cultures, civilizations, and millennia. Metalworking has evolved from the discovery of smelting various ores, producing malleable and ductile metal useful for tools and adornments. Modern metalworking processes, though diverse and specialized, can be categorized as forming, cutting or joining processes. Today's machine shop includes a number of machine tools capable of creating a precise, useful workpiece.

Prehistory

Metalworking predates history. No one knows with any certainty where or when metalworking began. The earliest technologies were impermanent and were unlikely to leave evidence for long. The advance that brought metal into focus was the connection of fire and metals. Who accomplished this is as unknown as the when and where, but the Egyptians are thought to have been one of the first civilizations to work gold.

Not all metal required fire to obtain it or work it. Isaac Asimov speculated that gold was the "first metal." His reasoning is that gold by its chemistry is found in nature as nuggets of pure gold. In other words, gold, as rare as it is, is always found in nature as the metal that it is. There are a few other metals that sometimes occur natively, and as a result of meteors. Almost all other metals are found in ores, a mineral bearing rock, that require heat or some other process to liberate the metal. Another feature of gold is that it is workable as it is found, meaning that no technology beyond eyes to find a nugget and a hammer and an anvil to work the metal is needed. Stone hammer and stone anvil will suffice for technology. This is the result of gold's properties of malleability and ductility. The earliest tools were stone, bone, wood, and sinew. They sufficed to work gold.

At some unknown point the connection between heat and the liberation of metals from rock became clear, rocks rich in copper, tin, and lead came into demand. These ores were mined wherever they were recognized. Remnants of such ancient mines have been found all over what is today the Middle East. Metalworking was being carried out by the South Asian inhabitants of Mehrgarh between 7000–3300 BCE. The end of the beginning of metalworking occurs sometime around 6000 BCE when copper smelting became common in the Middle East.

The ancients knew of seven metals. Here they are arranged in order of their oxidation potential:

- Iron +0.44,
- Tin +0.14
- Lead +0.13
- Copper -0.34
- Mercury -0.79
- Silver -0.80
- Gold -1.50

The oxidation potential is important because it is one indicator of how tightly bound to the ore the metal is likely to be. As can be seen, iron is significantly higher than the other six metals while gold is dramatically lower than the six above it. Gold's low oxidation is one of the main reasons that gold is found in nuggets. These nuggets are relatively pure gold and are workable as they are found.

Copper ore, being relatively abundant, and tin ore became the next important players in the story of metalworking. Using heat to smelt copper from ore, a great deal of copper was produced. It was used for both jewelry and simple tools. However, copper by itself was too soft for tools requiring edges and stiffness. At some point tin was added into the molten copper and bronze was born. Bronze is an alloy of copper and tin. Bronze was an important advance because it had the edge-durability and stiffness that pure copper lacked. Until the advent of iron, bronze was the most advanced metal for tools and weapons in common use.

Looking beyond the Middle East, these same advances and materials were being discovered and used the world around. China and Britain jumped into the use of bronze with little time being devoted to copper. Japan began the use of bronze and iron almost simultaneously. In the Americas things were different. Although the peoples of the Americas knew of metals, it wasn't until the arrival of Europeans that metal for tools and weapons took off. Jewelry and art were the principal uses of metals in the Americas prior to European influence.

Around the date 2700 BCE, production of bronze was common in locales where the necessary materials could be assembled for smelting, heating, and working the metal. Iron was beginning to be smelted. Iron began its emergence as an important metal for tools and weapons. The Iron Age was dawning.

History

A turret lathe operator machining parts for transport planes at the Consolidated Aircraft Corporation plant, Fort Worth, Texas, USA in the 1940s.

By the historical periods of the Pharaohs in Egypt, the Vedic Kings in India, the Tribes of Israel, and the Mayan Civilization in North America, among other ancient populations, precious metals began to have value attached to them. In some cases rules for ownership, distribution, and trade were created, enforced, and agreed upon by the respective peoples. By the above periods metalworkers were very skilled at creating objects of adornment, religious artifacts, and trade instruments of precious metals (non-ferrous), as well as weaponry usually of ferrous metals and/or alloys. These skills were finely honed and well executed. The techniques were practiced by artisans, blacksmiths, atharvavedic practitioners, alchemists, and other categories of metalworkers around the globe. For example, the ancient technique of granulation is found around the world in numerous ancient cultures before the historic record shows people traveled seas or overland to far regions of the earth to share this process that still being used by metalsmiths today.

As time progressed metal objects became more common, and ever more complex. The need to further acquire and work metals grew in importance. Skills related to extracting metal ores from the earth began to evolve, and metalsmiths became more knowledgeable.

Metalsmiths became important members of society. Fates and economies of entire civilizations were greatly affected by the availability of metals and metalsmiths. The metalworker depends on the extraction of precious metals to make jewelry, build more efficient electronics, and for industrial and technological applications from construction to shipping containers to rail, and air transport. Without metals, goods and services would cease to move around the globe on the scale we know today.

More individuals than ever before are learning metalworking as a creative outlet in the forms of jewelry making, hobby restoration of aircraft and cars, blacksmithing, tinsmithing, tinkering, and in other art and craft pursuits. Trade schools continue to teach welding in all of its forms, and there is a proliferation of schools of Lapidary and Jewelers arts and sciences at this- the beginning of the 21st Century AD.

General metalworking processes

A combination square used for transferring designs.

A caliper is used to precisely measure a short length.

Metalworking generally is divided into the following categories, *forming*, *cutting*, and, *joining*. Each of these categories contain various processes.

Compatibility chart of materials versus processes

	Material								
Process	**Iron**	**Steel**	**Aluminium**	**Copper**	**Magnesium**	**Nickel**	**Refractory metals**	**Titanium**	**Zinc**
Sand casting	X	X	X	X	X	X			0
Permanent mold casting	X	0	X	0	X	0			0
Die casting			X	0	X				X
Investment casting		X	X	X	0	0			
Closed-die forging		X	0	0	0	0	0	0	
Extrusion		0	X	X	X	0	0	0	
Cold heading		X	X	X		0			
Stamping		X	X	X	0	X		0	0

& deep drawing									
Screw machine	0	X	X	X	0	X	0	0	0
Powder metallurgy	X	X	0	X		0	X	0	
Key: **X** = Routinely performed, **0** = Performed with difficulty, caution, or some sacrifice, **blank** = Not recommended									

Prior to most operations, the metal must be marked out and/or measured, depending on the desired finished product.

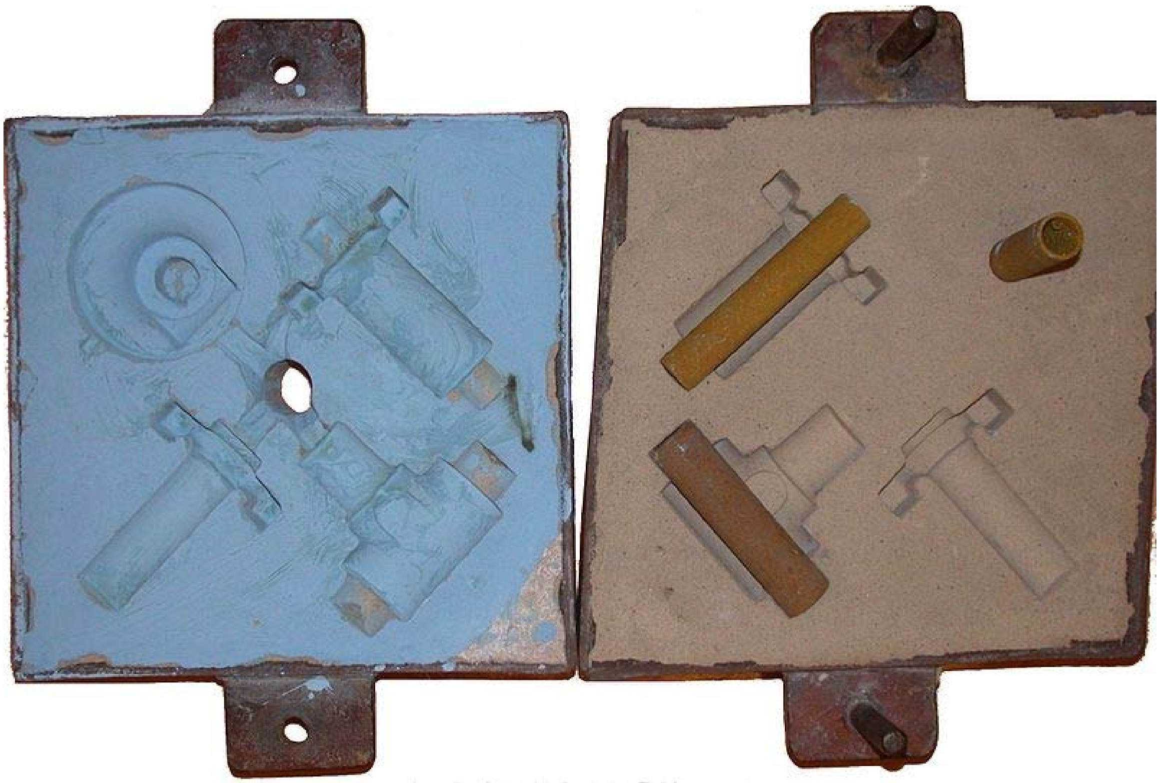
Marking out (also known as layout) is the process of transferring a design or pattern to a workpiece and is the first step in the handcraft of metalworking. It is performed in many industries or hobbies, although in the repetition industries the need to mark out every individual piece is eliminated. In the metal trades area, marking out consists of transferring the engineer's plan to the workpiece in preparation for the next step, machining or manufacture.

Calipers are hand tools designed to precisely measure the distance between two points. Most calipers have two sets of flat, perpendicular edges used for inner or outer diameter. These calipers can be accurate to within one-thousandth of an inch (25.4μm). Different types of calipers have different mechanisms for displaying the distance measured. Where larger objects need to be measured with less precision, a tape measure is often used.

Forming processes

These *forming* processes modify metal or workpiece by deforming the object, that is, without removing any material. Forming is done with heat and pressure, or with mechanical force, or both.

Casting



A sand casting mold

Casting achieves a specific form by pouring molten metal into a mold and allowing it to cool, with no mechanical force. Forms of casting include:

- Investment casting (called lost wax casting in art)
- Centrifugal casting
- Die casting
- Sand casting
- Shell casting
- Spin casting

Plastic deforming

A red-hot metal workpiece is inserted into a forging press.

Plastic deformation involves using heat or pressure to make a workpiece more conductive to mechanical force. Historically, this and casting were done by blacksmiths, though today the process has been industrialized.

- Cold sizing
- Extrusion
- Forging
- Hot metal gas forming
- Powder metallurgy

- Friction drilling

Sheet metal forming

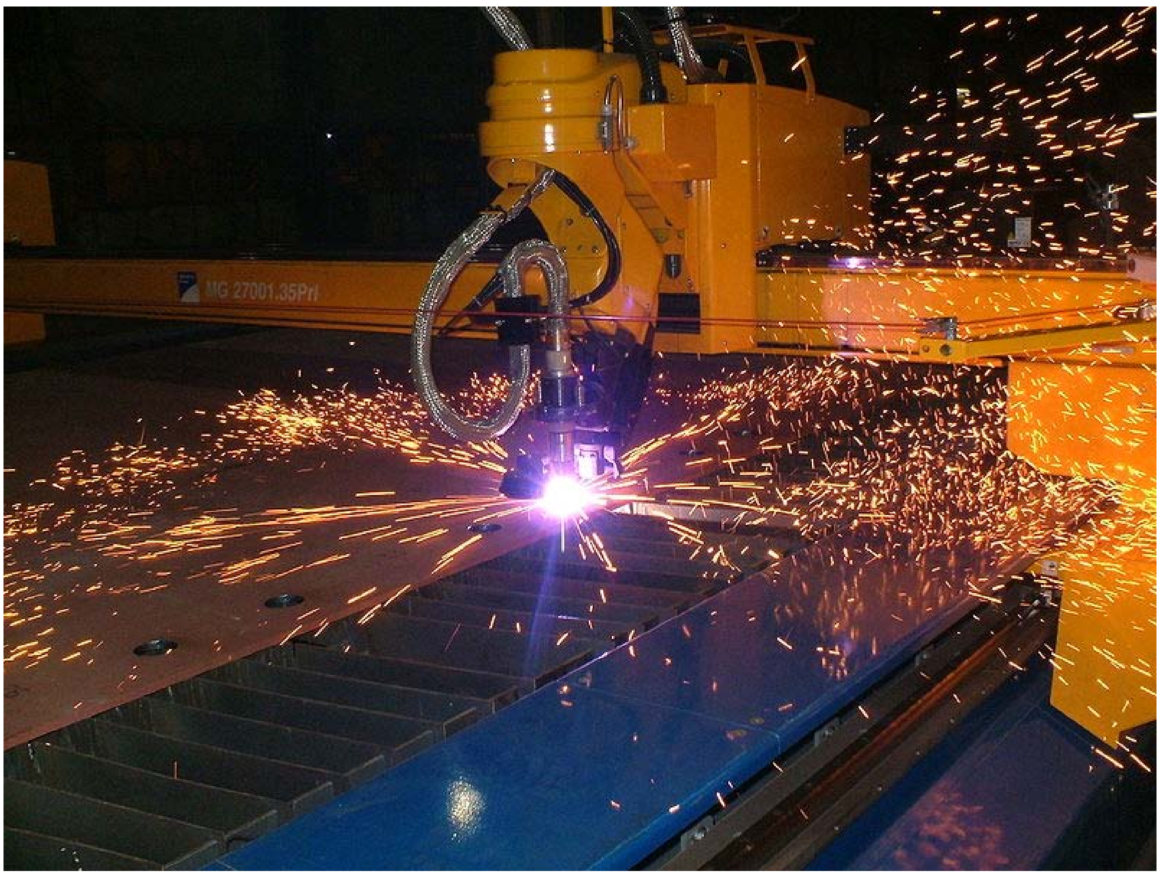
A metal spun brass vase

These types of forming process involve the application of mechanical force at room temperature.

- Bending
- Coining
- Decambering
- Deep drawing

- Drawing
- Spinning
- Flow turning
- Raising
- Roll forming
- Roll bending
- Repoussé and chasing
- Rolling
- Rubber pad forming
- Shearing
- Stamping
- Wheeling using an English wheel (wheeling machine)

Cutting processes



A CNC plasma cutting machining

Cutting is a collection of processes wherein material is brought to a specified geometry by removing excess material using various kinds of tooling to leave a finished part that meets specifications. The net result of cutting is two products, the waste or excess material, and the finished part. If this were a discussion of woodworking, the waste would be sawdust and excess wood. In cutting metals the waste is chips or swarf and excess metal. These processes can be divided into chip producing cutting, generally known as machining. Burning or cutting with an oxyfuel torch is a welding process not machining. There are also miscellaneous specialty processes such as chemical milling.

Cutting is nearly fully represented by:

- Chip producing processes most commonly known as machining
- Burning, a set of processes which cut by oxidizing a kerf to separate pieces of metal
- Specialty processes

Drilling a hole in a metal part is the most common example of a chip producing process. Using an oxy-fuel cutting torch to separate a plate of steel into smaller pieces is an example of burning. Chemical milling is an example of a specialty process that removes excess material by the use of etching chemicals and masking chemicals.

There are many technologies available to cut metal, including:

- Manual technologies: saw, chisel, shear or snips
- Machine technologies: turning, milling, drilling, grinding, sawing
- Welding/burning technologies: burning by laser, oxy-fuel burning, and plasma
- Erosion technologies:by water jet or electric discharge.

Cutting fluid or coolant is used where there is significant friction and heat at the cutting interface between a cutter such as a drill or an end mill and the workpiece. Coolant is generally introduced by a spray across the face of the tool and workpiece to decrease friction and temperature at the cutting tool/workpiece interface to prevent excessive tool wear. In practice there are many methods of delivering coolant.

Machining

A milling machine in operation, including coolant hoses.

Milling is the complex shaping of metal or other materials by removing material to form the final shape. It is generally done on a milling machine, a power-driven machine that in its basic form consists of a milling cutter that rotates about the spindle axis (like a drill), and a worktable that can move in multiple directions (usually two dimensions [x and y axis] relative to the workpiece). The spindle usually moves in the z axis. It is possible to raise the table (where the workpiece rests). Milling machines may be operated manually or under computer numerical control (CNC), and can perform a vast number of complex operations, such as slot cutting, planing, drilling and threading, rabbeting, routing, etc. Two common types of mills are the horizontal mill and vertical mill.

The pieces produced are usually complex 3D objects that are converted into x, y, and z coordinates that are then fed into the CNC machine and allow it to complete the tasks required. The milling machine can produce most parts in 3D, but some require the objects to be rotated around the x, y, or z coordinate axis (depending on the need). Tolerances are usually in the thousandths of an inch (Unit known as Thou), depending on the specific machine.

In order to keep both the bit and material cool, a high temperature coolant is used. In most cases the coolant is sprayed from a hose directly onto the bit and material. This coolant can either be machine or user controlled, depending on the machine.

Materials that can be milled range from aluminum to stainless steel and most everything in between. Each material requires a different speed on the milling tool and varies in the amount of material that can be removed in one pass of the tool. Harder materials are usually milled at slower speeds with small amounts of material removed. Softer materials vary, but usually are milled with a high bit speed.

The use of a milling machine adds costs that are factored into the manufacturing process. Each time the machine is used coolant is also used, which must be periodically added in order to prevent breaking bits. A milling bit must also be changed as needed in order to prevent damage to the material. Time is the biggest factor for costs. Complex parts can require hours to complete, while very simple parts take only minutes. This in turn varies the production time as well, as each part will require different amounts of time.

Safety is key with these machines. The bits are traveling at high speeds and removing pieces of usually scalding hot metal. The advantage of having a CNC milling machine is that it protects the machine operator.

Turning

A lathe cutting material from a workpiece.

Turning is a metal cutting process for producing a cylindrical surface with a single point tool. The workpiece is rotated on a spindle and the cutting tool is fed into it radially, axially or both. Producing surfaces perpendicular to the workpiece axis is called facing. Producing surfaces using both radial and axial feeds is called profiling.

A *lathe* is a machine tool which spins a block or cylinder of material so that when abrasive, cutting, or deformation tools are applied to the workpiece, it can be shaped to produce an object which has rotational symmetry about an axis of rotation. Examples of objects that can be produced on a lathe include candlestick holders, table legs, bowls, baseball bats, crankshafts, camshafts, and bearing mounts.

Lathes have three main components: the headstock, the carriage, and the tailstock. The headstock's spindle secures the workpiece with a chuck, whose jaws (usually three or four) are tightened around the piece. The spindle rotates at high speed, providing the energy to cut the material. While historic lathes were powered by belts from the ceiling, modern examples uses electric motors. The workpiece extends out of the spindle along the axis of rotation above the flat bed. The carriage is a platform that can be moved, precisely and independently, horizontally parallel and perpendicular to the axis of rotation. A hardened cutting tool is held at the desired height (usually the middle of the workpiece) by the toolpost. The carriage is then moved around the rotating workpiece, and the cutting tool gradually shaves material from the workpiece. The tailstock can be slid along the axis of rotation and then locked in place as necessary. It may hold centers to further secure the workpiece, or cutting tools driven into the end of the workpiece.

Other operation that can be performed with a single point tool on a lathe are:

Chamfering: Cutting an angle on the comer of a cylinder.
Parting: The tool is fed radially into the workpiece to cut off the end of a part.
Threading: A tool is fed along and across the outside or inside surface of rotating parts to produce external or internal threads.
Boring: A single-point tool is fed linearly and parallel to the axis of rotation.
Drilling: Feeding the drill into the workpiece axially.
Knurling: Produces a regular cross-hatched pattern in work surfaces intended to be gripped by hand.

Modern computer numerical control (CNC) lathes and (CNC) machining centres can do secondary operations like milling by using driven tools. When driven tools are used the work piece stops rotating and the driven tool executes the machining operation with a rotating cutting tool. The CNC machines use x, y, and z coordinates in order to control the turning tools and produce the product. Most modern day CNC lathes are able to produce most turned objects in 3D.

Materials appropriate for turning used are softer metals, although harder metals can be turned with a bit more time and effort.

The turning tool material must be harder than the material being turned in order for the process to work. Production rates for this process depend on the object being turned and the speed at which it can be done. More complex materials, therefore, will take more time.

Threading

Three different types and sizes of taps.

There are many threading processes including: cutting threads with a tap or die, thread milling, single-point thread cutting, thread rolling and forming, and thread grinding. A *tap* is used to cut a female thread on the inside surface of a pre-drilled hole, while a *die* cuts a male thread on a preformed cylindrical rod.

Grinding

A surface grinder

Grinding uses an abrasive process to remove material from the workpiece. A **grinding machine** is a machine tool used for producing very fine finishes, making very light cuts, or high precision forms using a abrasive wheel as the cutting device. This wheel can be made up of various sizes and types of stones, diamonds or inorganic materials.

The simplest grinder is a bench grinder or a hand-held angle grinder, for deburring parts or cutting metal with a zip-disc.

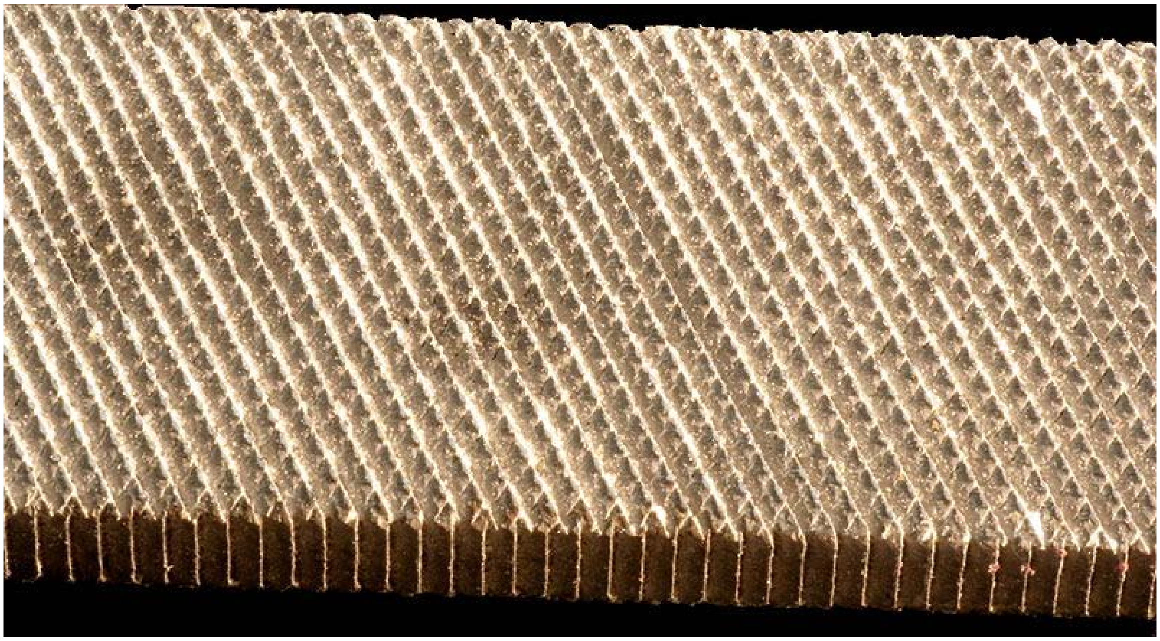
Grinders have increased in size and complexity with advances in time and technology. From the old days of a manual toolroom grinder sharpening endmills for a production shop, to today's 30000 RPM CNC auto-loading manufacturing cell producing jet turbines, grinding processes vary greatly.

Grinders need to be very rigid machines to produce the required finish. Some grinders are even used to produce glass scales for positioning CNC machine axis. The common rule is the machines used to produce scales be 10 times more accurate than the machines the parts are produced for.

In the past grinders were used for finishing operations only because of limitations of tooling. Modern grinding wheel materials and the use of industrial diamonds or other man-made coatings (cubic boron nitride) on wheel forms have allowed grinders to achieve excellent results in production environments instead of being relegated to the back of the shop.

Modern technology has advanced grinding operations to include CNC controls, high material removal rates with high precision, lending itself well to aerospace applications and high volume production runs of precision components.

Filing



A file is an abrasive surface like this one that allows machinists to remove small, imprecise amounts of metal.

Filing is combination of grinding and saw tooth cutting using a file. Prior to the development of modern machining equipment it provided a relatively accurate means for the production of small parts, especially those with flat surfaces. The skilled use of a file allowed a machinist to work to fine tolerances and was the hallmark of the craft. Today filing is rarely used as a production technique in industry, though it remains as a common method of deburring.

Other

Broaching is a machining operation used to cut keyways into shafts. Electron beam machining (EBM) is a machining process where high-velocity electrons are directed toward a work piece, creating heat and vaporizing the material. Ultrasonic machining uses ultrasonic vibrations to machine very hard or brittle materials.

