Introduction and classification of forging processes

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1. Introduction and classification of forging processes

1.1 Introduction:

Bulk deformation processes involve shaping of materials to finished products which have small surface area to thickness or surface area to volume ratio. Sheet metal forming produces parts having large surface area to thickness ratio. In sheet metal forming thickness variations are not desirable. Examples for sheet metal forming are: beverage cans, automobile body etc.

Bulk forming processes may be primary processes such as rolling of ingot to blooms or billets, in which the cast metal is formed into semi-finished raw material. In secondary forming, the raw materials, such as blooms, billets are converted into finished parts such as gears, wheels, spanners etc.

Rolling, forging, extrusion and drawing are bulk forming processes. The present module describes the salient aspects of forging process.

1.2 Forging:

In ancient times, people employed forging for making coins, jewelry, weapons,

Forging is a deformation processing of materials through compressive stress. It is carried out either hot or cold. Hot forging is done at temperatures above recrystallization temperatures, typically 0.6 T_m, or above, where T_m is melting temperature. Warm forging is done in the temperature range: 0.3 T_m to 0.5 Tm. Cold forging has advantages such as good surface finish, high strength and greater accuracy. Hot forging requires lower loads, because flow stress gets reduced at higher temperatures. Strain rates in hot working may be high – 0.5 to 500 s_{-1}. Strains in hot forging are also high – true strains of 2 to 4. Are common.

Typical applications of forging include bolts, disks, gears, turbine disk, crank shaft, connecting rod, valve bodies, small components for hydraulic circuits etc.

Forging has several advantages. Closer dimensional accuracies achieved require very little machining after forging. Material saving is the result. Higher strength, greater productivity, favorable grain orientation, high degree of surface finish are other merits. However, complex die making is costly.

1.3 Types of forging:

In forging the material is deformed applying either impact load or gradual load. Based on the type of loading, forging is classified as hammer forging or press forging. Hammer forging involves impact load, while press forging involves gradual loads.

Based on the nature of material flow and constraint on flow by the die/punch, forging is classified as open die forging, impression die forging and flashless forging.

Open die forging: In this, the work piece is compressed between two platens. There is no constraint to material flow in lateral direction. Upsetting is an open die forging in which the billet is subjected to lateral flow by the flat die and punch. Due to friction the material flow across the thickness is non uniform. Material adjacent to the die gets restrained from flowing, whereas, the material at center flows freely. This causes a phenomenon called barreling in upset forging.

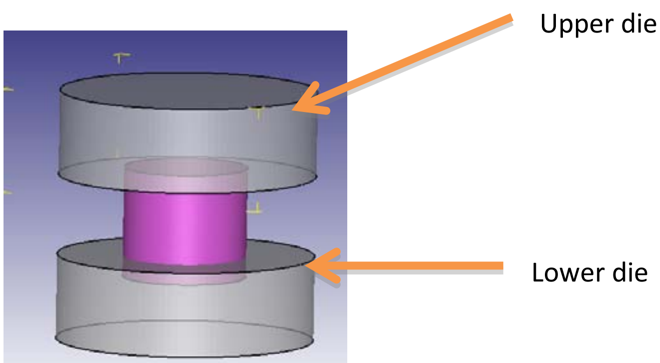

Fig. 1.3.1: Axisymmetric Upset Forging

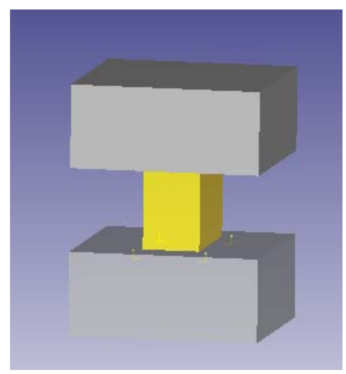

Fig. 1.3.2: Plane strain forging

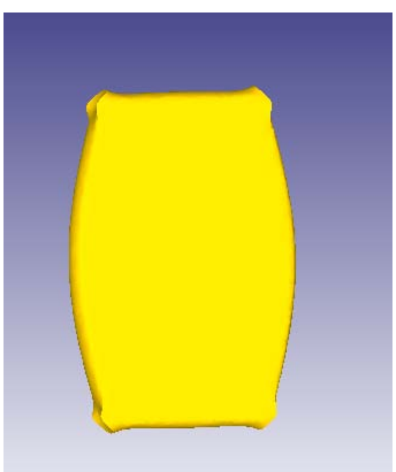

Fig. 1.3.3: A forged rectangular billet exhibiting bulging

Impression die forging both die and punch have impressions, shapes which are imparted onto the work piece. There is more constrained flow in this process. Moreover, the excess metal flows out of the cavity, forming flash.

Flashless forging – in this the work piece is totally constrained to move within die cavity. No excess material and hence no flash forms. Flashless forging involves high level of accuracy. Design of shape of die cavity, finished product volume are important.

