THE FORGING PROCESS

Forging is a metal forming process used to produce large quantities of identical parts, as in the manufacture of automobiles, and to improve the mechanical properties of the metal being forged, as in aerospace parts or military equipment. The design of forged parts is limited when undercuts or cored sections are required. All cavities must be comparatively straight and largest at the mouth, so that the forging die may be withdrawn. The products of forging may be tiny or massive and can be made of steel (automobile axles), brass (water valves), tungsten (rocket nozzles), aluminum (aircraft structural members), or any other metal. This process is also used for coining, but with slow continuous pushes.

The forging metal forming process has been practiced since the Bronze Age. Hammering metal by hand can be dated back over 4000 years ago. The purpose, as it still is today, was to change the shape and/or properties of metal into useful tools. Steel was hammered into shape and used mostly for carpentry and farming tools. An axe made easy work of cutting down trees and metal knives were much more efficient than stone cutting tools. Hunters used metal-pointed spears and arrows to catch prey. Blacksmiths used a forge and anvil to create many useful instruments such as horseshoes, nails, wagon tires, and chains.

Militaries used forged weapons to equip their armies, resulting in many territories being won and lost with the use and strength of these weapons. Today, forging is used to create various and sundry things. The operation requires no cutting or shearing, and is merely a reshaping operation that does not change the volume of the material.

Forging changes the size and shape, but not the volume, of a part. The change is made by force applied to the material so that it stretches beyond the yield point. The force must be strong enough to make the material deform. It must not be so strong, however, that it destroys the material. The yield point is reached when the material will reform into a new shape. The point at which the material would be destroyed is called the fracture point.

In forging, a block of metal is deformed under impact or pressure to form the desired shape. Cold forging, in which the metal is not heated, is generally limited to relatively soft metals. Most metals are hot forged; for example, steel is forged at temperatures between 2,100°F and 2,300°F (1,150°C to 1,260°C). These temperatures cause deformation, in which the grains of the metal elongate and assume a fibrous structure of increased strength along the direction of flow.

Normally this results in metallurgical soundness and improved mechanical properties. Strength, toughness, and general durability depend upon the way the grain is placed. Forgings are somewhat stronger and more ductile along the grain structure than across it. The feature of greatest importance is that along the grain structure there is a greater ability to resist shock, wear, and impact than across

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the grain. Material properties also depend on the heat-treating process after forging. Slow cooling in air may normalize work pieces, or they can be quenched in oil and then tempered or reheated to achieve the desired mechanical properties and to relieve any internal stresses. Good forging practice makes it possible to control the flow pattern resulting in maximum strength of the material and the least chances of fatigue failure. These characteristics of forging, as well as fewer flaws and hidden defects, make it more desirable than some other operations (i.e. casting) for products that will undergo high stresses.

Die Forging: Open and closed die operations can be used in forging [We adopt closed die forging]. In open-die forging the dies are either flat or rounded. Large forgings can be formed by successive applications of force on different parts of the material. Hydraulic presses and forging machines are both employed in closed die forging. In closed-die forging the metal is trapped in recessed impressions, which are machined into the top and bottom dies. As the dies press together, the material is forced to fill the impressions. Flash, or excess metal, is squeezed out between the dies. Closed-die forging can produce parts with more complex shapes than open-die forging. Die forging is the best method, as far as tolerances that can be met, and also results in a finished part that is completely filled out and is produced with the least amount of flashing. The final shape and the improvement in metallurgical properties are dependent on the skill of the operator. Closer dimensional tolerances can be held with closed die forgings than with open die forgings and the operator requires less skill.

Heat Treatment:

Materials can be improved before or after manufacturing by different heat treatment processes. Forging is usually performed to hot metals, allowing for smoother flow and easier deformation. Steel is heated to varying temperatures, usually between 1700^{o}F to 2000^{o}F but can reach as high as 2400^{o}F, depending on the carbon content. Depending on the amount of work required to the piece, it may be necessary to reheat the piece one or more times. The temperature of the metal when completely forged is called the finishing temperature. After forging, the material must be cooled uniformly and protected from moisture or cold air. This is done by placing the material into dry ashes, lime or mica dust in order to retard the rate of cooling.