Joining processes

Mig welding

Welding

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the workpieces and adding a filler material to form a pool of molten material that cools to become a strong joint, but sometimes pressure is used in conjunction with heat, or by itself, to produce the weld.

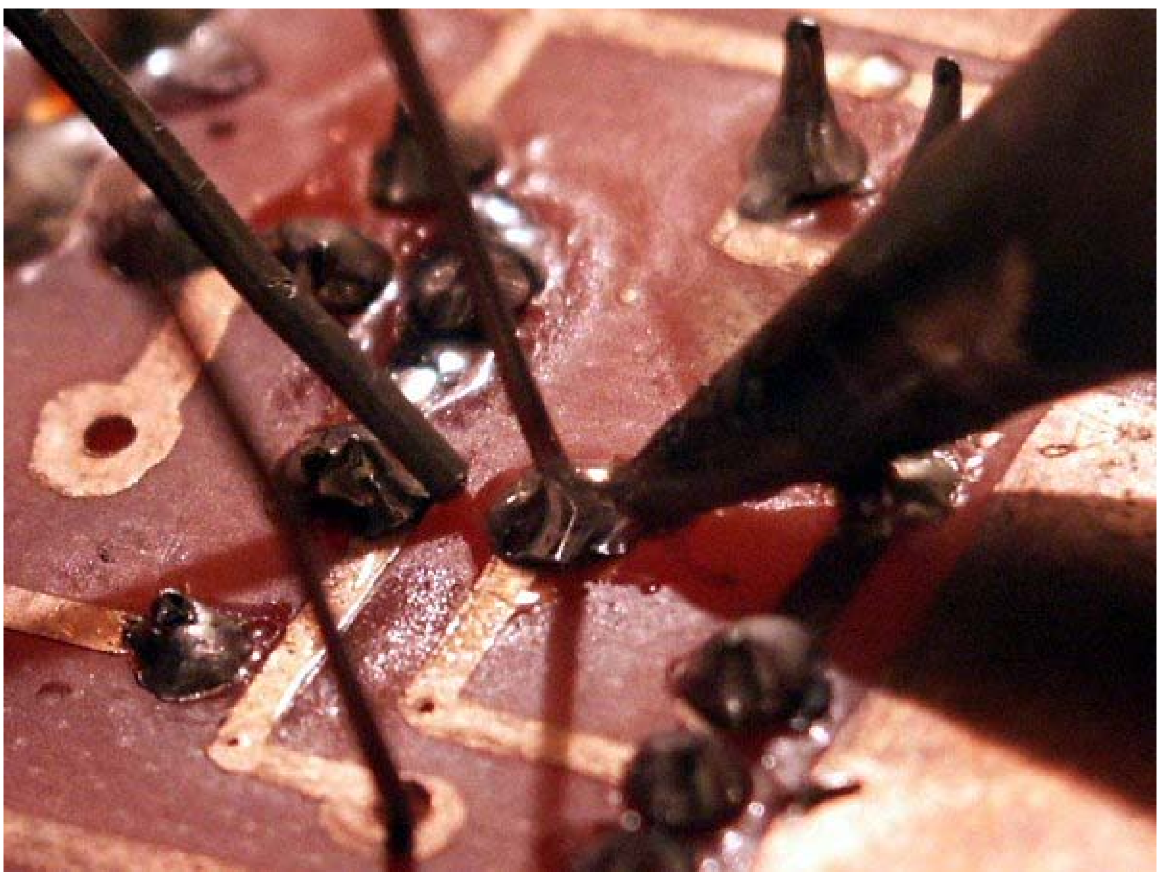
Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, underwater and in space. Regardless of location, however, welding remains dangerous, and precautions must be taken to avoid burns, electric shock, poisonous fumes, and overexposure to ultraviolet light.

Brazing

Brazing is a joining process in which a filler metal is melted and drawn into a capillary formed by the assembly of two or more work pieces. The filler metal reacts metallurgically with the workpiece(s) and solidifies in the capillary, forming a strong joint. Unlike welding, the work piece is not melted. Brazing is similar to soldering, but occurs at temperatures in excess of 450 °C (842 °F). Brazing has the advantage of producing less thermal stresses than welding, and brazed assemblies tend to be more ductile than weldments because alloying elements can not segregate and precipitate.

Brazing techniques include, flame brazing, resistance brazing, furnace brazing, diffusion brazing, and inductive brazing.

Soldering



Soldering a printed circuit board.

Soldering is a joining process that occurs at temperatures below 450 °C (842 °F). It is similar to brazing in the fact that a filler is melted and drawn into a capillary to form a join, although at a lower temperature. Because of this lower temperature and different alloys used as fillers, the metallurgical reaction between filler and work piece is minimal, resulting in a weaker joint.

Riveting

Riveting is one of the most ancient metalwork joining processes. Its use has declined markedly during the second half of the 20th century, but it still retains important uses in industry and construction into the 21st century. The earlier use of rivets is being superseded by improvements in welding and component fabrication techniques.

A rivet is essentially a two-headed and unthreaded bolt which holds two other pieces of metal together. Holes are drilled or punched through the two pieces of metal to be joined. The holes being aligned, a rivet is passed through the holes and permanent heads are formed onto the ends of the rivet utilizing hammers and forming dies (by either coldworking or hotworking). Rivets are commonly purchased with one head already formed.

When it is necessary to remove rivets, one of the rivet's heads is sheared off with a cold chisel. The rivet is then driven out with a hammer and punch.

Associated processes

While these processes are not primary metalworking processes, they are often performed before or after metalworking processes.

Heat treatment

Metals can be heat treated to alter the properties of strength, ductility, toughness, hardness or resistance to corrosion. Common heat treatment processes include annealing, precipitation strengthening, quenching, and tempering. The **annealing** process softens the metal by allowing recovery of cold work and grain growth. **Quenching** can be used to harden alloy steels, or in precipitation hardenable alloys, to trap dissolved solute atoms in solution. **Tempering** will cause the dissolved alloying elements to precipitate, or in the case of quenched steels, improve impact strength and ductile properties.

Often, mechanical and thermal treatments are combined in what is known as thermo-mechanical treatments for better properties and more efficient processing of materials. These processes are common to high alloy special steels, super alloys and titanium alloys.

Plating

Electroplating is a common surface-treatment technique. It involves bonding a thin layer of another metal such as gold, silver, chromium or zinc to the surface of the product. It is used to reduce corrosion as well as to improve the product's aesthetic appearance.

Thermal spraying

Thermal spraying techniques are another popular finishing option, and often have better high temperature properties than electroplated coatings.

Chapter-2

Foundry

Glow of a foundry crucible

A **foundry** is a factory that produces metal castings. Metals are cast into shapes by melting them into a liquid, pouring the metal in a mold, and removing the mold material or casting after the metal has solidified as it cools. The most common metals processed are aluminum and cast iron. However, other metals, such as bronze, steel, magnesium, copper, tin, and zinc, are also used to produce castings in foundries.

Process

Melting

Melting is performed in a furnace. Virgin material, external scrap, internal scrap, and alloying elements are used to charge the furnace. Virgin material refers to commercially pure forms of the primary metal used to form a particular alloy. Alloying elements are either pure forms of an alloying element, like electrolytic nickel, or alloys of limited composition, such as ferroalloys or master alloys. External scrap is material from other forming processes such as punching, forging, or machining. Internal scrap consists of the gates, risers, or defective castings.

The process includes melting the charge, refining the melt, adjusting the melt chemistry and tapping into a transport vessel. Refining is done to remove deleterious gases and elements from the molten metal to avoid casting defects. Material is added during the melting process to bring the final chemistry within a specific range specified by industry and/or internal standards. During the tap, final chemistry adjustments are made.

Furnace

Several specialised furnaces are used to melt the metal. Furnaces are refractory lined vessels that contain the material to be melted and provide the energy to melt it. Modern furnace types include electric arc furnaces (EAF), induction furnaces, cupolas, reverberatory, and crucible furnaces. Furnace choice is dependent on the alloy system and quantities produced. For ferrous materials, EAFs, cupolas, and induction furnaces are commonly used. Reverberatory and crucible furnaces are common for producing aluminum castings.

Furnace design is a complex process, and the design can be optimized based on multiple factors. Furnaces in foundries can be any size, ranging from mere ounces to hundreds of tons, and they are designed according to the type of metals that are to be melted. Also, furnaces must be designed around the fuel being used to produce the desired temperature. For low temperature melting point alloys, such as zinc or tin, melting furnaces may reach around 327 Celsius. Electricity, propane, or natural gas are usually used for these temperatures. For high melting point alloys such as steel or nickel based alloys, the furnace must be designed for temperatures over 3600 Celsius. The fuel used to reach these high temperatures can be electricity or coke.

The majority of foundries specialize in a particular metal and have furnaces dedicated to these metals. For example, an iron foundry (for cast iron) may use a cupola, induction furnace, or EAF, while a steel foundry will use an EAF or induction furnace. Bronze or brass foundries use crucible furnaces or induction furnaces. Most aluminum foundries use either an electric resistance or gas heated crucible furnaces or reverberatory furnaces.

Degassing

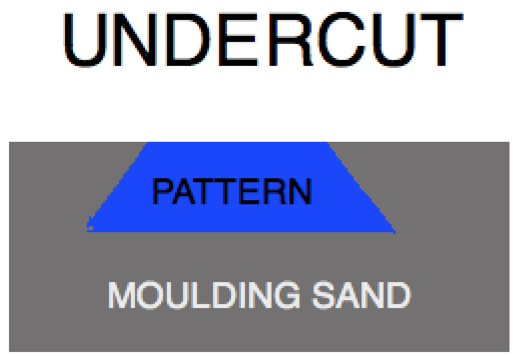
In the case of aluminium alloys, a degassing step is usually necessary to reduce the amount of hydrogen in the liquid metal. If the hydrogen concentration in the melt is too high, the resulting casting will contain gas porosity that will deteriorate its mechanical properties.

An efficient way of removing hydrogen from the melt is to bubble argon or nitrogen. To do that, several different types of equipment are used by foundries. When the bubbles go up in the melt, they catch the dissolved hydrogen and bring it to the top surface. There are various equipment which measure the amount of hydrogen present in it. Alternatively, the density of the aluminum sample is calculated to check amount of hydrogen dissolved in it.

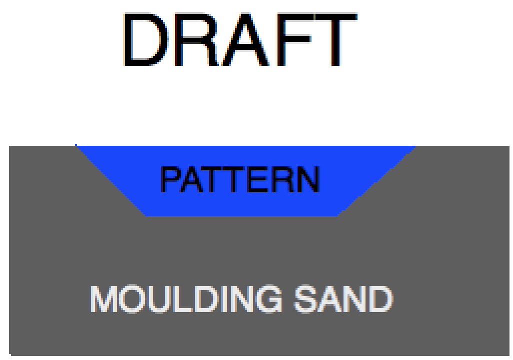
Mould making

Many large foundries operate their own industrial railways

In the casting process a pattern is made in the shape of the desired part. This pattern is made out of wax, wood, plastic or metal. Simple designs can be made in a single piece or solid pattern. More complex designs are made in two parts, called split patterns. A split pattern has a top or upper section, called a cope, and a bottom or lower section called a drag. Both solid and split patterns can have cores inserted to complete the final part shape. Where the cope and drag separates is called the parting line.



A diagram of an undercut in a mould.

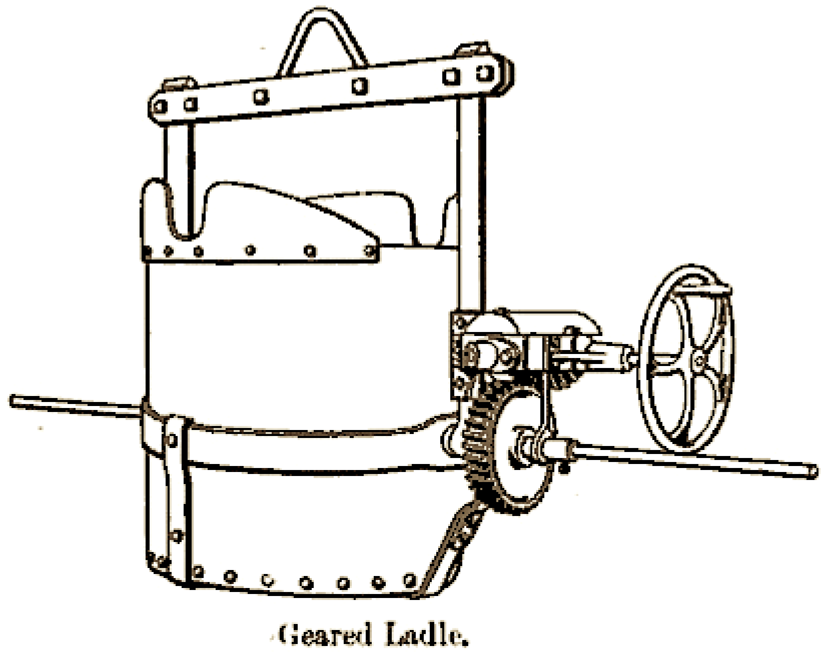


A diagram of draft on a pattern.

When making a pattern it is best to taper the edges so that the pattern can be removed without breaking the mold. This is called draft. The opposite of draft is an undercut where there is part of the pattern under the sand making it impossible to remove the pattern without damaging the mould. The molds are constructed by several different processes dependent upon the type of foundry, metal to be poured, quantity of parts to be produced, size of the casting and complexity of the casting. These mold processes include:

- Sand casting - Green or resin bonded sand mold.
- Lost-foam casting - Polystyrene pattern with a mixture of ceramic and sand mold.
- Investment casting - Wax or similar sacrificial pattern with a ceramic mold.
- Plaster casting - Plaster mold.
- V-Process casting - Vacuum is used in conjunction with thermoformed plastic to form sand molds. No moisture, clay or resin is needed for sand to retain shape.
- Billet (ingot) casting - Simple mold for producing ingots of metal normally for use in other foundries.

Pouring



An old geared ladle

In a foundry, molten metal is poured into molds. Pouring can be accomplished with gravity, or it may be assisted with a vacuum or pressurized gas. Many modern foundries use robots or automatic pouring machines for pouring molten metal. Traditionally, molds were poured by hand using ladles.

Shakeout

The solidified metal component is then removed from its mold. Where the mold is sand based, this can be done by shaking or tumbling. This frees the casting from the sand, which is still attached to the metal runners and gates - which are the channels through which the molten metal traveled to reach the component itself.

Degating

Degating is the removal of the heads, runners, gates, and risers from the casting. Runners, gates, and risers may be removed using cutting torches, bandsaws or ceramic cutoff blades. For some metal types, and with some gating system designs, the sprue, runners and gates can be removed by breaking them away from the casting with a hammer or specially designed knockout machinery. Risers must usually be removed using a cutting method but some newer methods of riser removal use knockoff machinery with special designs incorporated into the riser neck geometry that allow the riser to break off at the right place.

The gating system required to produce castings in a mold yields leftover metal, including heads, risers and sprue, sometimes collectively called sprue, that can exceed 50% of the metal required to pour a full mold. Since this metal must be remelted as salvage, the yield of a particular gating configuration becomes an important economic consideration when designing various gating schemes, to minimize the cost of excess sprue, and thus melting costs.

Surface cleaning

After degating, sand or other molding media may adhere to the casting. To remove this the surface is cleaned using a blasting process. This means a granular media will be propelled against the surface of the casting to mechanically knock away the adhering sand. The media may be blown with compressed air, or may be hurled using a shot wheel. The media strikes the casting surface at high velocity to dislodge the molding media (for example, sand, slag) from the casting surface. Numerous materials may be used as media, including steel, iron, other metal alloys, aluminum oxides, glass beads, walnut shells, baking powder among others. The blasting media is selected to develop the color and reflectance of the cast surface. Terms used to describe this process include cleaning, bead blasting, and sand blasting. Shot peening may be used to further work-harden and finish the surface.

Finishing

The final step in the process usually involves grinding, sanding, or machining the component in order to achieve the desired dimensional accuracies, physical shape and surface finish.

Removing the remaining gate material, called a gate stub, is usually done using a grinder or sanding. These processes are used because their material removal rates are slow enough to control the amount of material. These steps are done prior to any final machining.

After grinding, any surfaces that require tight dimensional control are machined. Many castings are machined in CNC milling centers. The reason for this is that these processes have better dimensional capability and repeatability than many casting processes. However, it is not uncommon today for many components to be used without machining.

A few foundries provide other services before shipping components to their customers. Painting components to prevent corrosion and improve visual appeal is common. Some foundries will assemble their castings into complete machines or sub-assemblies. Other foundries weld multiple castings or wrought metals together to form a finished product.

More and more the process of finishing a casting is being achieved using robotic machines which eliminate the need for a human to physically grind or break parting lines, gating material or feeders. The introduction of these machines has reduced injury to workers, costs of consumables whilst also reducing the time necessary to finish a casting.

It also eliminates the problem of human error so as to increase repeatability in the quality of grinding. With a change of tooling these machines can finish a wide variety of materials including iron, bronze and aluminium.

Chapter-3

Polishing and Planing (shaping)

Polishing

Polishing and **buffing** are finishing processes for smoothing a workpiece's surface using an abrasive and a work wheel. Technically *polishing* refers to processes that use an abrasive that is glued to the work wheel, while *buffing* uses a loose abrasive applied to the work wheel. Polishing is a more aggressive process while buffing is less harsh, which leads to a smoother, brighter finish. A common misconception is that a polished surface has a mirror bright finish, however most mirror bright finishes are actually buffed.

Polishing is often used to enhance the looks of an item, prevent contamination of medical instruments, remove oxidation, create a reflective surface, or prevent corrosion in pipes. In metallography and metallurgy, polishing is used to create a flat, defect-free surface for examination of a metal's microstructure under a microscope. Silicon-based polishing pads or a diamond solution can be used in the polishing process.

The removal of oxidization (tarnish) from metal objects is accomplished using a metal polish or tarnish remover; this is also called polishing. To prevent further unwanted oxidization, polished metal surfaces may be coated with wax, oil, or lacquer. This is of particular concern for copper alloy products such as brass and bronze.

Process

Polishing is usually a multistage process. The first stage starts with a rough abrasive and each subsequent stage uses a finer abrasive until the desired finish is achieved. The rough pass removes surface defects like pits, nicks, lines and scratches. The finer abrasives leave very thin lines that are not visible to the naked eye. Lubricants like wax and kerosene may be used as lubricating and cooling media during these operations, although some polishing materials are specifically designed to be used "dry." Buffing may be done by hand with a stationary polisher or die grinder, or it may be automated using specialized equipment.

When buffing there are two types of buffing motions: the *cut motion* and the *color motion*. The cut motion is designed to give a uniform, smooth, semi-bright surface finish.

This is achieved by moving the workpiece against the rotation of the buffing wheel, while using medium to hard pressure. The color motion gives a clean, bright, shiny surface finish. This is achieved by moving the workpiece with the rotation of the buffing wheel, while using medium to light pressure.

When polishing brass, there are often minute marks in the metal caused by impurities. To overcome this, the surface is polished with a very fine (600) grit, copper plated, then buffed to a mirror finish with an airflow mop.

Polishing operations for items such as chisels, hammers, screwdrivers, wrenches, etc., are given a fine finish but not plated. In order to achieve this finish four operations are required: roughing, dry fining, greasing, and coloring. Note that roughing is usually done on a solid grinding wheel and for an extra fine polish the greasing operation may be broken up into two operations: rough greasing and fine greasing. However, for inexpensive items money is saved by only performing the first two operations.

Polishing knives and cutlery is known as fine glazing or blue glazing. Sand buffing, when used on German silver, white metal, etc., is technically a buffing operation because it uses a loose abrasive, but removes a significant amount of material, like polishing.

Equipment

Aluminium oxide abrasives are used on high tensile strength metals, such as carbon and alloy steel, tough iron, and nonferrous alloys. Silicon carbide abrasives are used on hard and brittle substances, such as grey iron and cemented carbide, and low tensile strength metals, such as brass, aluminium, and copper.

Polishing wheels come in a wide variety of types to fulfill a wide range of needs. The most common materials used for polishing wheels are wood, leather, canvas, cotton cloth, plastic, felt, paper, sheepskin, impregnated rubber, canvas composition, and wool; leather and canvas are the most common. Wooden wheels have emery or other abrasives glued onto them and are used to polish flat surfaces and maintained good edges. There are many types of cloth wheels. Cloth wheels that are cemented together are very hard and used for rough work, whereas other cloth wheels that are sewn and glued together are not as aggressive. There are cloth wheels that are not glued or cemented, instead these are sewed and have metal side plates for support. Solid felt wheels are popular for fine finishes. Hard roughing wheels can be made by cementing together strawboard paper disks. Softer paper wheels are made from felt paper. Most wheels are run at approximately 7500 surface feet per minute (SFM), however muslin, felt and leather wheels are usually run at 4000 SFM.

Buffing wheels, also known as mops, are either made from cotton or wool cloth and come bleached or unbleached. Specific types include: sisal, spiral sewn, loose cotton, canton flannel, domet flannel, denim, treated spiral sewn, cushion, treated vented, untreated vented, string buff, finger buff, sisal rope, mushroom, facer, tampered, scrubbing mushroom, hourglass buff, rag, "B", climax, swansdown, airflow, coolair, and bullet.

The following chart will help in deciding which wheels and compounds to use when polishing different materials. This chart is a starting point and experienced polishers may vary the materials used to suit different applications.

Common buffing compound and wheel combinations

	Silver, gold & thin plates			Nickel & chrome plating			Copper, brass, aluminium, pot metal & soft metals			Steel & iron			Stainless steel		
Buff type	**Rough**	**Initial buff**	**Final buff**	**Rough**	**Initial buff**	**Final buff**	**Rough**	**Initial buff**	**Final buff**	**Rough**	**Initial buff**	**Final buff**	**Rough**	**Initial buff**	**Final buff**
Sisal							X			X			X		
Spiral sewn					X			X			X			X	
Loose									X			X			X
Canton flannel			X			X									
String															
Compound															
Black							X			X			X		
Brown								X							
White					X				X		X				
Blue			X			X						X			
Green														X	X
Red			X			X						X			

BLACK = Emery Compound, a coarse abrasive material for removal of scratches, pits, paint, rust etc.
BROWN = Tripoli compound used for general purpose cut and color on most soft metals.
WHITE = Blizzard compound, used for color and final finish of harder metals, has a cutting action.
RED = Jeweller's Rouge, designed to polish without any cutting action. Safe on thin plates. Use on its own wheel.
BLUE = A dryer, almost greaseless wheel - designed to polish without any cutting action. Safe on thin plates. Use on its own wheel.
GREEN = Used exclusively for Stainless Steel.

Applications

Polishing may be used to enhance the looks of certain parts on cars, motorbikes, handrails, cookware, kitchenware, and architectural metal applications. Pharmaceutical, dairy, and water pipes are buffed to maintain hygienic conditions and prevent corrosion. Buffing is used to manufacture of high-quality lighting reflectors.

Planing (shaping)

Planing is a manufacturing process of material removal in which the workpiece reciprocates against a stationary single-point cutting tool producing a plane or sculpted surface. Planing is analogous to shaping. The main difference between these two processes is that in shaping the tool reciprocates across the stationary workpiece. Planing motion is the opposite of shaping. Both planing and shaping are rapidly being replaced by milling.

The mechanism used for this process is known as a planer. The size of the planer is determined by the largest workpiece that can be machined on it. The cutting tools are usually carbide tipped or made of high speed steel and resemble those used in facing and turning.

Process Characteristics

•Uses single-point cutting tools
•Involves a reciprocating motion between the tool and workpiece
•Produces plane or sculpted surfaces
•Leaves parallel feed marks

Process

In shaping, the tool is brought into position with the workpiece. The tool then repeatedly moves in a straight line while the workpiece is incrementally fed into the line of motion of the tool, this produces a flat, smooth, and sculpted surface. For shaped pieces the tool reciprocates across the stationary workpiece. The tools are usually tilted or lifted after each stroke. This is done hydraulically or manually in order to prevent the tool surface from chipping when the workpiece travels back across.

Workpiece Geometry

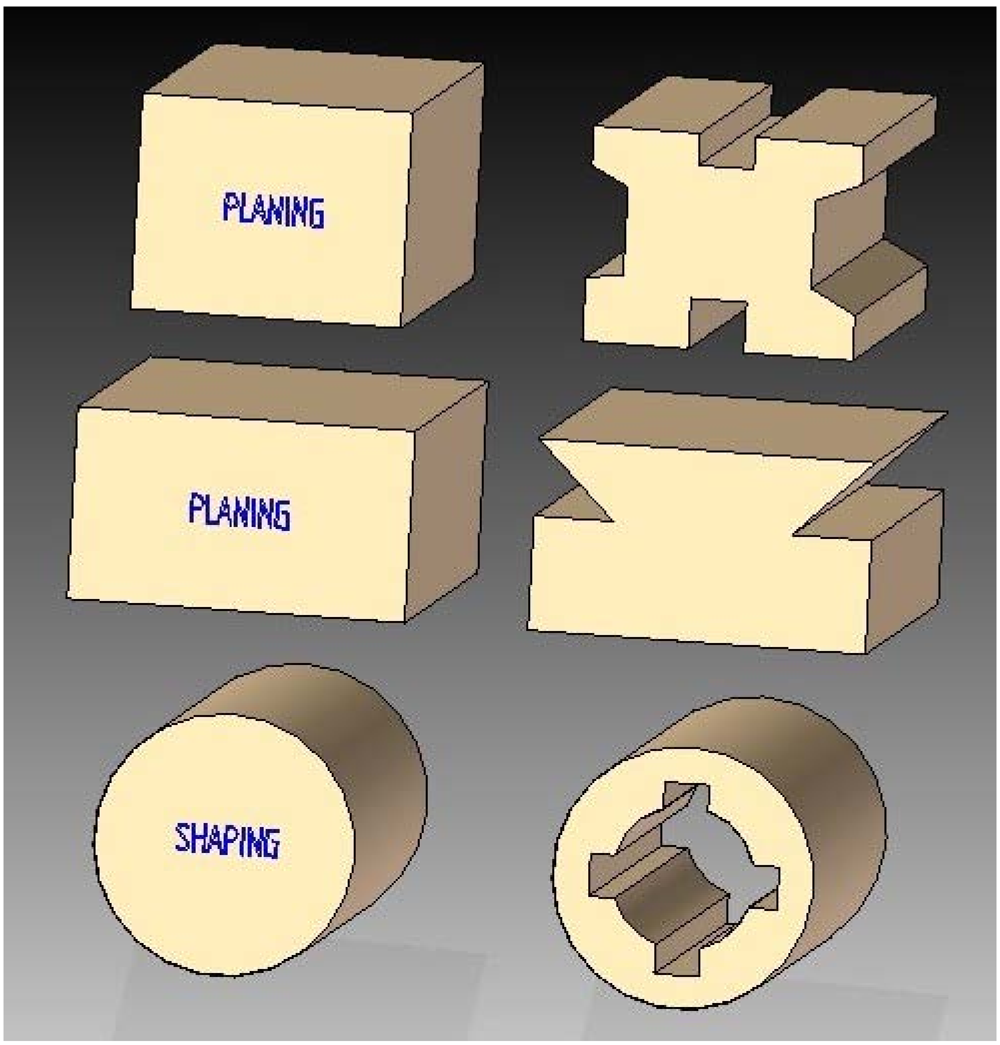
Planing can be used to produce flat surfaces, as well as cross-sections with grooves and notches, are produced along the length of workpiece. Shaping is basically the same as planing, except the workpiece is usually smaller, and it is the tool that moves and not the workpiece. Planing can be used to produce horizontal, vertical, or inclined flat surfaces on workpieces usually too large for shaping. Shaping is used not only for flat surfaces, but also for external or internal surfaces (either horizontal or inclined). Curved and irregular surfaces can also be produced by using special attachments

Setup and Equipment

Flat, angular, and contoured surfaces are made by horizontal shapers. Concerning shaping, the device that holds the piece being worked on has a very heavy movable jaw to withstand cutting forces. The size of the planer needed is determined by the workpiece. Depending on the size of the workpiece many clamps and supporting devices may be used to hold it on the planer.

Typical Tools and Geometry Produced

The tools for shaping/planing are usually made of high speed steel or carbide tipped. Except for some slight angle difference, cutting tools resemble those used in facing and turning. Some advantages of using single-point cutting tools over multipoint tools is that they are more easily sharpened and fabricated. Internal shapes can be made by using a special extension tool.



Before and after geometry

Material Properties

Although the most common material to be planed or shaped is wood, there are planers and shaping machines capable of processing anything from metal pieces to plastic objects.

Chapter-4

Parts Cleaning

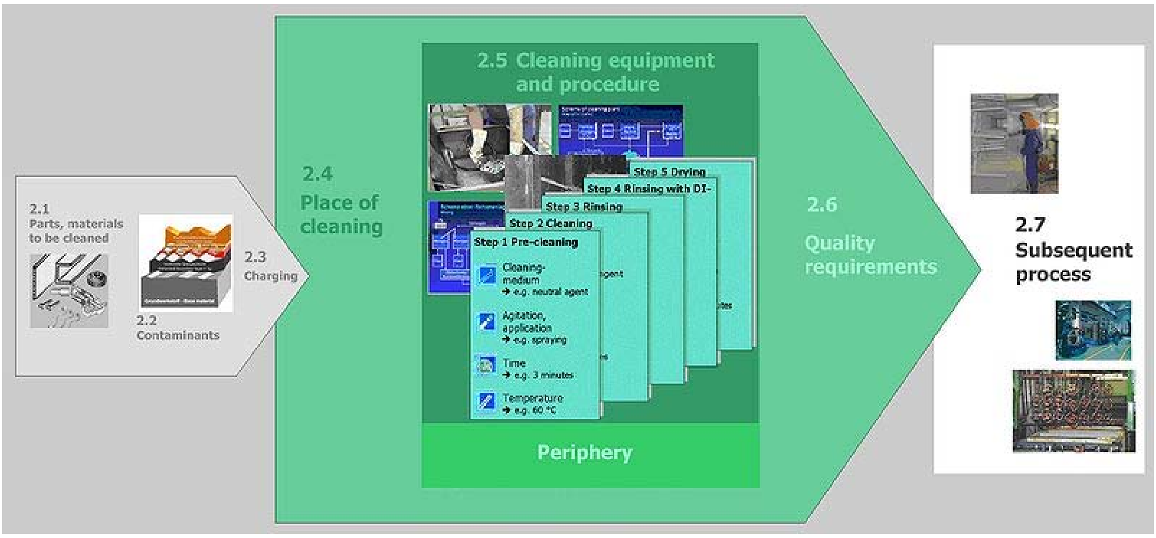
Parts cleaning is essential to many industrial processes, as a prelude to surface finishing or to protect sensitive components. Electroplating is particularly sensitive to part cleanliness, since molecular layers of oil can prevent adhesion of the coating. ASTM B322 is a standard guide for cleaning metals prior to electroplating. Cleaning processes include solvent cleaning, hot alkaline detergent cleaning, electrocleaning, and acid etch. The most common industrial test for cleanliness is the waterbreak test, in which the surface is thoroughly rinsed and held vertical. Hydrophobic contaminants such as oils cause the water to bead and break up, allowing the water to drain rapidly. Perfectly clean metal surfaces are hydrophilic and will retain an unbroken sheet of water that does not bead up or drain off. ASTM F22 describes a version of this test. This test does not detect hydrophilic contaminants, but the electroplating process can displace these easily since the solutions are water-based. Surfactants such as soap reduce the sensitivity of the test, so these must be thoroughly rinsed off.

Definitions and classifications

For the activities described here the following terms are often found: metal cleaning, metal surface cleaning, component cleaning, degreasing, parts washing, parts cleaning. These are well established in technical language usage but they have their shortcomings. Metal cleaning can easily be mixed up with refinement of unpurified metals. Metal surface cleaning and metal cleaning do not consider the increasing usage of plastics and composite materials in this sector. The term component cleaning leaves out the cleaning of steel sections and sheets and finally degreasing only describes a part of the topic as in most cases also chips, fines, particles, salts etc. have to be removed.

The terms 'commercial and industrial parts cleaning', 'parts cleaning in craft and industry' or 'commercial parts cleaning' probably best describe this field of activity. There are some specialists who prefer the term 'industrial parts cleaning', because they want to exclude maintenance of buildings, rooms, areas, windows, floors, tanks, machinery, hygiene, hands washing, showers etc.

Elements and their interactions



Factors

Cleaning activities in this sector can only be characterised sufficiently by a description of a number of different factors. These are outlined in illustration 1.

Parts and materials to be cleaned

First, consider the parts to be cleaned. They may consist of non- or hardly-processed sections, sheets and wires. But also machined parts or assembled components needing cleaning. Therefore, they may be composed of different metals or different combinations of metals. Plastics and composite materials can frequently be found and indeed are on the increase because e.g. the automobile industry as well as others uses more and more lighter materials.

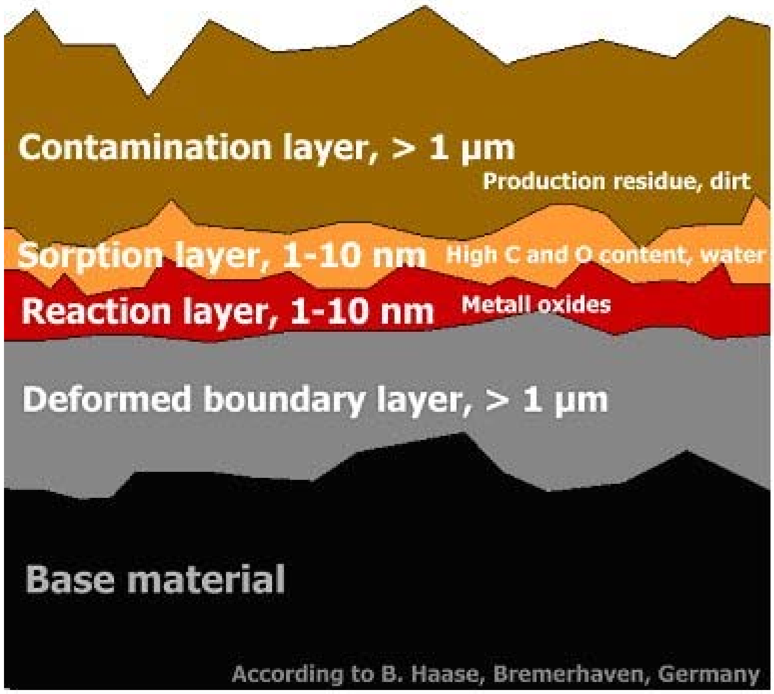
Mass and size can be very important for the selection of cleaning methods, for example big shafts for ships are usually cleaned manually, whereas tiny shafts for electrical appliances are often cleaned in bulk in highly automated plants.

Similarly important is the geometry of the parts. Long, thin, branching, threaded holes, which could contain jammed chips, feature among the greatest challenges in this technical field. high pressure and the power wash process are one way to remove these ships as well as robots, which are programmed to exactly flush the drilled holes under high pressure.

Contaminations

The parts are usually covered by unwanted substances, the contaminations or soiling. The definition used is quite varied. In certain cases these coverings may be desired: e.g. one may not wish to remove a paint layer but only the material on top. In another case, where crack proofing is necessary one has to remove the paint layer and it is regarded as an unwanted substance.

The classification of soiling follows the layer structure starting from the base material:



Structure of a metallic surface

- Deformed boundary layer, > 1 µm
- Reaction layer, 1 - 10 nm
- Sorption layer, 1 - 10 nm
- Contamination layer, > 1 µm

See illustration 2: Structure of a metallic surface

The nearer the layers are to the substrate surface, the more energy is needed to remove them. Correspondingly the cleaning itself can be structured according to the type of energy input :

- mechanical - abrasive: blasting, grinding
- mechanical - non-abrasive: stirring, mixing, ultrasound, spraying
- thermal - reactive: heat treatment much above 100°C in reactive gases
- thermal - non-reactive: temperature below 100°C, increased bath temperature, vapour degreasing

- chemical - abrasive/reactive: pickling in liquids, plasma-assisted, sputter-cleaning, elektropolishing
- chemical - non-reactive: organic solvents, aqueous solutions, supercritical CO_2

The contamination layer may then be further classified according to:

- Origin
- Composition: e.g. cooling lubricants may be composed very differently, thereby single components may account for big problems especially for job shop cleaners, who have no control over prior processes and thus don't know the contaminants. For example silicates may obstruct nitriding.
- State of aggregation
- Chemical and physical properties

The American Society for Testing and Materials (ASTM) presents six groups of contaminations in their manual "Choosing a cleaning process" and relates them to the most common cleaning methods, thereby the suitability of cleaning methods for the removal of a given contaminate is discussed in detail . In addition they list exemplary cleaning processes for different typical applications. Since one has to consider very many different aspects when choosing a process, this can only serve as a first orientation. The groups of contaminants are stated as follows:

- Pigmented drawing compounds
- Unpigmented oil and grease
- Chips and cutting fluids
- Polishing and buffing compounds
- Rust and scale
- Others

Charging

In order to select suitable equipment and media it should be known also which amount and which throughput has to be handled. Small amounts can hardly be cleaned economically in larger plants. Also the type of charging has to be ascertained. Sensitive parts sometimes need to be fixed in boxes. Very economically when dealing with large amounts is bulk charging, but it is quite difficult to achieve a sufficient level of cleanliness with flat pieces clinging together. Also drying can be difficult in these cases.

Place of cleaning

Another consideration is the place of cleaning. E.g. is the cleaning to be done on site, which can be the case with repair and maintenance work.

Usually the cleaning takes place in a workshop. Several common methods are solvent degreasing, vapor degreasing and using an aqueous parts washer. Companies often want the charging, loading and unloading to be integrated into the production line, which is much more demanding as regards size and throughput ability of the cleaning system.

Such cleaning systems often exactly match the requirements regarding parts, contaminants and charging methods (special production). Nonetheless central cleaning equipment, often built as multi task systems, are commonly used. These systems can suit different cleaning requirements. Typical examples are the wash stands or the small cleaning machines which are found in many insdustrial plants.

Cleaning equipment and procedure

First, one can differentiate between the following techniques:

- Manual
- Mechanical
- Automatic
- Robot supported

The process may be performed in one step, which is especially true for the manual cleaning, but typically it requires several steps. Therefore, it is not uncommon to find 10 to 20 steps in large plants e.g. for the medical and optical industry. This can be especially complex because non-cleaning steps may be integrated in such plants like application of corrosion protection layers or phosphating. Cleaning can also be simple, the cleaning processes are integrated into other processes as it is the case with electroplating or galvanising, where it usually serves as a pre-treatment step.

The following procedure is quite common:

1. Pre cleaning
2. Main cleaning
3. Rinsing
4. Rinsing with deionised water
5. Rinsing with corrosion protection
6. Drying

Each of these steps may take place in its own bath or chamber or in case of spray cleaning in its own zone (line or multi-chamber equipment). But quite often these steps may have a single chamber into which the respective media are pumped in (single chamber plant).

Besides equipment and procedure, cleaning media plays an important role as it removes the contaminants from the substrate.

For liquid media the following cleaners are in use: aqueous agents, semi-aqueous agents (an emulsion of solvents and water), hydrocarbon based solvents and halogenated solvents. Usually the latter are referred to as chlorinated agents, but there are also brominated and fluorated substances in (limited) use, that is why we have chosen the higher level classification. The hazardous traditionally used chlorinated agents TCI and PCE are nowadays only applied in airtight plants and the modern volume shift systems limits any emissions.

Aqueous cleaners are mostly a combination of various substances like Alkaline builders, surfactants, sequestering agents, etc. Their use is on the rise as their results have proven to be in many cases as good or better than hydrocarbon cleaners. Additionally, the wastes generated are less hazardous resulting in less costly disposal. In the group of hydrocarbon based solvents, there are some newly developed agents like fatty acid esters made of natural fats and oils, modified alcohols and dibasic esters.

Aqueous cleaners have advantages as regards to particle and polar contaminants an only require higher inputs of mechanical and thermal energy to be effective, whereas solvents easily remove oils and greases but have health and environmental risks. In addition most solvents are flammable and create fire and explosion hazards. Now days, with the proper equipment, it is generally accepted that aqueous cleaners remove oil and grease as easily as solvents.

Another approach is with solid cleaning media (blasting) which constitutes of the CO_2 dry ice process: For tougher requirements pellets are used while for more sensitive materials or components CO_2 in form of snow is applied. One draw back is the high energy consumption required to make dry ice.

Last but not least there are processes without any media like vibration, laser, brushing and blow/exhaust systems.

All cleaning steps are characterised by media and applied temperatures and their individual agitation/application (mechanical impact). There is a wide range of different methods and combinations of these methods:

- Sprinkling
- Spraying
- Power Wash Process
- Blasting
- Flooding
- Movement of parts (turning, oscillating, pivoting)
- Circulation of bath
- Gas or air injection into bath
- Boiling under pressure
- Injection flooding
- Pressure flooding
- Hydroson
- Ultrasonic
- Megasonic

Finally, every cleaning step is described by the time which the parts to be cleaned spends in the respective zone, bath or chamber and thus medium, temperature and agitation can impact on the contamination.

Every cleaning equipment needs a so-called periphery. This term describes measures and equipment on the one hand side to maintain and control baths and on the other hand side to protect human beings and the environment.

In most plants the cleaning agents are circulated until their cleaning power has eventually decreased and reached the maximum tolerable contaminant level. In order to delay the necessary bath exchange as much as possible there are sophisticated treatment attachments in use, removing contaminants and the used up agents from the system. At the same time fresh cleaning agents or parts thereof have to be supplemented, which requires a bath control. The latter is more and more facilitated online and thus allows a computer aided adjustment of the bath. With the help of oil separators, demulsifying agents and evaporators aqueous processes can be conducted 'waste water free'. Complete exchange of baths becomes only necessary every 3 to 12 months.

When using organic solvents the preferred method to achieve a long operating bath life is distillation, an especially effective method to separate contaminants and agents.

The periphery also includes measures to protect the workers like encapsulation, automatic shut off of power supply, automatic refill and sharpening of media (e.g. gas shuttle technique), explosion prevention measures, exhaust ventilation etc., and also measures to protect the environment, e.g. capturing of volatile solvents, impounding basins, extraction, treatment and disposal of resulting wastes. Solvents based cleaning processes have the advantage that the dirt and the cleaning agent can be more easily separated, whereas in aqueous processes is more complex.

In processes without cleaning media like laser ablation and vibration cleaning, only the removed dirt has to be disposed of as there is no cleaning agent. Quite little waste is generated in processes like CO_2 blasting and automatic brush cleaning at the expense of higher energy costs.

Quality requirements

A standardisation of the quality requirements for cleaned surfaces regarding the following process (e.g. coating, heat treatment) or from the point of view of technical functionality is difficult. However it is possible to use general classifications. In Germany it was attempted to define cleaning as a sub category of metal treatment (DIN 8592: Cleaning as sub category of cutting processes), but this does not cope with all the complexities of cleaning.

The rather general rules includes the classification in intermediate cleaning, final cleaning, precision cleaning and critical cleaning (s. table), in practice seen only as a general guideline.

Terms	Max. allowed dirt	Soils removed	Explanations
Intermediate cleaning			E.g. in metal cutting manufacturing
Final cleaning	≤ 500 mg / m² (1)	Mil-sized particles and residues thicker than a monolayer	E.g. before assembling or coating
• Parts for phosphating, painting, enamelling	• 500 - ≤ 5 mg C / m² (2)		
• Parts for case-hardening, nitriding, nitro carburising resp. vacuum treatment	• 500 - ≤ 5 mg C / m² (2)		
• Parts for electroplating, electronic parts	• 20 - ≤ 5 mg C / m² (2)		
Precision cleaning	≤ 50 mg / m² (1)	Supermicrometre particles and residues *thinner* than a monolayer	Controlled environment (Durkee)
Critical cleaning	≤ 5 mg / m² (1)	Sub-micrometre particles and non-volatile residue measured in Angstroms	cleanroom (Durkee)

(1) Related to the total dirt; (2) Only related to Carbon

Thus in practice the rule of thumb is still followed, stating that the quality requirements are met, if the subsequent process does not cause any problems, for example a paint coating does not flake off before the guarantee period ends.

Where this is not sufficient, especially in case of external orders, because of missing standards there are often specific customer requirements regarding remaining contamination, corrosion protection, spots and gloss level etc.

Measuring methods to ensure quality therefore do not play a bigger role in the workshops, although there exist a broad scale of different methods, from visual control over simple testing methods (among other things water break test, wipe test, measurement of contact angle, test inks, tape test) to complex analysis methods (among others gravimetric test, particle counting, infrared spectroscopy, glow discharge spectroscopy, energy dispersive X-ray analysis, scanning electron microscopy and electrochemical methods). Nevertheless there are only few methods, which can be applied directly in the line and which offer reproducible and comparable results. It was not until recently that bigger advancements in this area have been made

The general situation has changed meanwhile, because of dramatically rising cleanliness requirements for certain components in the automotive industry. For example brake systems and fuel-injection systems need to be fitted with increasingly smaller diameters and they have to withstand increasingly higher pressures. Therefore, a very minor particle contamination may lead to big problems. Due to the rising innovation speed, the industry cannot afford to identify possible failures at a relatively late stage. Therefore, the standard VDA 19/ISO 16232 'Road Vehicles – Cleanliness of Components of Fluid Circuits' was developed which describes methods that can control the compliance with the cleanliness requirements.

Subsequent process

When choosing cleaning techniques, cleaning agents and cleaning processes, the subsequent processes, i.e. the further processing of the cleaned parts is of special interest.

The classification follows basically the metal work theory:

- machining
- cutting
- joining
- coating
- heat treatment
- assembling
- measuring, testing
- repairing, maintenance.

In the course of time empirical values were established, how efficient the cleaning has to be, to assure the processes for the particular guarantee period and beyond. Choosing the cleaning method often starts from here.

Challenges and trends

The details above illustrate how extremely complex this specific field is. Already small changes in the requirements can necessitate completely different processes. Thus it defies scientific technical determination. On the other hand it becomes more and more important to receive the required degree of cleanliness as cost-effective as possible and with continuously minimised health and environmental risks, because cleaning has become of central importance for the supply chain in manufacturing . Applying companies usually rely on their suppliers, who—due to a big experience base—suggest adequate equipment and processes, which are then adapted to the detailed requirements in tests stations at the supplier's premises. However they are limited to their scope of technology. To put practitioners in a position to consider all relevant possibilities meeting their requirements, some institutes have developed different tools:

SAGE: Unfortunately no longer in operation the comprehensive expert system for parts cleaning and degreasing provided a graded list with relatively general processes of possible solvent and process alternatives. Developed by the Surface Cleaning Programme at the Research Triangle Institute, Raleigh, North Carolina, USA, in cooperation with the U.S. EPA.

Cleantool: A 'Best Practice' database in seven languages with comprehensive and specific processes, directly recorded in companies. It contains furthermore an integrated evaluation tool, which covers the areas technology, quality, health and safety at work, environmental protection as well as costs. Also included is a comprehensive glossary.

Bauteilreinigung: A selection system for component cleaning developed by the University of Dortmund, assisting the users to analyse their cleaning tasks with regard to the suitable cleaning processes and cleaning agents.

TURI, Toxic Use Reduction Institute: A department of the University of Lowell, Massachusetts (USA). TURI's laboratory has been conducting evaluations on alternative cleaning products since 1993. A majority of these products were designed for metal surface cleaning. The results of these tests are available on-line through the Institute's laboratory database.

Chapter-5

Hot Working and Hot Pressing

Hot working

A forge fire for hot working of metal

Hot working refers to processes where metals are plastically deformed above their recrystallization temperature. Being above the recrystallization temperature allows the material to recrystallize during deformation. This is important because recrystallization keeps the materials from strain hardening, which ultimately keeps the yield strength and hardness low and ductility high. This contrasts with cold working.

Temperature

The lower limit of the hot working temperature is determined by its recrystallization temperature. As a guideline, the lower limit of the hot working temperature of a material is 0.6 times its melting temperature (on an absolute temperature scale). The upper limit for hot working is determined by various factors, such as: excessive oxidation, grain growth, or an undesirable phase transformation. In practice materials are usually heated to the upper limit first to keep forming forces as low as possible and to maximize the amount of time available to hot work the workpiece.

The most important aspect of any hot working process is controlling the temperature of the workpiece. Of 90% of the energy imparted into the workpiece is converted into heat. Therefore, if the deformation process is quick enough the temperature of the workpiece should rise, however, this does not usually happen in practice. Most of the heat is lost through the surface of the workpiece into the cooler tooling. This causes temperature gradients in the workpiece, usually due to non-uniform cross-sections where the thinner sections are cooler than the thicker sections. Ultimately, this can lead to cracking in the cooler, less ductile surfaces. One way to minimize the problem is to heat the tooling. The hotter the tooling the less heat lost to it, but as the tooling temperature rises, the tool life decreases. Therefore the tooling temperature must be compromised; commonly, hot working tooling is heated to 500–850 °F (325–450 °C).

Lower limit hot working temperature for various metals

Metal	Temperature
Tin	Room temperature
Steel	2,000 °F (1,090 °C)
Tungsten	4,000 °F (2,200 °C)

Advantages & disadvantages

The advantages are:

- Decrease in yield strength, therefore it is easier to work and uses less energy or force
- Increase in ductility
- Elevated temperatures increase diffusion which can remove or reduce chemical inhomogeneities
- Pores may reduce in size or close completely during deformation
- In steel, the weak, ductile, face-centered-cubic austenite microstructure is deformed instead of the strong body-centered-cubic ferrite microstructure found at lower temperatures

Usually the initial workpiece that is hot worked was originally cast. The microstructure of cast items does not optimize the engineering properties, from a microstructure standpoint.