(1) *Preheating*: Preheating of materials is done to help prevent cracking or distortion of the material. This is done by placing the metal in a series of furnaces of increasing temperatures instead of throwing it directly into the furnace used to heat the metal for forging, annealing, normalizing or hardening. Another way to achieve this is to start in a cold furnace and slowly bring it to temperature.

(2) *Annealing*: Annealing should follow forging as soon as possible whenever machining is required. Annealing is the heating and then cooling of metal to make the metal less brittle, or more malleable and ductile. This will soften the steel that was previously hardened and reduce internal stresses. Annealing is done by heating the metal to a temperature beyond the critical temperature and holding it there for a period of time. The metal is then cooled with the furnace and not removed until the fu

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rnace is cold. It can also be cooled to a temperature within the furnace that is known to be below the lower critical temperature, at which the annealing is complete. Slower cooling rates are required as carbon content increases in the metal.

(3) *Normalizing*: Normalizing is done to improve the crystalline structure of the steel, thus obtaining superior properties. Heating the forged part just beyond the critical temperature and then allowing it to air-cool completes normalizing. This allows the grain-size to be refined and, if not held at that temperature too long, will result in a newly formed crystalline structure. The internal stresses, if any, will be relieved, hardened steels will be softened, overheated steels will have a more favorable, normal fine-grained structure, and structural distortion will be removed.

(4) *Hardening*: Hardening of steels can also be done after forging. The workpiece is heated slowly to obtain the finest grain-sizes, to its hardening temperature - much higher than annealing temperatures. The metal is kept at this temperature only until uniform heat distribution and completion of the thermal transformation. Prolonged exposure at these elevated temperatures will result in increased grain growth and surface decarbonization, if no protection from oxidation is provided. Oxidation can be avoided by surrounding the metal with some material that will use up the oxygen that is present in the furnace. Once the metal has been uniformly heated to temperature, it is removed from the furnace and placed directly into a quenching tank. This rapidly cools the metal and the metal retains its new qualities.

When metal is hot, it is in a soft and pliable condition allowing it to be easily formed under pressure without breaking. This process is called forging.

Metal is strongest in the direction of its **grain flow**. Machining cuts through the grain, thereby weakening the metal. Forging causes the grain to flow in the shape of the part. Therefore, forgings are stronger than machined parts. Also, since the shape of the part is created by pressure, not cutting, much less metal is lost in the process. This means that parts with complex shapes can be formed and mass produced by forging more economically than by machining.

DROP FORGING - Drop forging is a mass production technique which hammers the metal between two dies. Half of the die is attached to the hammer (upper section) and half to the anvil (lower section). The hot metal is placed in the lower half of the die and struck one on more time with the upper die. This forces the metal to flow in all directions, filling the die cavity. Excess metal squeezed out between the die faces is called *flash* or *flashing*. After the forging is completed the flash is cut off in another press with a *trimming die*.

UPSET FORGING Upset forging, also called hot heading, is a process by which the cross-sectional size of a bar is increased, either at an end or at some point along its length. It is done on specially designed upsetting machines, using closed dies to control size and shape.

Typically, dies have several stations, and the parts are formed progressively by moving the parts from one die station or cavity to another until the forging is complete.

Upset forging machines are made in several sizes, the largest capable of handling bars ten inches (25.4cm) in diameter. Heads of bolts, valves, single and cluster gear blanks, artillery shells, and cylinders for radial engines are examples of parts made by upset forging.

This same process, when performed cold, is called *cold heading* . Cold heading makes possible the economical mass production of fasteners; such as nails, screws, bolts, hinge pins, and rivets.

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