Hot working improves the engineering properties of the workpiece because it replaces the microstructure with one that has fine spherical shaped grains. These grains increase the strength, ductility, and toughness of the material.

The engineering properties can also be improved by reorienting the inclusions (impurities). In the cast state the inclusions are randomly oriented, which, when intersecting the surface, can be a propagation point for cracks. When the material is hot worked the inclusions tend to flow with the contour of the surface, creating *stringers*. As a whole the strings create a *flow structure*, where the properties are anisotropic (different based on direction). With the stringers oriented parallel to the surface it strengthens the workpiece, especially with respect to fracturing. The stringers act as "crack-arrestors" because the crack will want to propagate through the stringer and not along it.

The disadvantages are:

- Undesirable reactions between the metal and the surrounding atmosphere (scaling or rapid oxidation of the workpiece)
- Less precise tolerances due to thermal contraction and warping from uneven cooling
- Grain structure may vary throughout the metal for various reasons
- Requires a heating unit of some kind such as a gas or diesel furnace or an induction heater, which can be very expensive

Hot pressing

Hot pressing is a high-pressure, low-strain-rate powder metallurgy process for forming of a powder or powder compact at a temperature high enough to induce sintering and creep processes. This is achieved by the simultaneous application of heat and pressure.

Hot pressing is mainly used to fabricate hard and brittle materials. One large use is in the consolidation of diamond-metal composite cutting tools and technical ceramics. The densification works through particle rearrangement and plastic flow at the particle contacts. The loose powder or the pre-compacted part is in most of the cases filled to a graphite mould that allows induction or resistance heating up to temperatures of typically 2,400 °C (4,350 °F). Pressures of up to 50 MPa (7,300 psi) can be applied.

Within hot pressing technology, three distinctly different types of heating can be found in use: induction heating, indirect resistance heating, and direct hot pressing.

Inductive heating

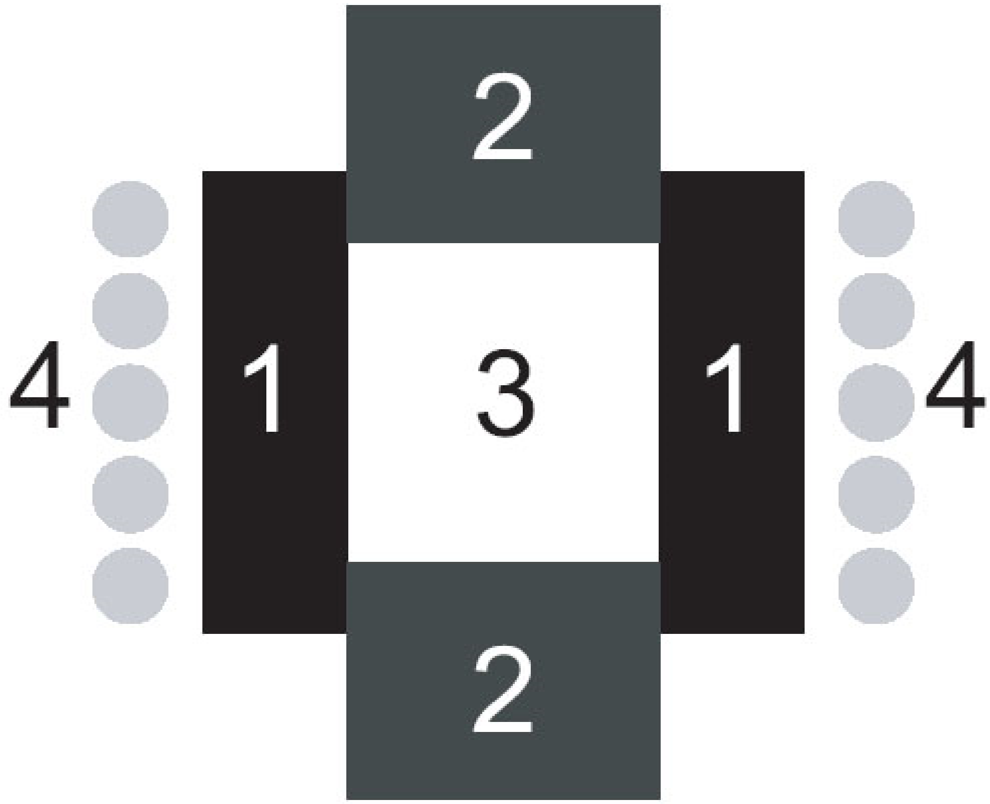


Figure I: Conventional inductive heating

In this process heat is produced within the mould when it is subjected to a high frequency electromagnetic field, generated by using an induction coil coupled to an electronic generator. The mould is made out of graphite or steel, and pressure is applied by one or two cylinders onto the punches. The mould is positioned within the induction coil. The advantage here is that the pressure and the inductive power are completely independent. Even powders with a liquid phase are amenable to this process and low pressures are possible, too. Among the disadvantages are the expense of a high-frequency generator and the need for proper alignment. If the mould is placed off centre, the heat distribution is uneven. But the main disadvantage is the dependence of the process on good inductive coupling and thermal conductivity of the mould. The magnetic field can penetrate the mould only 0.5mm to 3mm. From there on, the heat has to be "transported" into the mould by the thermal conductivity of the mould material. Uniform heating is much more difficult if the air gap between the mould and the inductive coil is not the same all along the mould profile. Another potential problem is heating rate. Too high a heat up rate will result in high temperature differences between the surface and core that can destroy the mould.

Indirect resistance heating

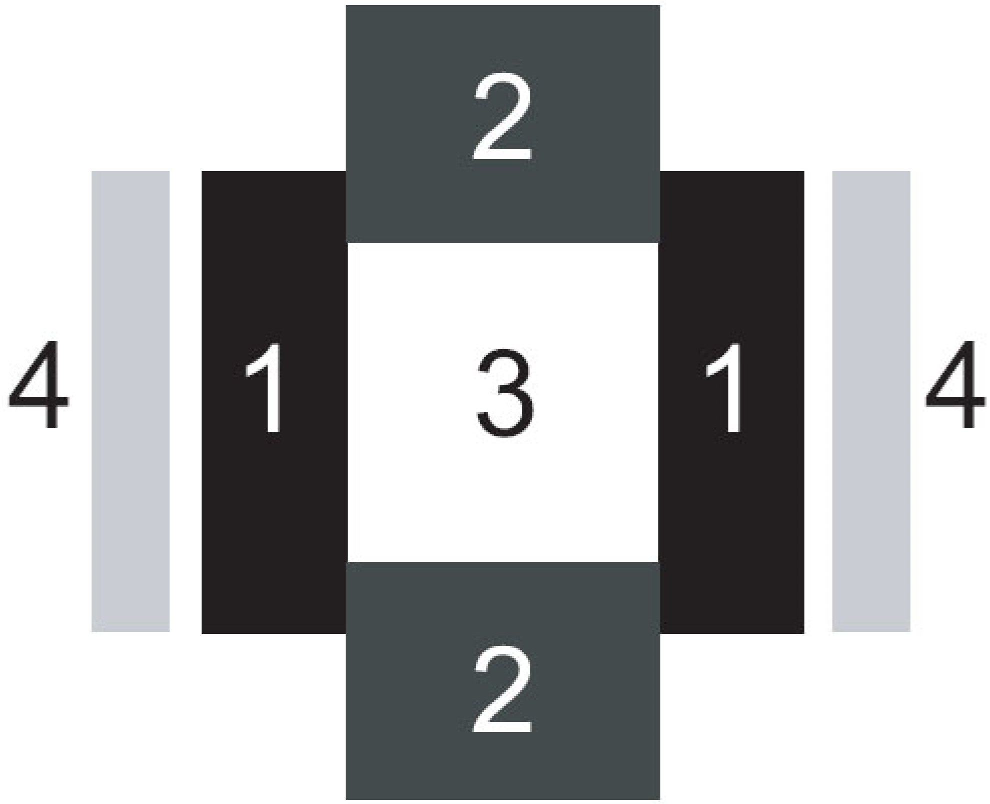


Figure II: Indirect resistance heating

With indirect resistance heating technology, the mould is placed in a heating chamber. The chamber is heated by graphite heating elements. These elements are heated by electrical current. The heat is then transferred into the mould by convection. As the electrical energy heats the heating elements that then heat the mould in a secondary manner, the process is called indirect resistance heating.

Advantages are high achievable temperatures, independent from the conductivity of the mould and independent from heat and pressure. Main disadvantage is the time that it takes to heat up the mould. It takes relatively long for heat transfer to take place from the furnace atmosphere to the mould surface and subsequently through out the cross-section of the mould.

Direct hot pressing

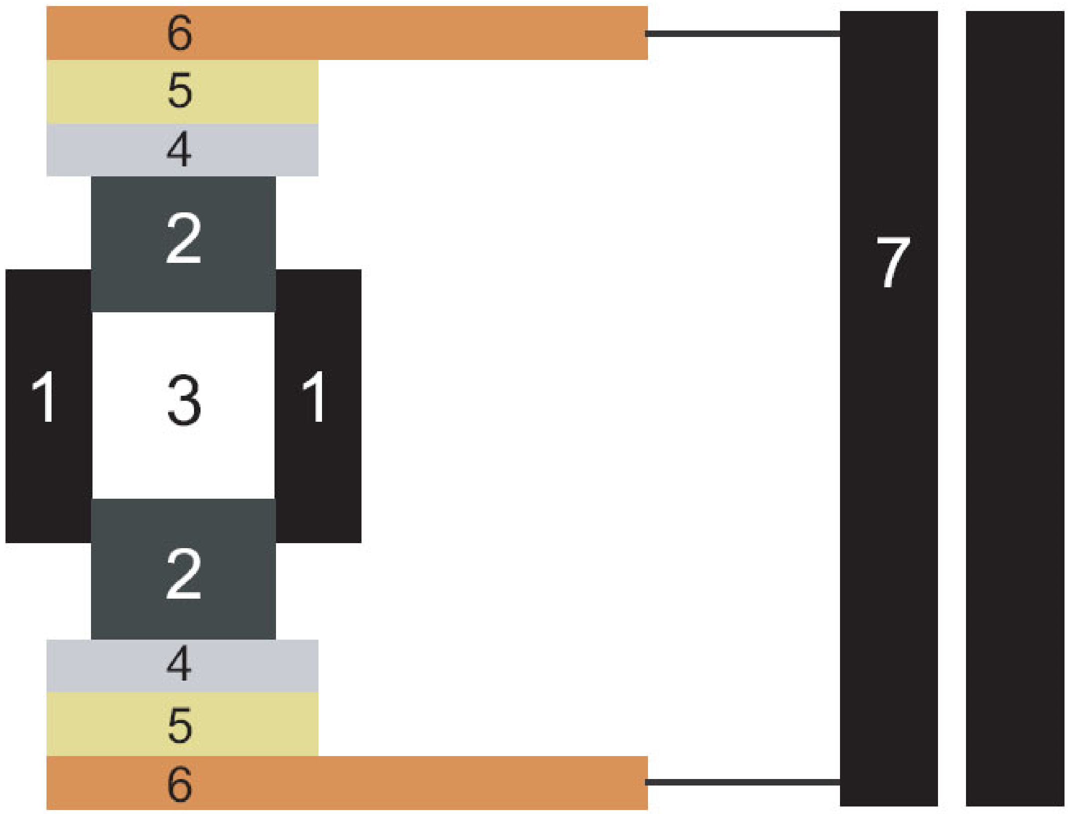


Figure III: Direct hot pressing

The basic idea of sintering with electric current going through the mould is quite old. Resistance heating of cemented carbide powders was patented by Tayler as early as 1933. This method is currently undergoing renewed interest. When applying a standard (unpulsed) AC or DC current, it is referred to as Direct Hot-Pressing (DHP) which is a common term in many industries. When applying a pulsed DC current, it is referred to as Spark Plasma Sintering(SPS) or Field Assisted Sintering Technique(FAST). The compelling reason for shortening the cycle time then was to avoid grain growth and also save energy. In direct hot pressing, the mould is directly connected to electrical power. The resistance of the mould and the powder part generates the heat directly in the mould. This results in very high heating rates. Additionally, this leads to significant increase in the sintering activity of fine metal powder aggregates which makes short cycle times of a few minutes possible. Further, this process lowers the threshold sintering temperature and pressure compared to that required in conventional sintering processes. The previous two methods are both closely dependent on the an intrinsic property of the mould material, i.e., its thermal conductivity. With direct resistance heating, however, the heat is generated where it is needed.

Recently, the manufacture of such critical items as sputtering targets and high-performance ceramic components, such as boron carbide, titanium diboride, and sialon, have been achieved. Using metal powder, the conductivity of the mould is ideal for fast heating of the work-piece. Moulds that have a big diameter and relatively small height can be heated up very fast. The process is especially suitable for applications that need high heating rates, e.g. for materials that should not be kept at high temperatures too long or for processes that require fast heating rates for high productivity.

With the direct hot pressing technology, materials can be sintered to their final density. The near net-shape precision achieved is very high and saves in many cases mechanical reworking of the high grade materials that are often difficult to process.

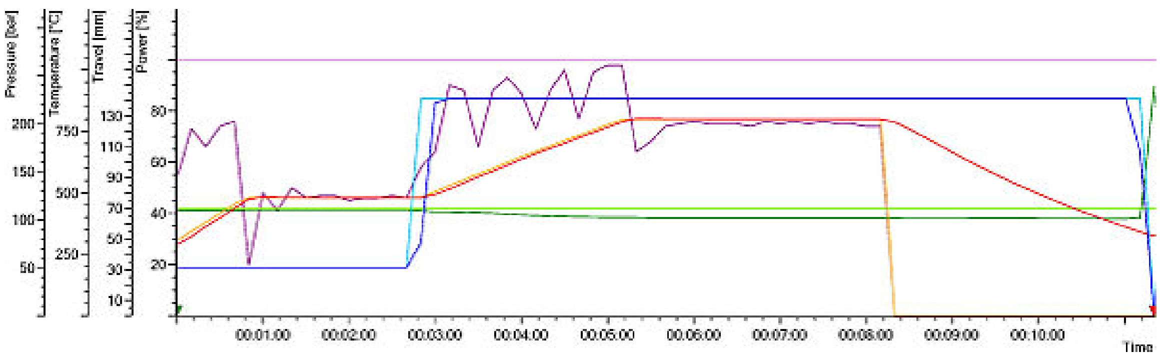


Figure IV: Process layout of the co-sintering process; total cycle time 11.5 mins Key: Red/orange line: actual/set temperature Green line: densification of powder/green compact Dark blue/light blue: actual/set pressure

Chapter-6

Forge

A blacksmith's coal forge

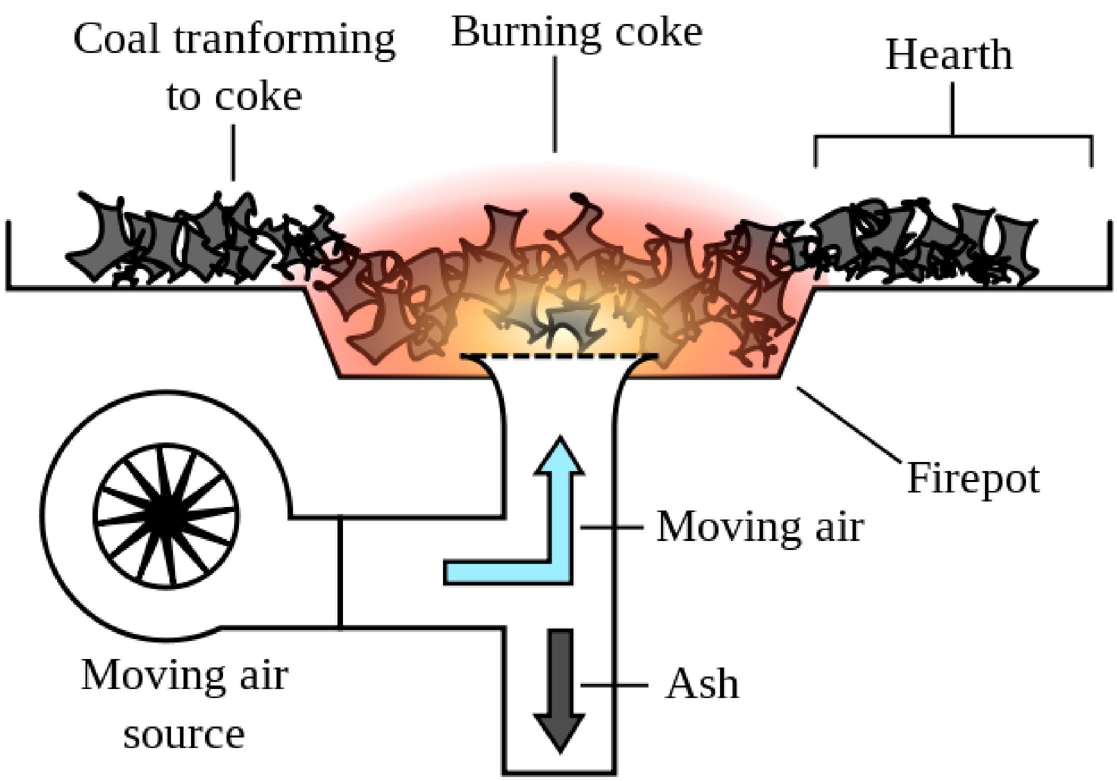
Wooden smithy in Opole, Upper Silesia

A **forge** is a hearth used for forging. The term "forge" can also refer to the workplace of a smith or a blacksmith, although the term **smithy** is then more commonly used.

The basic smithy contains a forge, also known as a hearth, for heating metals. The forge heats the workpiece to a malleable temperature (a temperature where the metal becomes easier to shape) or to the point where work hardening no longer occurs. The workpiece is transported to and from the forge using tongs. The tongs are also used to hold the workpiece on the smithy's anvil while the smith works it with a hammer. Finally the workpiece is transported to the slack tub, which rapidly cools the workpiece in a large body of water. The slack tub also provides water to control the fire in the forge.

Types of forges

Coal/coke/charcoal forge



Standard coal forge

A forge typically uses bituminous coal, industrial coke or charcoal as the fuel to heat metal. The designs of these forges have varied over time, but whether the fuel is coal, coke or charcoal the basic design has remained the same.

A forge of this type is essentially a hearth or fireplace designed to allow a fire to be controlled such that metal introduced to the fire may be brought to a malleable state or to bring about other metallurgical effects (hardening, annealing, and drawing temper as examples). The forge fire in this type of forge is controlled in three ways: amount of air, volume of fuel, and shape of the fuel/fire.

A forge fire for hot working of metal

Over thousands of years of forging, these devices have evolved in one form or another as the essential features of this type of forge:

- Tuyere — a pipe through which air can be forced into the fire
- Bellows or blower — a means for forcing air into the tuyere
- Firepot or hearth — a place where the burning fuel can be contained over or against the tuyere opening.

During operation, fuel is placed in or on the hearth and ignited. A source of moving air, such as a fan or bellows, introduces additional air into the fire through the tuyere. With additional air, the fire consumes more fuel and burns hotter.

A typical Scottish smithy at Auchentiber, North Ayrshire, Scotland.

A blacksmith balances the fuel and air in the fire to suit particular kinds of work. Often this involves adjusting and maintaining the shape of the fire.

In a typical, but by no means universal, coal forge, a firepot will be centered in a flat hearth. The tuyere will enter the firepot at the bottom. In operation, the hot core of the fire will be a ball of burning coke in and above the firepot. The heart of the fire will be surrounded by a layer of hot but not burning coke. Around the unburnt coke will be a transitional layer of coal being transformed into coke by the heat of the fire. Surrounding all is a ring or horseshoe-shaped layer of raw coal, usually kept damp and tightly packed to maintain the shape of the fire's heart and to keep the coal from burning directly so that it "cooks" into coke first.

If a larger fire is necessary, the smith increases the air flowing into the fire as well as feeding and deepening the coke heart. The smith can also adjust the length and width of the fire in such a forge to accommodate different shapes of work.

The major variation from the forge and fire just described is a 'back draft' where there is no fire pot, and the tuyere enters the hearth horizontally from the back wall.

Coke and charcoal may be burned in the same forges that use coal, but since there is no need to convert the raw fuel at the heart of the fire (as with coal), the fire is handled differently.

Individual smiths and specialized applications have fostered development of a variety of forges of this type, from the coal forge described above, to simpler constructions amounting to a hole in the ground with a pipe leading into it.

Gas forge

A gas forge typically uses propane or natural gas as the fuel. One common, efficient design uses a cylindrical forge chamber and a burner tube mounted at a right angle to the body. The chamber is typically lined with refractory materials, preferably a hard castable refractory ceramic. The burner mixes fuel and air which are ignited at the tip, which protrudes a short way into the chamber lining. The air pressure, and therefore heat, can be increased with a mechanical blower or by taking advantage of the Venturi effect.

Gas forges vary in size and construction, from large forges using a big burner with a blower or several atmospheric burners to forges built out of a coffee can utilizing a cheap, simple propane torch. A small forge can even be carved out of a single soft firebrick.

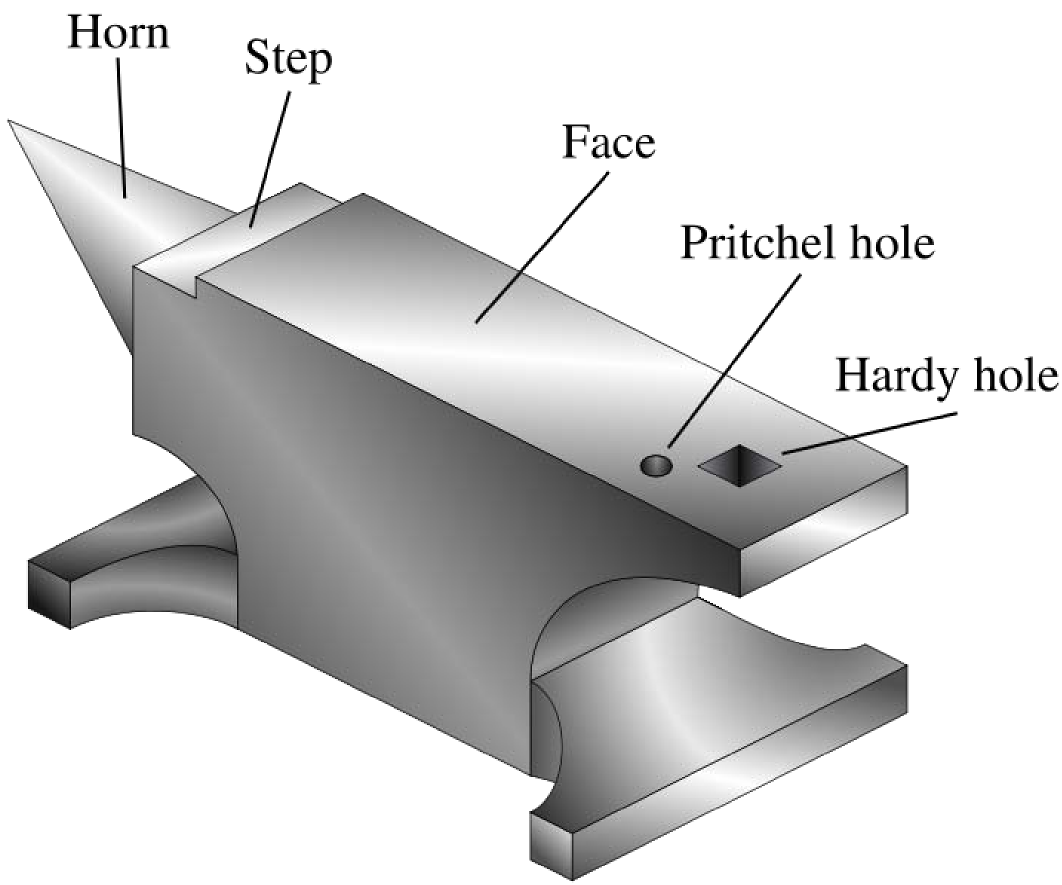
The primary advantage of a gas forge is ease of use, particularly for a novice. A gas forge is simple to operate compared to coal forges, and the fire produced is clean and consistent. They are less versatile, as the fire cannot be reshaped to accommodate large or unusually shaped pieces;. It is also difficult to heat a small section of a piece. A common misconception is that gas forges cannot produce enough heat to enable forge-welding, but a well designed gas forge is hot enough for any task.

Finery forge

A finery forge is a water-powered mill where pig iron is refined into wrought iron.

Forging equipment

Anvil



The anvil serves as a work bench to the blacksmith, where the metal to be beaten is placed. Anvils are made of cast or wrought iron with a tool steel face welded on or of a single piece of cast or forged tool steel. The flat top has two holes; the wider is called the hardy hole, where the square shank of the hardy fits. The smaller hole is called the punch hole, used as clearance when punching holes in hot metal.

Chisel

Chisels are made of high carbon steel. They are hardened and tempered at the cutting edge while the head is left soft so it will not crack when hammered. Chisels are of two types, hot and cold chisels. The cold chisel is used for cutting cold metals while the hot chisel is for hot metals. Usually hot chisels are thinner and therefore can not be substituted with cold chisels.

Tongs

Tongs are used by the blacksmith for holding hot metals securely. The mouths are custom made by the smith in various shapes to suit the gripping of various shapes of metal.

Fuller

Fullers are forming tools of different shapes used in making grooves or hollows. They are often used in pairs, the bottom fuller has a square shank which fits into the hardy hole in the anvil while the top fuller has a handle. The work is placed on the bottom fuller and the top is placed on the work and struck with a hammer. The top fuller is also used for finishing round corners and for stretching or spreading metal.

Hardy

The hardy is a cutting tool similar to the chisel. It is used as a chisel or hammer for cutting both hot and cold metals. It has a square shank that fits into the hardy hole in the anvil, with the cutting edge facing upwards. The metal to be cut is placed on the cutting edge and struck with a hammer. They are also used with set tools which are placed over the workpiece and struck.

Slack tub

A *slack tub* is usually a large container full of water, brine, or oil used by a blacksmith to quench hot metal. The term is believed to derive from the word "slake", as in slaking the heat.

Types of Forging

Drop Forging

Drop forging is a process used to shape metal into complex shapes by dropping heated metal into a punch and die which compresses to gradually change the shape of the metal.

Process

The workpiece is placed into a die and punch, then the impact of a ram on the punch causes the heated material, which is very malleable, to conform to the shape of the punch and die cavities. Typically only one ram is needed to completely form the part. The extra space between the die and punch is called the flash. It acts as a relief valve for the extreme pressure produced by the closing of the die halves but is eventually trimmed off of the finished part.

Equipment

The equipment used in the drop forming process is commonly known as a power or drop hammer. These may be powered by air, hydraulics, or mechanics. Depending on how the machine is powered, the mass of the ram, and the drop height, the striking force can be anywhere from 11,000 to 425,000 pounds. The tools that are used, dies and punches, come in many different shapes and sizes, as well as materials. Examples of these shapes are flat and v-shaped which are used for open-die forging, and single or multiple-impression dies used for closed die-forging. The designs for the dies have many aspects to them that must be considered. They all must be properly aligned, they must be designed so the metal and the flash will flow properly and fill all the grooves, and special considerations must be made for supporting webs and ribs and the parting line location. The materials must also be selected carefully. Some factors that go into the material selection are cost, their ability to harden, their ability to withstand high pressures, hot abrasion, heat cracking, and other such things. The most common materials used for the tools are carbon steel and, in some cases, nickel based alloys.

Workpiece Materials

The materials that are used most commonly in drop forging are aluminum, copper, nickel, mild steel, stainless steel, and magnesium. Mild steel is the best choice, and magnesium generally performs pretty poorly as a drop forging material.

Forge fire

Brake Drum Coal Forge

Chapter-7

Cutting Fluid

Thin-wall milling of aluminum using a water-based cutting fluid on the milling cutter.

Cutting fluid is a type of coolant and lubricant designed specifically for metalworking and machining processes. There are various kinds of cutting fluids, which include oils, oil-water emulsions, pastes, gels, aerosols (mists), and air or other gases. They may be made from petroleum distillates, animal fats, plant oils, water and air, or other raw ingredients. Depending on context and on which type of cutting fluid is being considered, it may be referred to as **cutting fluid**, **cutting oil**, **cutting compound**, **coolant**, or **lubricant**.

Most metalworking and machining processes can benefit from the use of cutting fluid, depending on workpiece material. A common exception to this is machining cast iron or brass, which are machined dry.

The properties that are sought after in a good cutting fluid are the ability to:

- keep the workpiece at a stable temperature (critical when working to close tolerances). Very warm is OK, but extremely hot or alternating hot-and-cold are avoided.
- maximize the life of the cutting tip by lubricating the working edge and reducing tip welding.
- ensure safety for the people handling it (toxicity, bacteria, fungi) and for the environment upon disposal.
- prevent rust on machine parts and cutters.

Functions

Cooling

Metal cutting operations involve generation of heat due to friction between the tool and the pieces and due to energy lost deforming the material. The surrounding air alone is a rather poor coolant for the cutting tool, because the rate of heat transfer is low. Ambient-air cooling is adequate for light cuts with periods of rest in between, such as are typical in maintenance, repair and operations (MRO) work or hobbyist contexts. However, for heavy cuts and constant use, such as in production work, more heat is produced per time period than ambient-air cooling can remove. It is not acceptable to introduce long idle periods into the cycle time to allow the air-cooling of the tool to "catch up" when the heat-removal can instead be accomplished with a flood of liquid, which can "keep up" with the heat generation.

Lubrication

Besides cooling, cutting fluids also aid the cutting process by lubricating the interface between the tool's cutting edge and the chip. By preventing friction at this interface, some of the heat generation is prevented. This lubrication also helps prevent the chip from being welded onto the tool, which interferes with subsequent cutting.

Extreme pressure additives are often added to cutting fluids to further reduce tool wear.

Delivery methods

Every conceivable method of applying cutting fluid (e.g., flooding, spraying, dripping, misting, brushing) can be used, with the best choice depending on the application and the equipment available. For many metal cutting applications the ideal has long been high-pressure, high-volume pumping to force a stream of liquid (usually an oil-water emulsion) directly into the tool-chip interface, with walls around the machine to contain the splatter and a sump to catch, filter, and recirculate the fluid. This type of system is commonly employed, especially in manufacturing. It is often not a practical option for MRO or hobbyist metalcutting, where smaller, simpler machine tools are used. Fortunately it is also not necessary in those applications, where heavy cuts, aggressive speeds and feeds, and constant, all-day cutting are not vital.

As technology continually advances, the flooding paradigm is no longer always the clear winner. It has been complemented since the 2000s by new permutations of liquid, aerosol, and gas delivery, such as MQL and through-the-tool-tip cryogenic cooling.

Types

Liquids

There are generally three types of liquids: mineral, semi-synthetic, and synthetic. Semi-synthetic and synthetic cutting fluids try to blend the best properties of oil into the best properties of water. They basically achieve this by allowing oil to emulsify into water. Some of these properties are: rust inhibition, tolerance of a wide range of water hardness (maintain pH stability around 9 to 10), ability to work with many metals, resist thermal breakdown, and environmental safety.

Water is a great conductor of heat but has drawbacks as a cutting fluid. It boils easily, promotes rusting of machine parts, and does not lubricate well. Therefore, other ingredients are necessary to create an optimal cutting fluid.

Mineral oils, which are petroleum-based, began in the late 19th century. They vary from the thick, dark, sulfur-rich cutting oils used in heavy industry to light, clear oils.

Semi-synthetic coolants are an emulsion or microemulsion of water with mineral oil. They began in the 1930s. A typical CNC usually uses emulsified coolant, which consists of a small amount of oil emulsified into a larger amount of water through the use of a detergent.

Synthetic coolants originated in the late 1950s and are usually water-based.

A hand-held refractometer is used to determine the mix ratio (also called concentration) of water soluble coolants. Numerous other test equipment are used to determine such things as acidity, and amount of conductivity.

Others include:

- Kerosene, rubbing alcohol, and 3-In-One Oil often give good results when working on aluminium.
- WD-40
- Dielectric fluid is the cutting fluid used in Electrical discharge machines (EDMs). It is usually deionized water or a high-flash-point kerosene. Intense heat is generated by the cutting action of the electrode (or wire) and the fluid is used to stabilise the temperature of the workpiece, along with flushing any eroded particles from the immediate work area. The dielectric fluid is nonconductive.
- Liquid- (water- or petroleum oil-) cooled water tables are used with the plasma arc cutting (PAC) process.

Pastes or gels

Cutting fluid may also take the form of a paste or gel when used for some applications, in particular hand operations such as drilling and tapping. In sawing metal with a bandsaw, it is common to periodically run a stick of paste against the blade. This product is similar in form factor to lipstick or beeswax. It comes in a cardboard tube, which gets slowly consumed with each application.

Aerosols (mists)

Some cutting fluids are used in aerosol (mist) form (air with tiny droplets of liquid scattered throughout). The main problems with mists have been that they are rather bad for the workers, who have to breathe the surrounding mist-tainted air, and that they often don't even work very well. Both of those problems come from the imprecise delivery that often puts the mist everywhere and all the time except at the cutting interface, during the cut—the one place and time where it's wanted. However, a newer form of aerosol delivery, MQL (minimum quantity of lubricant), avoids both of those problems. The delivery of the aerosol is directly through the flutes of the tool (it arrives directly through or around the insert itself—an ideal type of cutting fluid delivery that traditionally has been unavailable outside of a few contexts such as gun drilling or expensive, state-of-the-art liquid delivery in production milling). MQL's aerosol is delivered in such a precisely targeted way (with respect to both location and timing) that the net effect seems almost like dry machining from the operators' perspective. The chips generally seem like dry-machined chips, requiring no draining, and the air is so clean that machining cells can be stationed closer to inspection and assembly than before.

Air or other gases (e.g., nitrogen)

Ambient air, of course, was the original machining coolant. Compressed air, supplied through pipes and hoses from an air compressor and discharged from a nozzle aimed at the tool, is sometimes a useful coolant. The force of the decompressing air stream blows chips away, and the decompression itself has a slight degree of cooling action ($pV=nRT$; lowering the pressure lowers the temperature).

Liquid nitrogen, supplied in pressurized steel bottles, is sometimes used in similar fashion. In this case, the decompression is enough to provide a powerful refrigerating effect. For years this has been done (in limited applications) by flooding the work zone. Since 2005, this mode of coolant has been applied in a manner comparable to MQL (with through-the-spindle and through-the-tool-tip delivery). This refrigerates the body and tips of the tool to such a degree that it acts as a "thermal sponge", sucking up the heat from the tool–chip interface. This new type of nitrogen cooling is still under patent. Tool life has been increased by a factor of 10 in the milling of tough metals such as titanium and inconel.

Past practice

- In 19th-century machining practice, it was not uncommon to use plain water. This was simply a practical expedient to keep the cutter cool, regardless of whether it provided any lubrication at the cutting edge–chip interface. When one considers that high-speed steel (HSS) had not been developed yet, the need to cool the tool becomes all the more apparent. (HSS retains its hardness at high temperatures; other carbon tool steels do not.) An improvement was soda water, which better inhibited the rusting of machine slides. These options are generally not used today because better options are available.
- Lard was very popular in the past. It is used infrequently today, because of the wide variety of other options, but it is still an option.
- Old machine shop training texts speak of using red lead and white lead, often mixed into lard or lard oil. This practice is obsolete due to the toxicity of lead.
- From the mid-20th century to the 1990s, 1,1,1-trichloroethane was used as an additive to make some cutting fluids more effective. In shop-floor slang it was referred to as "one-one-one". It has been phased out because of its ozone-depleting and central nervous system-depressing properties.

Safety concerns

Cutting fluids present some mechanisms for causing illness or injury in workers. These mechanisms are based on the external (skin) or internal contact involved in machining work, including touching the parts and tooling; being splattered or splashed by the fluid; or having mist settle on the skin or enter the mouth and nose in the normal course of breathing.

The mechanisms include the chemical toxicity or physical irritating ability of:

- the fluid itself
- the metal particles (from previous cutting) that are borne in the fluid
- the bacterial or fungal populations that naturally tend to grow in the fluid over time
- the biocides that are added to inhibit those life forms
- the corrosion inhibitors that are added to protect the machine and tooling

- the tramp oils that result from the way oils (the lubricants for the slideways) inevitably finding their way into the coolant

The toxicity or irritating ability is usually not high, but it is sometimes enough to cause problems for the skin or for the tissues of the respiratory tract or alimentary tract (e.g., the mouth, larynx, esophagus, trachea, or lungs).

Some of the diagnoses that can result from the mechanisms explained above include irritant contact dermatitis; allergic contact dermatitis; occupational acne; tracheitis; esophagitis; bronchitis; asthma; allergy; hypersensitivity pneumonitis (HP); and worsening of pre-existing respiratory problems.

Safer cutting fluid formulations provide a resistance to tramp oils, allowing improved filtration separation without removing the base additive package. Room ventilation, splash guards on machines, and personal protective equipment (PPE) (such as safety glasses, respirator masks, and gloves) can mitigate hazards related to cutting fluids.

Bacterial growth is predominant in semi-synthetic and synthetic fluids. Tramp oil along with human hair or skin oil are some of the debris during cutting which accumulates and forms a layer on the top of the liquid; anaerobic bacteria proliferate due to a number of factors. An early sign of the need for replacement is the "Monday-morning smell" (due to lack of usage from Friday to Monday). Antiseptics are sometimes added to the fluid to kill bacteria. Such use must be balanced against whether the antiseptics will harm the cutting performance, workers' health, or the environment. Maintaining as low a fluid temperature as practical will slow the growth of microorganisms.

The discussion above could leave a reader with the mistaken idea that cutting fluid is "often extremely dangerous". That would be an exaggeration. In reality, cutting fluid exposure is like many exposures in life, such as second-hand tobacco smoke; ethanol ingestion; paint and thinner fumes; kitchen or bakery smoke; smoke from smelting, casting, forging, or welding; contact with animal manure in farming, veterinary work, or pest control work; or contact with sewage in plumbing or sewer work. Such exposures only cause acute illness or injury in occasional cases where some situational factor was "out of normal bounds". Rather, the main health risk is that of chronic illness from long-term occupational exposure. Most machinists work around cutting fluids for years without adverse effects. They generally don't worry about casual contact, and they use PPE to minimize it.

Degradation, replacement, and disposal

Cutting fluids degrade over time due to contaminants entering the lubrication system. A common type of degradation is the formation of *tramp oil*, also known as *sump oil*, which is unwanted oil that has mixed with cutting fluid. It originates as lubrication oil that seeps out from the slideways and washes into the coolant mixture, as the protective film with which a steel supplier coats bar stock to prevent rusting, or as hydraulic oil leaks. In extreme cases it can be seen as a film or skin on the surface of the coolant or as floating drops of oil.

Skimmers are used to separate the tramp oil from the coolant. These are typically slowly rotating vertical discs that are partially submerged below the coolant level in the main reservoir. As the disc rotates the tramp oil clings to each side of the disc to be scraped off by two wipers, before the disc passes back through the coolant. The wipers are in the form a channel that then redirects the tramp oil to a container where it is collected for disposal. Floating weir skimmers are also used in these situation where temperature or the amount of oil on the water becomes excessive.

Since the introduction of CNC additives, the tramp oil in these systems can be managed more effectively through a continuous separation effect. The tramp oil accumulation separates from the aqueous or oil based coolant and can be easily removed with an absorbent.

Old, used cutting fluid must be disposed of when it is fetid or chemically degraded and has lost its usefulness. As with used motor oil or other wastes, its impact on the environment should be mitigated. Legislation and regulation specify how this mitigation should be achieved. Modern cutting fluid disposal involves techniques such as ultrafiltration using polymeric or ceramic membranes which concentrates the suspended and emulsified oil phase.

One shop's total costs for each instance of cutting fluid replacement came to USD 373, which included 2 hours of machine downtime (accounted at USD 50 per hour); 2 hours of labor (accounted at USD 12 per hour); USD 69 worth of new coolant concentrate (which is then mixed with water); and USD 3 per U.S. gallon for proper disposal of about 60 gallons (about 225 L) of coolant. Clearly, fluid formulations and machining practices that extend the working lifespan of each batch of coolant can be worth the costs of developing them.

Chapter-8

Architectural Metals and Mass Finishing

Architectural metals

Architectural metals used in buildings and structures comprise several distinctive metallic materials. Metals serve a wide variety of uses in the built landscape, including structural features, such as nails and trusses, as well as decorative features, such as doorknobs and cladding. Some metals discovered by early civilizations are still in use today. Scientific study has brought a greater understanding of the performance and limits of the various types of metals used in buildings.

Metal Types

Lead

The low melting point of lead permitted its use on a wide scale throughout human history. Water pipes were frequently constructed of lead, until its health hazards were publicized in the late 19th century.

Lead has been a popular roofing material for centuries, being used for roofing, flashing, gutters, downspouts, and conductor heads. Lead was best suited for low-pitched roofs, as steep roofs experienced creep. Lead roofs in regions with large temperature fluctuations, such as the mid-Atlantic states, experienced deterioration from constant expansion and contraction, called fatigue. Beginning in the 19th century, a roofing material called “terne” or “terneplate” was used, consisting of sheet iron or sheet steel coated with a lead-tin alloy. It is frequently confused with tinplate.

Lead was also frequently used for window cames, for use in skylights and stained glass. It was also used for small pieces of sculpture and garden ornamentation. Finally, lead was frequently added to paint, with red lead used as an anti-corrosive pigment for iron, and white lead used as paint for wooden houses. Lead-based paint was one of the most durable materials developed as a protective exterior coating. The use of lead paint has been restricted on most buildings, due to concerns of lead poisoning.

Tin

The principal architectural uses of tin fall into two categories: the alloying of tin with other metals such as copper to form bronze, and the coating of tin on harder metals, such as tinplated iron or steel. Architectural bronzes usually contain about 90% copper and 10% tin, although the content may vary widely. The term “tin ceiling” is a misnomer, as these decorative sheets were never tinned; they were almost always painted sheet iron or steel.

Tinplate was a type of architectural material consisting of sheet iron coated with tin. “Tin roofs,” a type of tinplate, was originally used for armor but eventually as a roofing material. Tinplate was also used for decoration, such as ornamental windows and door lintels. Although tinplate is still available today for roofing and flashing, it is generally considered expensive since the initial cost is more than that for common modern roofing types such as asphalt shingles or built-up roofs. However, since a well-maintained tinplate roof typically lasts several times longer than either of these types of roofing, it is more economical when the cost is prorated over the longer lifespan.

Zinc

Pure zinc was used for roofing in Belgium, France and Germany, where it replaced more expensive copper and lead in roofing. Starting in the 1820s, Belgian sheet zinc was imported in America, used by builders in New York City and elsewhere. Pure zinc is subject to creep at ordinary temperatures.

Zinc-coated metals were first patented in 1837, separately by M. Sorel in France and H. W. Crawford in England. The methods employed a “hot dipping” process to coat sheet iron with zinc. By 1839 “galvanized” sheet iron roofing was being used in New York City. The Merchant's Exchange in Manhattan was one of the first buildings to have both a galvanized roof and galvanized gutters. Some galvanized sheet roofing was pressed with designs, a mode very popular in the Victorian era.

Zinc was also cast for sculptures and decorative elements in Germany as early as 1832. Decorative architectural elements were frequently cast in zinc, since it molded readily, was inexpensive compared to stone, and could be painted to imitate more expensive metals.

Zinc oxide paints were nontoxic and resistant to pollution. They became commercially successful and readily available in America in about 1850 and used widely starting around the 1870s. They had the added benefit of being good inhibitors against rust on iron and steel.

During the early decades of the 20th century, the use of pure zinc roofing and ornament decreased in use in the United States. It is now back on the upswing and gaining popularity in its pure form (99.95%)for building materials. Zinc is still used in alloys such as brass and nickel silver, and in the electroplating of steel as well. Today, galvanized steel and pure zinc material, usually Double Locked Standing Seam panels, are used for roofing a variety of buildings. Creep has been reduced by the introduction of titanium in most architectural zinc available in North America. Galvanized nails and sheet metal ducts are also common.

Copper and Copper Alloys

The "cupric" metals include copper and its alloys, especially bronze, an alloy of copper and tin, and brass, an alloy of copper and zinc. Copper is a very durable metal, withstanding corrosion when forming a green patina, copper sulfate. Sheet copper used as roofing is lighter than wooden shingles and much lighter than slate, tile, or lead. Roofing copper can be folded readily into waterproof seams, or shaped over curved frameworks for cupolas and domes.

The initial cost of copper was traditionally high, but its length of service more than compensated for the price. Copper could also be shaped to the bends and angles around chimneys and at roof edges and dormers. All nails, screws, bolts, and cleats used with sheet copper had to be made of copper or a copper alloy; otherwise "galvanic" action between the dissimilar metals would occur, causing deterioration.

Copper was also used for decorative purposes, including architectural ornaments or sculptures. A very famous example of this is the Statue of Liberty.

With aging it turns a deep light green color.

Nickel and Nickel Alloys

Although somewhat rare, nickel has been used for plating architectural details. Nickel is most frequently used for building components in the form of alloys: nickel silver, Monel metal, and stainless steel.

Nickel silver was originally called "German Silver," until World War I. It has been called "white brass" but probably should be termed "nickel brass," because it generally contains 75% copper, 20% nickel, and 5% zinc. Different percentages result in a range of colors, including silvery-white, yellow, slight blue, green or pink. Nickel silver hardware was popular in the United States during the Art Deco and Depression Modern periods. Architects and designers preferred nickel silver because it could take and retain appropriate finishes, and it resisted corrosion.

Monel metal is an alloy of approximately two-thirds nickel and one-third copper. It is similar to platinum in color. Monel pioneered many of the present uses of stainless steel. The first architectural use of Monel was for roofing of the Pennsylvania Railroad Terminal in New York City in 1909. In 1936, the copper roof on the New York City Public Library at Fifth Avenue and 42nd Street was replaced with a Monel metal roof. Its advantages as a roofing material included its ability to be brazed, welded, or soldered in place to provide a watertight, continuous cover. Monel was popular during the Art Deco periods. During World War II, however, large quantities of nickel and copper had to be diverted to the war effort and the supply of Monel was greatly reduced. Following the war, stainless steel and aluminium replaced Monel because of lower production costs.

Iron and Iron Alloys

Iron has become an important architectural building component. It has been used in four common forms: wrought iron, cast iron, sheet iron, and steel.

Wrought iron was used for minor structural and decorative elements starting in the 18th century. Until the mid-19th century, the use of wrought iron in buildings was generally limited to small items such as tie rods, straps, nails, and hardware, or to decorative ironwork in balconies, railings fences and gates. Around 1850 its structural use became more widespread as iron mills began to roll rails, bulb-tees, and eventually I-beams. It was also used for decorative purposes, such as ornamental balconies or hardware. Since wrought iron is handmade, no two pieces are identical.

Cast iron was a major 19th century building material of the Industrial Revolution. Although brittle, it is remarkably strong in compression. It was frequently used for structural purposes, such as columns,, building fronts, domes and light courts. Decorative uses have included stairs, elevators, lintels, grilles, verandas, balconies, railings, fences, streetlights, and tombs. The Bradbury Building is one example of extensive decorative cast iron use. Today, cast iron is used for plumbing fixtures and piping in new construction, and its structural and decorative use is used occasionally through historic preservation practices.

Sheet iron can be subject to rapid corrosion, forming rust. Sheet iron was used throughout the 19th century, although it is not clear how widespread sheet iron roofs became. Pressed decorative sheet iron used for ceilings was frequently called a “tin ceiling,” although tin was generally not present for indoor uses.

Steel was introduced to the construction industry at the end of the 19th century. The development of structural steel in the mid-19th century allowed tall buildings to be constructed. Builders and manufacturers turned to steel, which was stronger than cast iron in compression and wrought iron in tension. when the Bessemer process was developed in England in 1856, and the open-hearth process was invented, steel was produced in a quantity that allowed it to be economical. Bridges, railroad companies, and skyscrapers were among the first large-scale uses of structural steel. Although iron and steel are not combustible, they lose strength in a fire if they are not protected from the heat. Almost all structural steel has to be “fireproofed” in some manner, utilizing a cladding of terra-cotta, tile, plaster- poured concrete, sprayed concrete, or sprayed insulation. Ferro concrete, also called reinforced concrete, was developed in the late 19th century when steel wire was added to concrete.

Decorative steels used in buildings include:

- Stainless steel, a chromium-nickel steel, developed between 1903 and 1912. Its most important property is its resistance to corrosion. It contains about 18% chromium and 8-12% nickel. Stainless steel is expensive, so it was used primarily as a nonstructural metal or where there is a high potential for corrosion. One of the most extensive early uses of stainless steel was in the Chrysler Building.
- Copper-bearing steels, containing from .15% to .25% copper, develop increased resistance to atmospheric corrosion, when compared to ordinary steel, by forming a protective oxide coating, having a uniform deep brown color and texture. Eero Saarinen experimented with the material in the Deere and Company building in 1964.

Aluminum

Aluminum was not available at a reasonable price or in sufficient quantities for general architectural use until after the beginning of the 20th century. Architectural use of aluminum increased in the 1920s, mainly for decorative detailing. It was used for roofing, flashing, gutters, downspouts, wall panels, and spandrels. Art Deco designs frequently used aluminum for ornamental features. The first extensive use of aluminum in construction was the Empire State Building, where the entire tower portion is aluminum, as well as many decorative features, such as the entrances, elevator doors, ornamental trim, and some 6,000 window spandrels. Today, aluminum is used frequently in construction except major structural members.

Mass finishing

Mass finishing is a group of manufacturing processes that allow large quantities of parts to be simultaneously finished. The goal of this type of finishing is to burnish, deburr, clean, radius, de-flash, descale, remove rust, polish, brighten, surface harden, prepare parts for further finishing, or break off die cast runners. The two main types of mass finishing are tumble finishing, also known as barrel finishing, and vibratory finishing. Both involve the use of a cyclical action to create grinding contact between surfaces. Sometimes the workpieces are finished against each other; however, usually a finishing medium is used. Mass finishing can be performed dry or wet; wet processes have liquid lubricants, cleaners, or abrasives, while dry processes do not. Cycle times can be as short as 10 minutes for nonferrous workpieces or as long as 2 hours for hardened steel.

Mass finishing processes can be configured as either batch systems, in which batches of workpieces are added, run, and removed before the next batch is run, or as continuous systems, in which the workpieces enter at one end and leave at the other end in the finished state. They may also be sequenced, which involves running the workpieces through multiple different mass finishing processes; usually, the finish becomes progressively finer. Due to the random action of the processes, mass finishing is as much an art as it is a science.

Media

Media are designed for four things:

Cut
: Media which cut can remove burrs and can smooth surfaces. As a carrier of abrasive grain, the large medium pieces effectively increase the impact force of the abrasive on the metal part to be cut, thereby improving the efficiency of the abrasive. Cutting media develop dull, matte surfaces.

Luster
: Some grades of medium are designed to promote luster on the surface of metal parts. These products are generally non-abrasive or have a very low degree of abrasiveness. They deburr by peening, rather than actually removing the burr. Media selection, therefore, will control the degree of surface luster, making the part bright and shiny or developing a very matte, dull surface characterized by a completely random scratch pattern, or anything in between.

Part separation
: A very important function of the medium is to separate parts during the deburring, cutting, surface improving or burnishing operations. The media:parts volume ratio is normally used to control the amount of part-on-part contact which will occur in a vibratory or tumble finishing operation. At low ratios, considerable part-on-part contact occurs, while at higher ratios part-on-part contact is limited.

Surface scrubbing
: Media have the unique ability to scrub surfaces and physically assist compounds in their cleaning function. Both abrasive and non-abrasive media are effective in this. They can remove organic soils, scale, and other inorganic residues.

Media come in a wide range of materials in order to fulfill various needs.

Aluminum media
: Aluminium media are typically cast parts and are available in a wide variety of shapes and sizes. Aluminum scrubs parts and can work in conjunction with cleaning compounds to clean parts. Since aluminum is fairly nonabrasive it tends to remove surface impurities without affecting the part's surface qualities. Its cost is typically higher than other cast media. Wear rates are lower than ceramic but higher than steel media.

Preformed ceramic media
: Ceramic media are manufactured by mixing clay-like materials and water with abrasives, forming the mud into shapes, drying the shapes, and firing them at high temperatures to vitrify the binder. Many of these binders are porcelain-like in nature. Variability in these products occur both with the type of binder used, firing temperatures, the amount, size and type of abrasive grains they contain, and their uniformity of firing. This type of media today is the general workhorse of

mass finishing systems and is the type of medium generally used, because of its availability in a variety of shapes and sizes, low cost, and low wear rate.

Preformed resin-bonded media

Plastic or resin-bonded media utilize a wider range of abrasive types and sizes than preformed ceramics. The most popular grades are those using quartz as an abrasive. Aluminum oxide, silicon carbide and other abrasives are also used. Usually, low-cost polyester resins are employed as the binder and the various shapes are produced by casting. Resin bonded media is good for preparing a metal surface for plating.

Steel

Case hardened, stress-relieved steel preformed shapes are available in a variety of sizes and configurations. Balls, balls with flat spots, ovoids (footballs), diagonally cut wire similar to angle-cut cylinders, ball cones and cones (both of which are different than the general concept of cones) and pins are the most commonly used. Steel media weigh approximately 300 pounds per cubic foot and are expensive for initial installation, but, because of their minimal attrition rate and extreme cleanliness, are being more widely used for light deburring applications and cleaning. Compounds are available to keep steel burnishing media clean and bright for extended periods.

Synthetic random-shaped media

The most popular synthetic random media is fused aluminum oxide, which is available in a number of grades. The more loosely bound, coarse-grained materials are characterized by fast cut and high depreciation rates. Because of the dark color of fused aluminum oxide, the soil generated by this material is excessive in many applications. Fine-grained fused aluminum oxide is generally employed for burnishing and in this respect is unexcelled in many applications with the possible exception of steel. Where some light cutting is required, fine-grained aluminum oxide can develop a better luster on stainless steels and other hard surfaces than can be achieved with steel burnishing media.

Natural random-shaped media

River rock, granite, quartz, limestone, emery and other naturally occurring abrasive materials are also used in vibratory and tumble finishing applications. In general, these media are not very efficient in vibratory equipment because of their high attrition rates.

Cobmeal, walnut-shell flour, and related materials

These are used for drying applications because of the natural ability of these materials to absorb water from metal surfaces. These can also be blended with abrasives and used for fine-polishing applications in vibratory, barrel, or spindle finishing equipment.

Other

Shoe pegs, leather, carpet tacks, and many other solid materials have been used at one time or another in tumble or vibratory finishing for certain applications.

Compounds

Compounds are added to mass finishing processes to assist in deburring, burnishing, cutting, cleaning, descaling, and inhibiting corrosion. They may be liquids or dry powders. They are usually broken up into four types: deburring and finishing, burnishing, cleaning, and water stabilizing.

Deburring and finishing

These compounds are mainly designed to suspend the small particles created when deburring and abrading parts. They are also designed to keep workpieces clean and inhibit corrosion.

Burnishing

Burnishing compounds are designed to enhance brightness and to develop certain colors after mass finishing.

Cleaning

These compounds are usually dilute acids or soaps designed to remove soil, grease, or oil from the incoming parts. They also provide corrosion resistance for ferrous and non-ferrous parts.

Water stabilizers

These are used in conjunction with water to maintain a consistent water hardness and level of metal ions. This helps ensure consistent results from batch to batch.

Chapter-9

Abrasive

An **abrasive** is a material, often a mineral, that is used to shape or finish a workpiece through rubbing which leads to part of the workpiece being worn away. While finishing a material often means polishing it to gain a smooth, reflective surface it can also involve roughening as in satin, matte or beaded finishes.

Abrasives are extremely commonplace and are used very extensively in a wide variety of industrial, domestic, and technological applications. This gives rise to a large variation in the physical and chemical composition of abrasives as well as the shape of the abrasive. Common uses for abrasives include grinding, polishing, buffing, honing, cutting, drilling, sharpening, lapping, and sanding.

Files act by abrasion but are not classed as abrasives as they are a shaped bar of metal. However, diamond files are a form of coated abrasive (as they are metal rods coated with diamond powder).

Mechanics of abrasion

Abrasives generally rely upon a difference in hardness between the abrasive and the material being worked upon, the abrasive being the harder of the two substances. However, this is not necessary as any two solid materials that repeatedly rub against each other will tend to wear each other away (such as softer shoe soles wearing away wooden or stone steps over decades or centuries or glaciers abrading stone valleys).

Typically, materials used as abrasives are either hard minerals (rated at 7 or above on Mohs scale of mineral hardness) or are synthetic stones, some of which may be chemically and physically identical to naturally occurring minerals but which cannot be called minerals as they did not arise naturally. (While useful for comparative purposes, the Mohs scale is of limited value to materials engineers as it is an arbitrary, ordinal, irregular scale.) Diamond, a common abrasive, for instance occurs both naturally and is industrially produced , as is corundum which occurs naturally but which is nowadays more commonly manufactured from bauxite. However, even softer minerals like calcium carbonate are used as abrasives, such as "polishing agents" in toothpaste.

Grit size ranging from 2 mm (the large grain) (about F 10 using FEPA standards) to about 40 micrometres (about F 240 or P 360).

These minerals are either crushed or are already of a sufficiently small size (anywhere from macroscopic grains as large as about 2 mm to microscopic grains about 0.001 mm in diameter) to permit their use as an abrasive. These grains, commonly called grit, have rough edges, often terminating in points which will decrease the surface area in contact and increase the localised contact pressure. The abrasive and the material to be worked are brought into contact while in relative motion to each other. Force applied through the grains causes fragments of the worked material to break away while simultaneously smoothing the abrasive grain and/or causing the grain to work loose from the rest of the abrasive.

Some factors which will affect how quickly a substance is abraded include:

- Difference in hardness between the two substances: a much harder abrasive will cut faster and deeper
- Grain size (grit size): larger grains will cut faster as they also cut deeper
- Adhesion between grains, between grains and backing, between grains and matrix: determines how quickly grains are lost from the abrasive and how soon fresh grains, if present, are exposed

- Contact force: more force will cause faster abrasion
- Loading: worn abrasive and cast off work material tends to fill spaces between abrasive grains so reducing cutting efficiency while increasing friction
- Use of lubricant/coolant/metalworking fluid: Can carry away swarf (preventing loading), transport heat (which may affect the physical properties of the workpiece or the abrasive), decrease friction (with the substrate or matrix), suspend worn work material and abrasives allowing for a finer finish, conduct stress to the workpiece.

Abrasive minerals

Abrasives may be classified as either natural or synthetic. When discussing sharpening stones, natural stones have long been considered superior but advances in material technology are seeing this distinction become less distinct. Many synthetic abrasives are effectively identical to a natural mineral, differing only in that the synthetic mineral has been manufactured rather than been mined. Impurities in the natural mineral may make it less effective.

Some naturally occurring abrasives are:

- Calcite (calcium carbonate)
- Emery (impure corundum)
- Diamond dust (synthetic diamonds are used extensively)
- Novaculite
- Pumice dust
- Rouge
- Sand

Some abrasive minerals (such as zirconia alumina) occur naturally but are sufficiently rare or sufficiently more difficult/costly to obtain such that a synthetic stone is used industrially. These and other artificial abrasives include:

- Borazon (cubic boron nitride or CBN)
- Ceramic
- Ceramic aluminium oxide
- Ceramic iron oxide
- Corundum (alumina or aluminium oxide)
- Dry ice
- Glass powder
- Steel abrasive
- Silicon carbide (carborundum)
- Zirconia alumina

Manufactured abrasives

Abrasives are shaped for various purposes. Natural abrasives are often sold as dressed stones, usually in the from of a rectangular block. Both natural and synthetic abrasives are commonly available in a wide variety of shapes, often coming as bonded or coated abrasives, including blocks, belts, discs, wheels, sheets, rods and loose grains.

Bonded abrasives

Assorted grinding wheels as examples of bonded abrasives.

A grinding wheel with a reservoir to hold water as a lubricant and coolant.

A **bonded abrasive** is composed of an abrasive material contained within a matrix, although very fine aluminium oxide abrasive may comprise sintered material. This matrix is called a binder and is often a clay, a resin, a glass or a rubber. This mixture of binder and abrasive is typically shaped into blocks, sticks, or wheels. The most usual abrasive used is aluminium oxide. Also common are silicon carbide, tungsten carbide and garnet. Artificial sharpening stones are often a bonded abrasive and are readily available as a two sided block, each side being a different grade of grit.

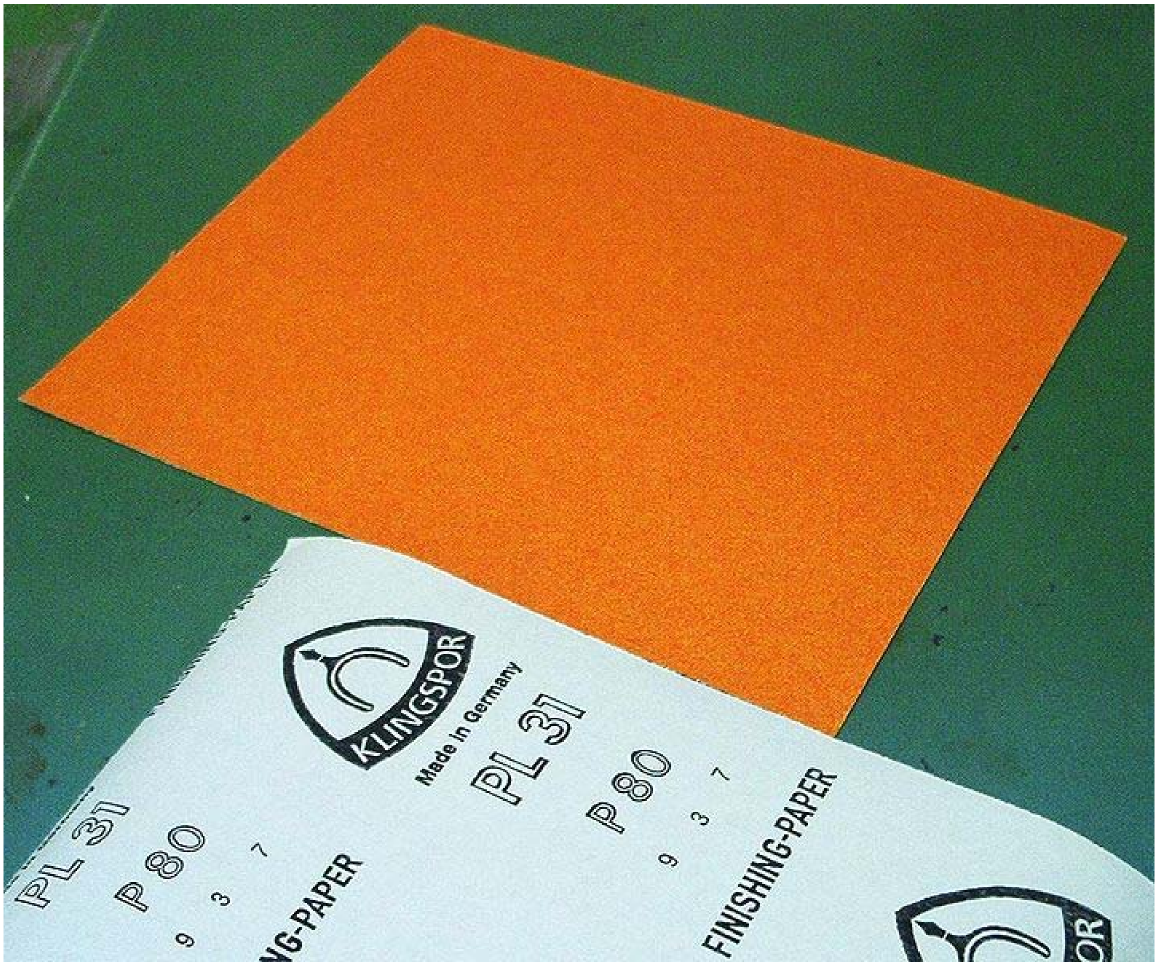
Grinding wheels are cylinders that are rotated at high speed. While once worked with a foot pedal or hand crank, the introduction of electric motors has made it necessary to construct the wheel to withstand greater radial stress to prevent the wheel flying apart as it spins. Similar issues arise with cutting wheels which are often structurally reinforced with impregnated fibres. High relative speed between abrasive and workpiece often makes necessary the use of a lubricant of some kind. Traditionally they were called coolants as they were used to prevent frictional heat build up which could damage the workpiece (such as ruining the temper of a blade). Some research suggests that the heat transport property of a lubricant is less important when dealing with metals as the metal will quickly conduct heat from the work surface. More important are their effects upon lessening tensile stresses while increasing some compressive stresses and reducing "thermal and mechanical stresses during chip formation".

Various shapes are also used as heads on rotary tools used in precision work, such as scale modelling.

Bonded abrasives need to be trued and dressed after they are used. Dressing is cleaning the waste material (swarf and loose abrasive) from the surface and exposing fresh grit. Depending upon the abrasive and how it was used, dressing may involve the abrasive being simply placed under running water and brushed with a stiff brush for a soft stone or the abrasive being ground against another abrasive, such as aluminium oxide used to dress a grinding wheel.

Truing is restoring the abrasive to its original surface shape. Wheels and stones tend to wear unevenly, leaving the cutting surface no longer flat (said to be "dished out" if it is meant to be a flat stone) or no longer the same diameter across the cutting face. This will lead to uneven abrasion and other difficulties.

Coated abrasives

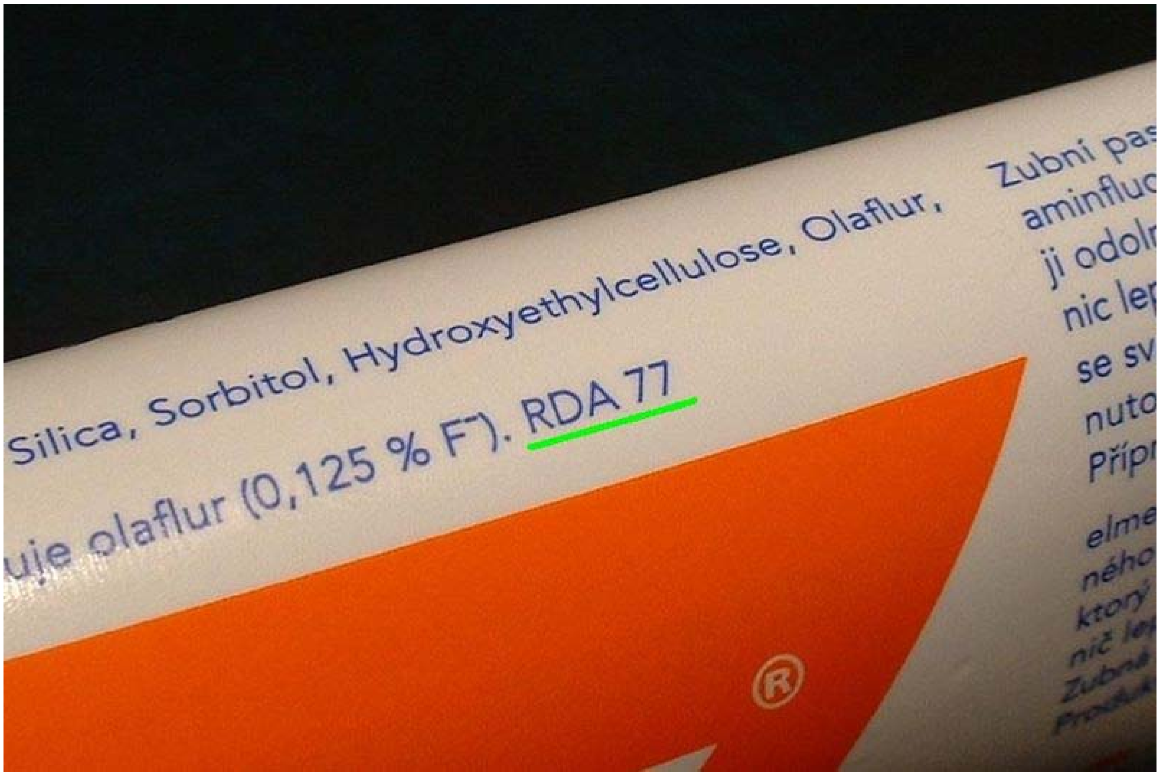


A German sandpaper showing its backing and FEPA grit size.

A *coated abrasive* comprises an abrasive fixed to a backing material such as paper, cloth, rubber, resin, polyester or even metal, many of which are flexible. Sandpaper is a very common coated abrasive. Coated abrasives are commonly the same minerals as are used for bonded abrasives. A bonding agent (often some sort of adhesive or resin) is applied to the backing to provide a flat surface to which the grit is then subsequently adhered. A woven backing may also use a filler agent (again, often a resin) to provide additional resilience.

Coated abrasives may be shaped for use in rotary and orbital sanders, for wrapping around sanding blocks, as handpads, as closed loops for use on belt grinders, as striking surfaces on matchboxes, on diamond plates and diamond steels. Diamond tools, though for cutting, are often abrasive in nature.

Other abrasives and their uses



Here the abrasiveness of toothpaste is detailed by its Relative Dentin Abrasivity (RDA)

Sand, glass beads, metal pellets copper slag and dry ice may all be used for a process called sandblasting (or similar, such as the use of glass beads which is "bead blasting"). Dry ice will sublimate leaving behind no residual abrasive.

Cutting compound used on automotive paint is an example of an abrasive suspended in a liquid, paste or wax, as are some polishing liquids for silverware and optical media. The liquid, paste or wax acts as a binding agent that keeps the abrasive attached to the cloth which is used to as a backing to move the abrasive across the workpiece. On cars in particular, wax may serve as both a protective agent by preventing exposure of the paint of metal to air and also act as an optical filler to make scratches less noticeable. Toothpaste contains calcium carbonate or silica as a "polishing agent" to remove plaque and other matter from teeth as the hardness of calcium carbonate is less than that of tooth enamel but more than that of the contaminating agent.

Very fine rouge powder was commonly used for grinding glass, being somewhat replaced by modern ceramics, and is still used in jewellery making for a highly reflective finish.

Cleaning products may also contain abrasives suspended in a paste or cream. They are chosen to be reasonably safe on some linoleum, tile, metal or stone surfaces. However, many laminate surfaces and ceramic topped stoves are easily damaged by these abrasive compounds. Even ceramic/pottery tableware or cookware can damage these surfaces, particularly the bottom of the tableware which is often unglazed in part or in whole and acts as simply another bonded abrasive.

Metal pots and stoves are often scoured with abrasive cleaners, typically in the form of the aforementioned cream or paste or of steel wool and non woven scouring pads which holds fine grits abrasives.

Human skin is also subjected to abrasion in the form of exfoliation. Abrasives for this can be much softer and more exotic than for other purposes and may include things like almond and oatmeal. Dermabrasion and microdermabrasion are now rather commonplace cosmetic procedures which use mineral abrasives.

Scratched compact discs and DVDs may sometimes be repaired through buffing with a very fine compound, the principle being that a multitude of small scratches will be more optically transparent than a single large scratch. However, this does take some skill and will eventually cause the protective coating of the disc to be entirely eroded (especially if the original scratch is deep), after which the data surface will be destroyed if abrasion continues.

Choice of abrasive

The shape, size and nature of the workpiece and the desired finish will influence the choice of the abrasive used. A bonded abrasive grind wheel may be used to commercially sharpen a knife (producing a hollow grind), but an individual may then sharpen the same knife with a natural sharpening stone or an even flexible coated abrasive (like a sandpaper) stuck to a soft, non-slip surface to make achieving a convex grind easier. Similarly, a brass mirror may be cut with a bonded abrasive, have its surface flattened with a coated abrasive to achieve a basic shape, and then have finer grades of abrasive successively appied culminating in a wax paste impregnated with rouge to leave a sort of "grainless finish" called, in this case, a "mirror finish".

Also, different shapes of adhesive may make it harder to abrade certain areas of the workpiece. Health hazards can arise from any dust produced (which may be ameliorated through the use of a lubricant) which could lead to silicosis (when the abrasive or workpiece is a silicate) and the choice of any lubricant. Besides water, oils are the most common lubricants. These may present inhalation hazards, contact hazards and, as friction necessarily produces heat, flammable material hazards.

An abrasive which is too hard or too coarse can remove too much material or leave undesired scratch marks. Besides being unsightly, scratching can have other, more serious effects. Excessive abrasion or the presence of scratches may:

- diminish or destroy usefulness (as in the case of scratched optics and compact discs or a dull knife);
- trap dirt, water, or other material;

- increase surface area (permitting greater chemical reactivity such as increased rusting which is also affected by matter caught in scratches);
- erode or penetrate a coating (such as a paint or a chemical or wear resistant coating);
- overly quickly cause an object to wear away (such as a blade or a gemstone);
- increase friction (as in jeweled bearings and pistons).

A finer or softer abrasive will tend to leave much finer scratch marks which may even be invisible to the naked eye (a "grainless finish"); a softer abrasive may not even significantly abrade a certain object. A softer or finer abrasive will take longer to cut as tends to cut less deeply than a coarser, harder material. Also, the softer abrasive may become less effective more quickly as the abrasive is itself abraded. This allows fine abrasives to be used in the polishing of metal and lenses where the series of increasingly fine scratches tends to take on a much more shiny or reflective appearance or greater transparency. Very fine abrasives may be used to coat the strop for a cut-throat razors, however, the purpose of stropping is not to abrade material but to straighten the burr on an edge. The final stage of sharpening Japanese swords is called polishing and may be a form of superfinishing.

Different chemical or structural modifications may be made to alter the cutting properties of the abrasive.

Other very important considerations are price and availability. Diamond, for a long time considered the hardest substance in existence, is actually softer than fullerite and even harder aggregated diamond nanorods, both of which have been synthesised in laboratories but no commercial process has yet been developed. Diamond itself is expensive due to scarcity in nature and the cost of synthesising it. Bauxite is a very common ore which, along with corundum's reasonably high hardness, contributes to corundum's status as a common, inexpensive abrasive.

Thought must be given to the desired task about using an appropriately hard abrasive. At one end, using an excessively hard abrasive wastes money by wearing it down when a cheaper, less hard abrasive would suffice. At the other end, if too soft, abrasion does not take place in a timely fashion, effectively wasting the abrasive as well as any accruing costs associated with loss of time.

Other instances of abrasion

Aside from the aforementioned uses of shaping and finishing, abrasives may also be used to prepare surfaces for application of some sort of paint of adhesive. An excessively smooth surface may prevent paint and adhesives from adhering as strongly as an irregular surface could allow. Inflatable tyre repair kits (which, on bicycles particularly, are actually patches for the inner tube rather than the tyre) require use of an abrasive so that the self-vulcanising cement will stick strongly.

Inadvertently, people who use knives on glass or metal cutting boards are abrading their knife blades. The pressure at the knife edge can easily create microscopic (or even macroscopic) cuts in the board. This cut is a ready source of abrasive material as well as a channel full of this abrasive through which the edge slides. For this reason—without regard for the health benefits—wooden boards are much more desirable. A similar occurrence arises with glass-cutters. Glass-cutters are have circular blades that are designed to roll not slide. They should never retrace an already effected cut.

Undesired abrasion may result from the presence of carbon in internal combustion engines. While smaller particles are readily transported by the lubrication system, larger carbon particles may abrade components with close tolerances. The carbon arises from the excessive heating of engine oil or from incomplete combustion. This soot may contain fullerenes which are noted for their extreme hardness—and small size and limited quantity which would tend to limit their effect.

Chapter-10

Fabrication (metal)

A typical steel fabrication shop

A set of six-axis welding robots.

Fabrication as an industrial term refers to building metal structures by cutting, bending, and assembling. The cutting part of fabrication is via sawing, shearing, or chiseling (all with manual and powered variants); torching with handheld torches (such as oxy-fuel torches or plasma torches); and via CNC cutters (using a laser, torch, or water jet). The bending is via hammering (manual or powered) or via press brakes and similar tools. The assembling (joining of the pieces) is via welding, binding with adhesives, riveting, threaded fasteners, or even yet more bending in the form of a crimped seam. Structural steel and sheet metal are the usual starting materials for fabrication, along with the welding wire, flux, and fasteners that will join the cut pieces. As with other manufacturing processes, both human labor and automation are commonly used. The product resulting from (the process of) fabrication may be called a fabrication. Shops that specialize in this type of metal work are called *fab shops*. The end products of other common types of metalworking, such as machining, metal stamping, forging, and casting, may be similar in shape and function, but those processes are not classified as fabrication.

Fabrication comprises or overlaps with various metalworking specialties:

- Fabrication shops and machine shops have overlapping capabilities, but fabrication shops generally concentrate on metal preparation and assembly as described above. By comparison, machine shops also cut metal, but they are more concerned with the machining of parts on machine tools. Firms that encompass both fab work and machining are also common.

- Blacksmithing has always involved fabrication, although it was not always called by that name.
- The products produced by welders, which are often referred to as weldments, are an example of fabrication.
- Boilermakers originally specialized in boilers, leading to their trade's name, but the term as used today has a broader meaning.
- Similarly, millwrights originally specialized in setting up grain mills and saw mills, but today they may be called upon for a broad range of fabrication work.
- Ironworkers, also known as steel erectors, also engage in fabrication. Often the fabrications for structural work begin as prefabricated segments in a fab shop, then are moved to the site by truck, rail, or barge, and finally are installed by erectors.

Metal fabrication

Metal fabrication is a value added process that involves the construction of machines and structures from various raw materials. A fab shop will bid on a job, usually based on the engineering drawings, and if awarded the contract will build the product.

Fabrication shops are employed by contractors, OEM's and VAR's. Typical projects include; loose parts, structural frames for buildings and heavy equipment, and hand railings and stairs for buildings.

Engineering

The fabricator may employ or contract out steel detailers to prepare shop drawings, if not provided by the customer, which the fabricating shop will use for manufacturing. Manufacturing engineers will program CNC machines as needed.

Raw materials

Standard raw materials used by metal fabricators are;

- plate metal
- formed and expanded metal
    - tube stock, CDSM
    - square stock
    - sectional metals (I beams, W beams, C-channel...)
- welding wire
- hardware
- castings
- fittings

Cutting and burning

The raw material has to be cut to size. This is done with a variety of tools.

The most common way to cut material is by Shearing (metalworking);

Special band saws designed for cutting metal have hardened blades and a feed mechanism for even cutting. Abrasive cut-off saws, also known as chop saws, are similar to miter saws but with a steel cutting abrasive disk. Cutting torches can cut very large sections of steel *with little effort*.

Burn tables are CNC cutting torches, usually natural gas powered. Plasma and laser cutting tables, and Water jet cutters, are also common. Plate steel is loaded on a table and the parts are cut out as programmed. The support table is made of a grid of bars that can be replaced. Some very expensive burn tables also include CNC punch capability, with a carousel of different punches and taps. Fabrication of structural steel by plasma and laser cutting introduces robots to move the cutting head in three dimensions around the material to be cut.

Forming

Hydraulic brake presses with v-dies are the most common method of forming metal. The cut plate is placed in the press and a v-shaped die is pressed a predetermined distance to bend the plate to the desired angle. Wing brakes and hand powered brakes are sometimes used.

Tube bending machines have specially shaped dies and mandrels to bend tubular sections without kinking them.

Rolling machines are used to form plate steel into a round section.

English Wheel or Wheeling Machines are used to form complex double curvature shapes using sheet metal.

Machining

Fab shops will generally have a limited machining capability including; metal lathes, mills, magnetic based drills along with other portable metal working tools.

Welding

Welding is the main focus of steel fabrication. The formed and machined parts will be assembled and tack welded into place then re-checked for accuracy. A fixture may be used to locate parts for welding if multiple weldments have been ordered.

The welder then completes welding per the engineering drawings, if welding is detailed, or per his own judgment if no welding details are provided.

Special precautions may be needed to prevent warping of the weldment due to heat. These may include re-designing the weldment to use less weld, welding in a staggered fashion, using a stout fixture, covering the weldment in sand during cooling, and straightening operations after welding.

Straightening of warped steel weldments is done with an Oxy-acetylene torch and is somewhat of an art. Heat is selectively applied to the steel in a slow, linear sweep. The steel will have a net contraction, upon cooling, in the direction of the sweep. A highly skilled welder can remove significant warpage using this technique.

Steel weldments are occasionally annealed in a low temperature oven to relieve residual stresses.

Final assembly

After the weldment has cooled it is generally sand blasted, primed and painted. Any additional manufacturing specified by the customer is then completed. The finished product is then inspected and shipped.

Specialities

Many fabrication shops have speciality processes which they develop or invest in, based on their customers needs and their expertise:

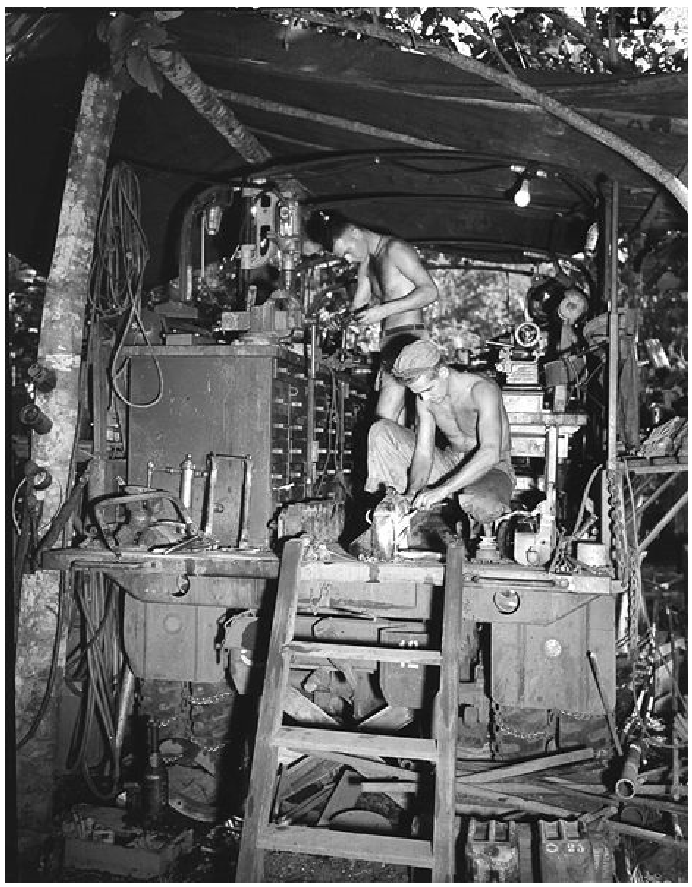
- brazing
- casting
- chipping
- drawing
- extrusion
- forging
- heat treatment
- hydroforming
- oven soldering
- plastic fabrication
- powder coating
- powder metallurgy
- punching
- shearing
- spinning
- English wheeling
- welding

And higher-level specializations such as:

- electrical
- hydraulics
- prototyping/machine design/technical drawing
- sub-contract manufacturing

Chapter-11

Machining

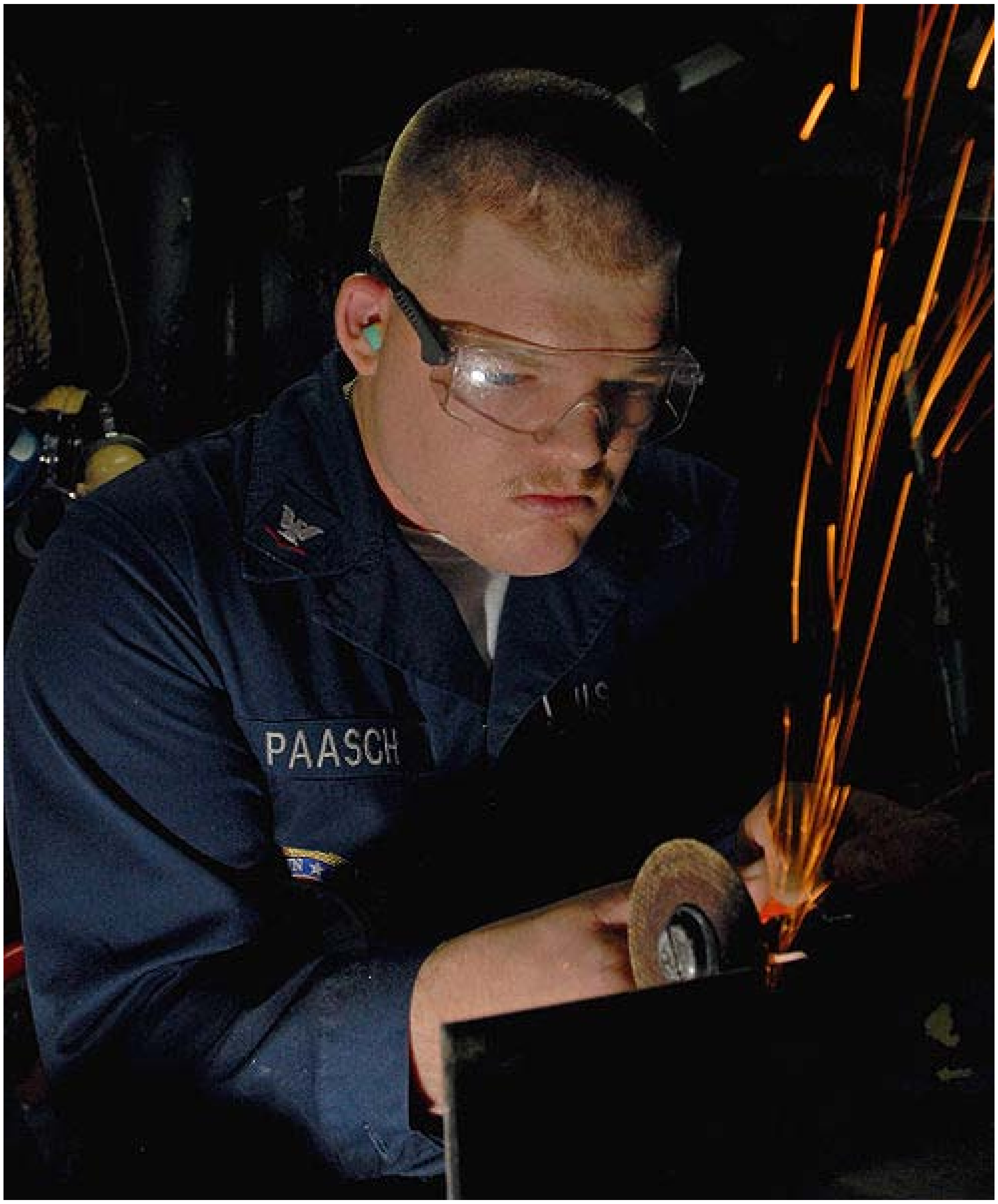


New Guinea in 1943. Mobile Machine Shop truck of the US Army with machinists working on automotive parts.

Conventional **machining**, one of the most important material removal methods, is a collection of material-working processes in which power-driven machine tools, such as saws, lathes, milling machines, and drill presses, are used with a sharp cutting tool to mechanically cut the material to achieve the desired geometry. Machining is a part of the manufacture of almost all metal products, and it is common for other materials, such as wood and plastic, to be machined. A person who specializes in machining is called a **machinist**. A room, building, or company where machining is done is called a **machine shop**. Much of modern day machining is controlled by computers using computer numerical control (CNC) machining. Machining can be a business, a hobby, or both.

The precise meaning of the term "machining" has evolved over the past 1.5 centuries as technology has advanced. During the Machine Age, it referred to (what we today might call) the "traditional" machining processes, such as turning, boring, drilling, milling, broaching, sawing, shaping, planing, reaming, and tapping, or sometimes to grinding. Since the advent of new technologies such as electrical discharge machining, electrochemical machining, electron beam machining, photochemical machining, and ultrasonic machining, the retronym "conventional machining" can be used to differentiate the classic technologies from the newer ones. The term "machining" without qualification usually implies conventional machining.

Machining operations



Making a shipboard manhole cover in the machine shop of the aircraft carrier USS *John C. Stennis*.

The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planing, boring, broaching and sawing.

- Turning operations are operations that rotate the workpiece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning.

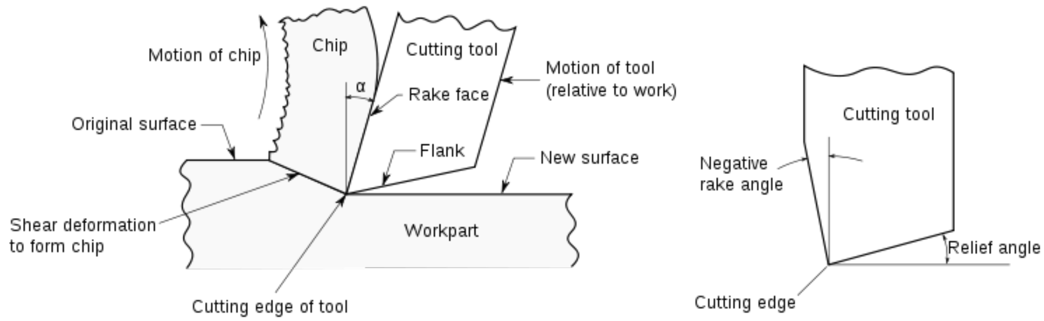
- Milling operations are operations in which the cutting tool rotates to bring cutting edges to bear against the workpiece. Milling machines are the principal machine tool used in milling.
- Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the workpiece. Drilling operations are done primarily in drill presses but sometimes on lathes or mills.
- Miscellaneous operations are operations that strictly speaking may not be machining operations in that they may not be swarf producing operations but these operations are performed at a typical machine tool. Burnishing is an example of a miscellaneous operation. Burnishing produces no swarf but can be performed at a lathe, mill, or drill press.

An unfinished workpiece requiring machining will need to have some material cut away to create a finished product. A finished product would be a workpiece that meets the specifications set out for that workpiece by engineering drawings or blueprints. For example, a workpiece may be required to have a specific outside diameter. A lathe is a machine tool that can be used to create that diameter by rotating a metal workpiece, so that a cutting tool can cut metal away, creating a smooth, round surface matching the required diameter and surface finish. A drill can be used to remove metal in the shape of a cylindrical hole. Other tools that may be used for various types of metal removal are milling machines, saws, and grinding machines. Many of these same techniques are used in woodworking.

More recent, advanced machining techniques include electrical discharge machining (EDM), electro-chemical erosion, laser cutting, or water jet cutting to shape metal workpieces.

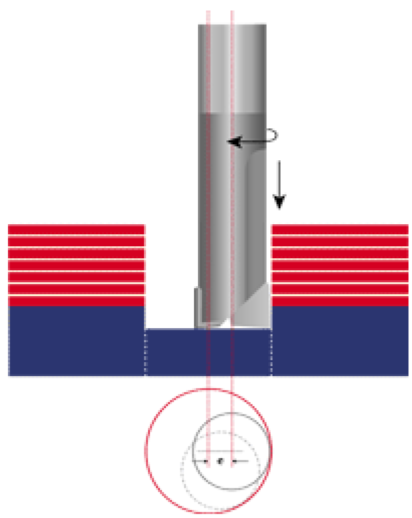
As a commercial venture, machining is generally performed in a machine shop, which consists of one or more workrooms containing major machine tools. Although a machine shop can be a stand-alone operation, many businesses maintain internal machine shops which support specialized needs of the business.

Machining requires attention to many details for a workpiece to meet the specifications set out in the engineering drawings or blueprints. Beside the obvious problems related to correct dimensions, there is the problem of achieving the correct finish or surface smoothness on the workpiece. The inferior finish found on the machined surface of a workpiece may be caused by incorrect clamping, a dull tool, or inappropriate presentation of a tool. Frequently, this poor surface finish, known as chatter, is evident by an undulating or irregular finish, and the appearance of waves on the machined surfaces of the workpiece.



Basic machining process.

Circle interpolating



The orbital drilling principle

Circle interpolating, also known as *orbital drilling*, is a process for creating holes using machine cutters.

Orbital drilling is based on rotating a cutting tool around its own axis and simultaneously about a centre axis which is off-set from the axis of the cutting tool. The cutting tool can then be moved simultaneously in an axial direction to drill or machine a hole – and/or combined with an arbitrary sidewards motion to machine an opening or cavity.

By adjusting the offset, a cutting tool of a specific diameter can be used to drill holes of different diameters as illustrated. This implies that the cutting tool inventory can be substantially reduced.

The term orbital drilling comes from that the cutting tool “orbits” around the hole center. The mechanically forced, dynamic offset in orbital drilling has several advantages compared to conventional drilling that drastically increases the hole precision. The lower thrust force results in a burr-less hole when drilling in metals. When drilling in composite materials the problem with delamination is eliminated.

Overview of machining technology

Machining is not just one process; it is a group of processes. The common feature is the use of a cutting tool to form a chip that is removed from the workpart, called swarf. To perform the operation, relative motion is required between the tool and work. This relative motion is achieved in most machining operation by means of a primary motion, called "cutting speed" and a secondary motion called "feed'". The shape of the tool and its penetration into the work surface, combined with these motions, produce the desired shape of the resulting work surface.

Types of machining operation

There are many kinds of machining operations, each of which is capable of generating a certain part geometry and surface texture.

In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. The speed motion in turning is provided by the rotating workpart, and the feed motion is achieved by the cutting tool moving slowly in a direction parallel to the axis of rotation of the workpiece.

Drilling is used to create a round hole. It is accomplished by a rotating tool that is typically has two or four cutting edges. The tool is fed in a direction parallel to its axis of rotation into the workpart to form the round hole.

In boring, the tool is used to enlarge an already available hole. It is a fine finishing operation used in the final stages of product manufacture.

In milling, a rotating tool with multiple cutting edges is moved slowly relative to the material to generate a plane or straight surface. The direction of the feed motion is perpendicular to the tool's axis of rotation. The speed motion is provided by the rotating milling cutter. The two basic forms of milling are:

- Peripheral milling
- Face milling

Other conventional machining operations include shaping, planing, broaching and sawing. Also, grinding and similar abrasive operations are often included within the category of machining.

The cutting tool

A "numerical controlled machining cell machinist" monitors a B-1B aircraft part being manufactured.

A cutting tool has one or more sharp cutting edges and is made of a material that is harder than the work material. The cutting edge serves to separate chip from the parent work material. Connected to the cutting edge are the two surfaces of the tool:

- The rake face; and
- The flank.

The rake face which directs the flow of newly formed chip, is oriented at a certain angle is called the rake angle "α". It is measured relative to the plane perpendicular to the work surface. The rake angle can be positive or negative. The flank of the tool provides a clearance between the tool and the newly formed work surface, thus protecting the surface from abrasion, which would degrade the finish. This angle between the work surface and the flank surface is called the relief angle. There are two basic types of cutting tools:

- Single point tool; and
- Multiple-cutting-edge tool

A single point tool has one cutting edge and is used for turning, boreing and planing. During machining, the point of the tool penetrates below the original work surface of the workpart. The point is sometimes rounded to a certain radius, called the nose radius.

Multiple-cutting-edge tools have more than one cutting edge and usually achieve their motion relative to the workpart by rotating. Drilling and milling uses rotating multiple-cutting-edge tools. Although the shapes of these tools are different from a single-point tool, many elements of tool geometry are similar.

Cutting conditions

Relative motion is required between the tool and work to perform a machining operation. The primary motion is accomplished at a certain cutting speed. In addition, the tool must be moved laterally across the work. This is a much slower motion, called the feed. The remaining dimension of the cut is the penetration of the cutting tool below the original work surface, called the depth of cut. Collectively, speed, feed, and depth of cut are called the cutting conditions. They form the three dimensions of the machining process, and for certain operations, their product can be used to obtain the material removal rate for the process:

$$R_{MR} = vfd$$

where

- R_{MR}— the material removal rate in *mm*^{3}*/s*, (*in*^{3}*/s*),
- v— the cutting speed in *m/s*, (*ft/min*),
- f— the feed in *mm*, (*in*),
- d— the depth of cut in *mm*, (*in*).

Note: All units must be converted to the corresponding decimal (or USCU) units.

Stages in metal cutting

Machining operations usually divide into two categories, distinguished by purpose and cutting conditions:

- Roughing cuts, and
- Finishing cuts

Roughing cuts are used to remove large amount of material from the starting workpart as rapidly as possible, in order to produce a shape close to the desired form, but leaving some material on the piece for a subsequent finishing operation. Finishing cuts are used to complete the part and achieve the final dimension, tolerances, and surface finish. In production machining jobs, one or more roughing cuts are usually performed on the work, followed by one or two finishing cuts. Roughing operations are done at high feeds and depths — feeds of .04-1.25 mm/rev (0.015-0.050 in/rev) and depths of 2.5–20 mm

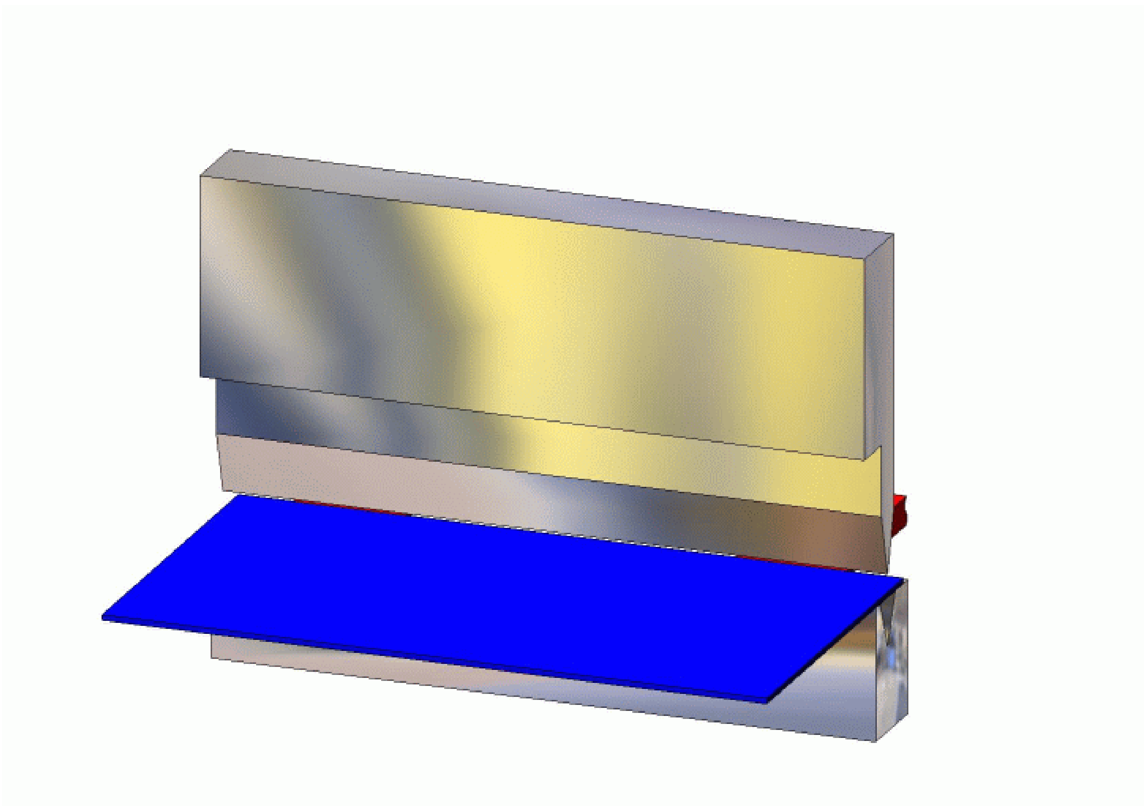
(0.100-0.750 in) are typical. Finishing operations are carried out at low feeds and depths - feeds of 0.0125-0.04 mm/rev (0.0005-0.0015 in/rev) and depths of 0.75-2.0 mm (0.030-0.075 in) are typical. Cutting speeds are lower in roughing than in finishing.

A cutting fluid is often applied to the machining operation to cool and lubricate the cutting tool. Determining whether a cutting fluid should be used, and, if so, choosing the proper cutting fluid, is usually included within the scope of cutting condition.

Today other forms of metal cutting are becoming increasingly popular. An example of this is water jet cutting. Water jet cutting involves pressurized water in excess of 90,000 PSI and is able to cut metal and have a finished product. This process is called cold cutting, and it increases efficiency as opposed to laser and plasma cutting.

Chapter-12

Bending (metalworking)

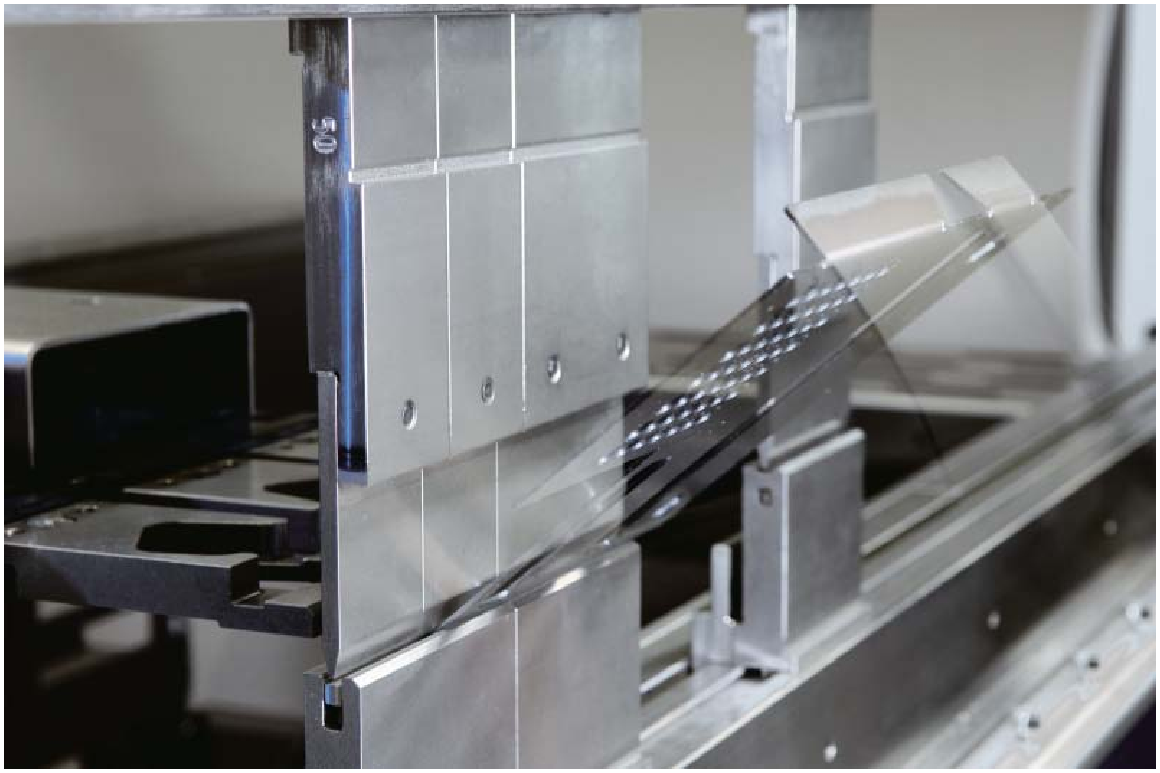


Bending

Press brake

Bending is a manufacturing process that produces a V-shape, U-shape, or channel shape along a straight axis in ductile materials, most commonly sheet metal. Commonly used equipment include box and pan brakes, brake presses, and other specialized machine presses. Typical products that are made like this are boxes such as electrical enclosures and rectangular ductwork.

Process

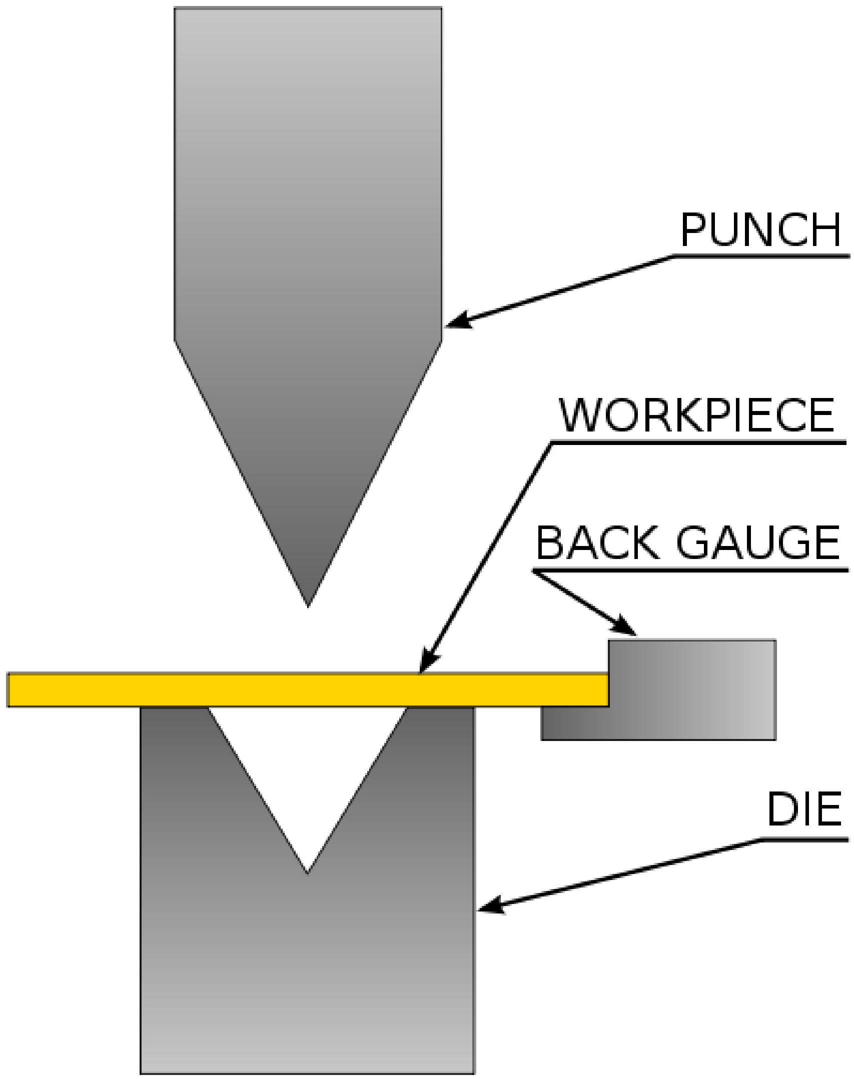


Bending process

In press brake forming, a work piece is positioned over the die block and the die block presses the sheet to form a shape. Usually bending has to overcome both tensile stresses as well as compressive stresses. When bending is done, the residual stresses cause the material to *spring back* towards its original position, so the sheet must be over-bent to achieve the proper bend angle. The amount of springback is dependent on the material, and the type of forming. When sheet metal is bent, it stretches in length. The *bend deduction* is the amount the sheet metal will stretch when bent as measured from the outside edges of the bend. The *bend radius* refers to the inside radius. The formed bend radius is dependent upon the dies used, the material properties, and the material thickness.

The U-punch forms a U-shape with a single punch.

Types



A schematic of air bending with a backgauge.

There are three basic types of bending on a press brake, each is defined by the relationship of the end tool position to the thickness of the material. These three are Air Bending, Bottoming and Coining. The configuration of the tools for these three types of bending are nearly identical. A die with a long rail form tool with a radiused tip that locates the inside profile of the bend is called a punch. Punches are usually attached to the ram of the machine by clamps and move to produce the bending force. A die with a long rail form tool that has concave or V shaped lengthwise channel that locate the outside profile of the form is called a die. Dies are usually stationary and located under the material on the bed of the machine. Note that some locations do not differentiate between the two different kinds of dies (punches and dies.) The other types of bending listed use specially designed tools or machines to perform the work.

Air bending

This bending method forms material by pressing a punch (also called the upper or top die) into the material, forcing it into a bottom V-die, which is mounted on the press. The punch forms the bend so that the distance between the punch and the side wall of the V is greater than the material thickness (T).

Either a V-shaped or square opening may be used in the bottom die (dies are frequently referred to as tools or tooling). A set of top and bottom dies are made for each product or part produced on the press. Because it requires less bend force, air bending tends to use smaller tools than other methods.

Some of the newer bottom tools are adjustable, so, by using a single set of top and bottom tools and varying press-stroke depth, different profiles and products can be produced. Different materials and thicknesses can be bent in varying bend angles, adding the advantage of flexibility to air bending. There are also fewer tool changes, thus, higher productivity.

A disadvantage of air bending is that, because the sheet does not stay in full contact with the dies, it is not as precise as some other methods, and stroke depth must be kept very accurate. Variations in the thickness of the material and wear on the tools can result in defects in parts produced.

Air bending's angle accuracy is approximately ±0.5 deg. Angle accuracy is ensured by applying a value to the width of the V opening, ranging from 6 T (six times material thickness) for sheets to 3 mm thick to 12 T for sheets more than 10 mm thick. Springback depends on material properties, influencing the resulting bend angle.

Depending on material properties, the sheet may be overbended to compensate for springback.

Air bending does not require the bottom tool to have the same radius as the punch. Bend radius is determined by material elasticity rather than tool shape.

The flexibility and relatively low tonnage required by air bending are helping to make it a popular choice. Quality problems associated with this method are countered by angle-measuring systems, clamps and crowning systems adjustable along the x and y axes, and wear-resistant tools.

The K-Factor approximations given below are more likely to be accurate for air bending than the other types of bending due to the lower forces involved in the forming process.

Bottoming

In bottoming, the sheet is forced against the V opening in the bottom tool. U-shaped openings cannot be used. Space is left between the sheet and the bottom of the V opening. The optimum width of the V opening is 6 T (T stands for material thickness) for sheets about 3 mm thick, up to about 12 T for 12 mm thick sheets. The bending radius for must be at least 0.8 T to 2 T for sheet steel. Larger bend radii require about the same force as larger radii in air bending, however, smaller radii require greater force—up to five times as much—than air bending. Advantages of bottoming include greater accuracy and less springback. A disadvantage is that a different tool set is needed for each bend angle, sheet thickness, and material. In general, air bending is the preferred technique.

Coining

In coining, the top tool forces the material into the bottom die with five to 30 times the force of air bending, causing permanent deformation through the sheet. There is little, if any, springback. Coining can produce an inside radius is as low as 0.4 T, with a 5 T width of the V opening. While coining can attain high precision, higher costs mean that it is not often used.

Three-point bending

Three-point bending is a newer process that uses a die with an adjustable-height bottom tool, moved by a servo motor. The height can be set within 0.01 mm. Adjustments between the ram and the upper tool are made using a hydraulic cushion, which accommodates deviations in sheet thickness. Three-point bending can achieve bend angles with 0.25 deg. precision. While three-point bending permits high flexibility and precision, it also entails high costs and there are fewer tools readily available. It is being used mostly in high-value niche markets.

Folding

In folding, clamping beams hold the longer side of the sheet. The beam rises and folds the sheet around a bend profile. The bend beam can move the sheet up or down, permitting the fabricating of parts with positive and negative bend angles. The resulting bend angle is influenced by the folding angle of the beam, tool geometry, and material properties. Large sheets can be handled in this process, making the operation easily automated. There is little risk of surface damage to the sheet.

Wiping

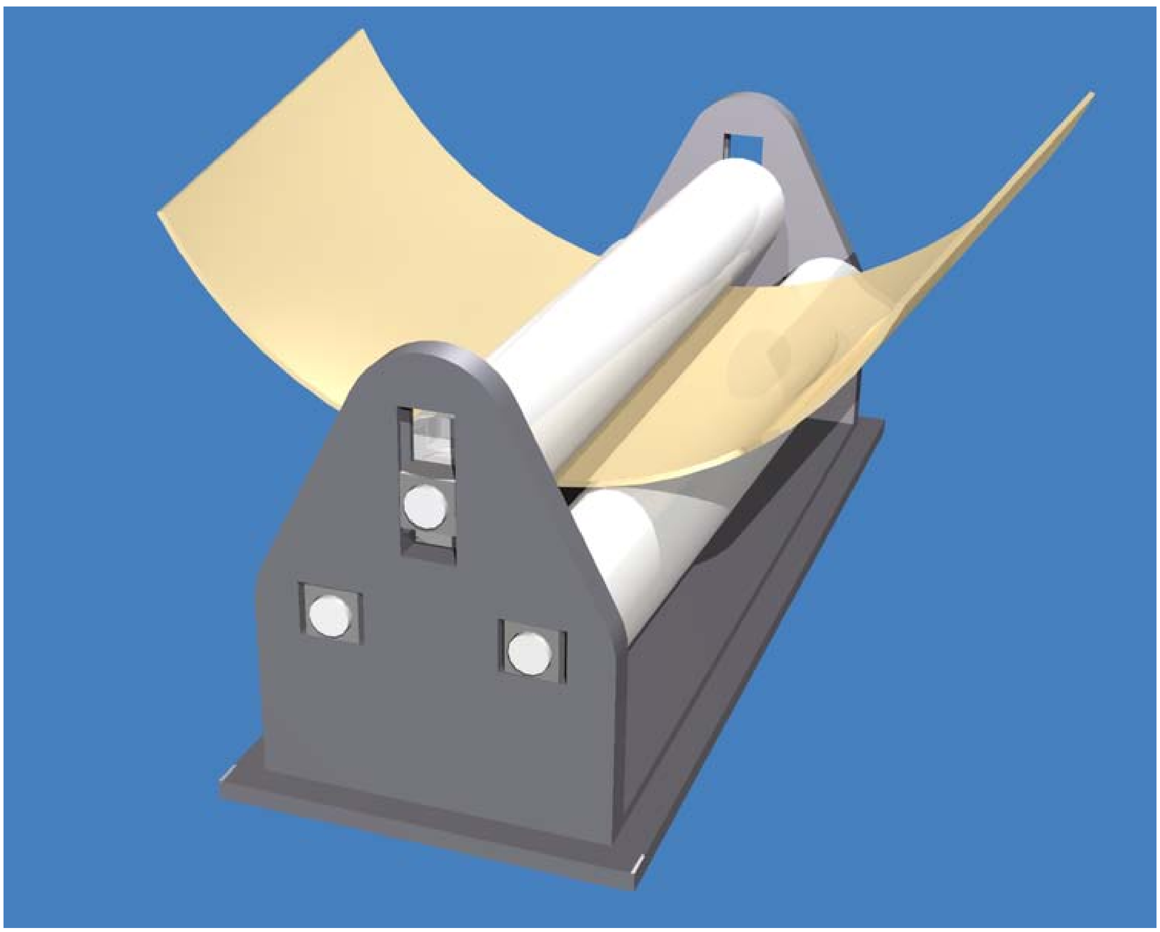
In wiping, the longest end of the sheet is clamped, then the tool moves up and down, bending the sheet around the bend profile. Though faster than folding, wiping has a higher risk of producing scratches or otherwise damaging the sheet, because the tool is moving over the sheet surface. The risk increases if sharp angles are being produced. Wiping on press brakes involves special tools.

This method will typically bottom or coin the material to set the edge to help overcome springback. In this bending method, the radius of the bottom die determines the final bend radius.

Rotary bending

Rotary bending is similar to wiping but the top die is made of a freely rotating cylinder with the final formed shape cut into it and a matching bottom die. On contact with the sheet, the roll contacts on two points and it rotates as the forming process bends the sheet. This bending method is typically considered a "non-marking" forming process suitable to pre-painted or easily marred surfaces. This bending process can produce angles greater than 90° in a single hit on standard press brakes or flat presses.

Roll bending



Roll bending

The roll bending process induces a curve into bar or plate workpieces.

Elastomer bending

In this method, the bottom V-die is replaced by a flat pad of urethane or rubber. As the punch forms the part, the urethane deflects and allows the material to form around the punch. This bending method has a number of advantages. The urethane will wrap the material around the punch and the end bend radius will be very close to the actual radius on the punch. It provides a non-marring bend and is suitable for pre-painted or sensitive materials. Using a special punch called a *radius ruler* with relieved areas on the urethane U-bends greater than 180° can be achieved in one hit, something that is not possible with conventional press tooling. Urethane tooling should be considered a consumable item and while they are not cheap , they are a fraction of the cost of dedicated steel tooling. It also has some drawbacks, this method requires tonnage similar to bottoming and coining and does not do well on flanges that are irregular in shape, that is where the edge of the bent flange is not parallel to the bend and is short enough to engage the urethane pad.

Joggling

A joggle bend in sheet metal and a joggling tool

Joggling, also known as **joggle bending**, is an offset bending process in which the two opposite bends are each greater than 90°, and are separated by a neutral web less than 5 workpiece thicknesses apart.

Joggle bends are commonly used on complex airframe parts because it reduces modeling time from days to hours. They also increase strength, hardness, and possibly resistance to wear.

Calculations

Many variations of these formulas exist and are readily available online. These variations may often seem to be at odds with one another, but they are invariably the same formulas simplified or combined. What is presented here are the unsimplified formulas. All formulas use the following keys:

- BA = bend allowance
- BD = bend deduction
- R = inside bend radius
- K = K-Factor, which is t / T
- T = material thickness
- t = distance from inside face to the neutral line
- A = bend angle in degrees (the angle through which the material is bent)

The *neutral line* (also called the *neutral axis*) is an imaginary line that can be drawn through the cross-section of the workpiece that represents the lack of any internal forces. Its location in the material is a function of the forces used to form the part and the material yield and tensile strengths.

Both bend deduction and bend allowance represent the difference between the neutral line or unbent *flat pattern* (the required length of the material prior to bending) and the formed bend. Subtracting them from the combined length of both flanges gives the flat pattern length. The question of which formula to use is determined by the dimensioning method used to define the flanges as shown in the two diagrams below.

Bend allowance

The *bend allowance* (BA) is the length of the arc of the neutral line between the tangent points of a bend in any material. Adding the length of each flange taken between the center of the radius to the BA gives the Flat Pattern length. This bend allowance formula is used to determine the flat pattern length when a bend is dimensioned from 1) the center of the radius, 2) a tangent point of the radius or 3) the outside tangent point of the radius on an acute angle bend.

The BA can be calculated using the following formula:

$$BA = A\left(\frac{\pi}{180}\right)(R + K \times T)$$

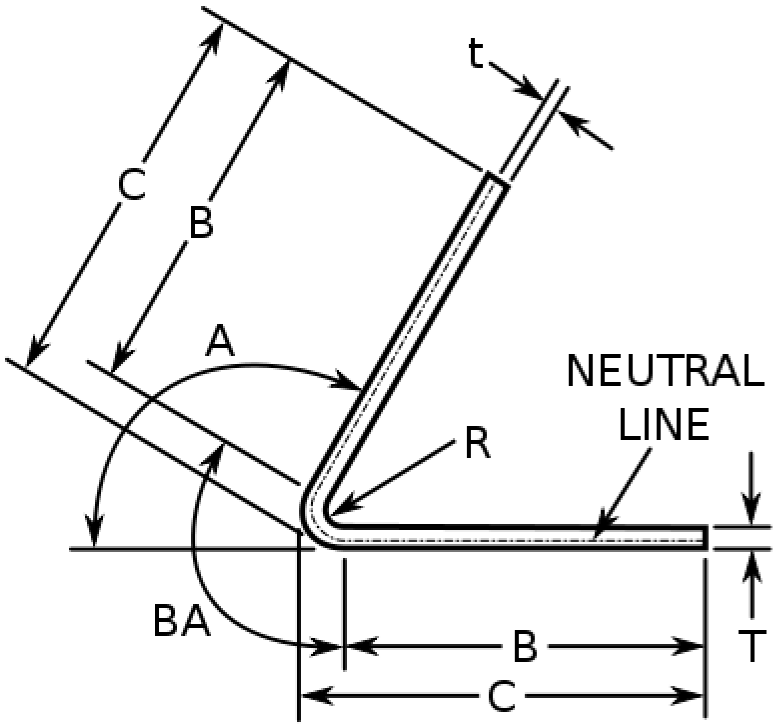


Diagram showing standard dimensioning scheme when using Bend Allowance formulas. Note that when dimensions "C" are specified, dimension B = C - R - T

Bend deduction

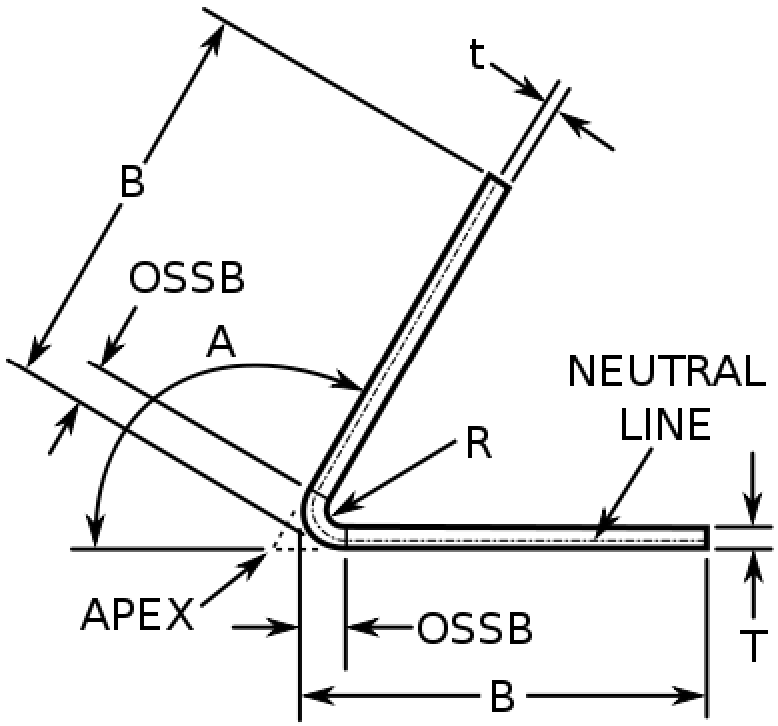


Diagram showing standard dimensioning scheme when using Bend Deduction formulas.

The *outside set back* (OSSB) is the length from the tangent point of the radius to the apex of the outside of the bend. The *bend deduction* (BD) is twice the outside setback minus the bend allowance. Most sheet metal drawings use this kind of dimensioning because it is offers more precise control over the flange lengths (compared to dimensioning it to the outside tangent of the radius) by removing any variations in the formed radius from the measurement. Because of this, the BD calculation is used more often than BA alone. BD is calculated using the following formula:

$$BD = 2\,(R + T)\tan\frac{A}{2} - BA$$

K-factor

K-factor is a ratio of material thickness to the location of the neutral line as defined by t/T where t = location of the neutral line and T = material thickness. The K-Factor formulation does not take the forming stresses into account but is simply a geometric calculation of the location of the neutral line after the forces are applied and is thus the roll-up of all the unknown (error) factors for a given setup. The K-factor depends on many factors including the material, the type of bending operation (coining, bottoming, air-bending, etc.) the tools, etc. and is typically between 0.3 to 0.5.

The following equation relates the K-factor to the bend allowance:

$$K = \frac{-R + \frac{BA}{\pi A/180}}{T}$$

The following table is a "Rule of Thumb". Actual results may vary remarkably.

Generic K-Factors		**Aluminum**	**Steel**
Radius	**Soft Materials**	**Medium Materials**	**Hard Materials**
Air Bending			
0 to Thickness	0.33	0.38	0.40
Thickness to 3 x Thickness	0.40	0.43	0.45
Greater than 3 x Thickness	0.50	0.50	0.50
Bottoming			
0 to Thickness	0.42	0.44	0.46
Thickness to 3 x Thickness	0.46	0.47	0.48
Greater than 3 x Thickness	0.50	0.50	0.50
Coining			
0 to Thickness	0.38	0.41	0.44
Thickness to 3 x Thickness	0.44	0.46	0.47
Greater than 3 x Thickness	0.50	0.50	0.50

The following formula can be used in place of the table as a good *approximation* of the K-Factor for Air Bending:

LOG(MIN(100,MAX(20 × R,T) / T)) / LOG(100) / 2

Material considerations

Material sheet thickness varies from 1/32 to ½ in with length from 6 in to 20 ft. Ductile materials are best suited for the pressing like aluminum, mild steel and new plastic materials.

Advantages

Bending is a cost effective process when used for low to medium quantities, because it does not require significant amounts of tooling.