1.4 Open die forging:

In open die forging a cylindrical billet is subjected to upsetting between a pair of flat dies or platens. Under frictionless homogeneous deformation, the height of the cylinder is reduced and its diameter is increased. Forging of shafts, disks, rings etc are performed using open die forging technique. Square cast ingots are converted into round shape by this process.

Open die forging is classified into three main types, namely, cogging, fullering and edging.

Fullering and Edging operations are done to reduce the cross section using convex shaped or concave shaped dies. Material gets distributed and hence gets elongated and reduction in thickness happens. Cogging operation involves sequence of compressions on cast ingots to reduce thickness and lengthen them into blooms or billets. Flat or contoured dies are used.

Swaging is carried out using a pair of concave dies to obtain bars of smaller diameter.

1.5 Closed die forging:

It is also known as impression die forging. Impressions are made in a pair of dies. These impressions are transferred to the work piece during deformation. A small gap between the dies called flash gutter is provided so that the excess metal can flow into the gutter and form a flash. Flash has got a very important role during deformation of the work piece inside the die cavity. Due to high length to thickness ratio of the flash gutter, friction in the gap is very high. Due to this the material in the flash gap is subjected to high pressure. There is high resistance to flow. This in turn promotes effective filling of the die cavity. In hot forging, the flash cools faster as a result of it being smaller in size. This enhances the resistance of the flash material to deformation resistance. As a result of this, the bulk of work piece is forced to deform and fill the die cavity more effectively – even intricate parts of the die cavity is filled.

Flash is subsequently trimmed off in order to obtain the required dimensions on the forged part. Often multiple steps are required in closed die forging.Flash is to be properly designed so that the metal could flow and fill the intricate parts of the die cavity. A thin flash with larger width requires higher forging loads. Before getting forged to intermediate shape inside the primary die set called blocking die, the billet is fullered and edged. This is called preforming. Subsequently, it is forged to final shape and dimensions in the finishing die. Closer dimensional accuracy is possible in closed die forging. However, higher forging loads are required. Parts with wider and thinner ribs, or webs are difficult to forge as they require higher forming loads. Impression dies are usually provided with taper called draft of 5^{o} in order to facilitate easy removal of the finished part. Die preheating may be required to prevent the die chilling effect which may increase the flow stress on the periphery of the billet. As a result, incomplete filling or cracking of the preform may occur.

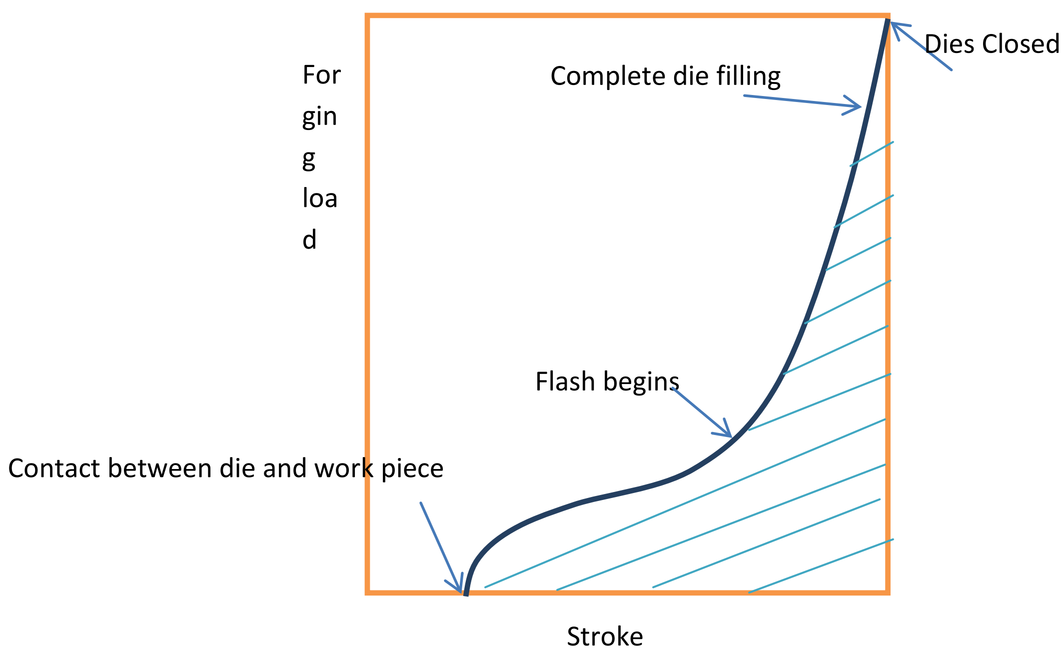

Fig. 1.5.1: Load-stroke diagram for closed die forging

Dimensional tolerances in impression die forging may be as close as ±0.5% of the dimensions of the forged part. In case of hot forging, dimensional accuracy is less.

Some of the factors such as die surface finish, draft allowance, accuracy of die impression dimensions, die wear, lubrication etc control the quality of finished product.

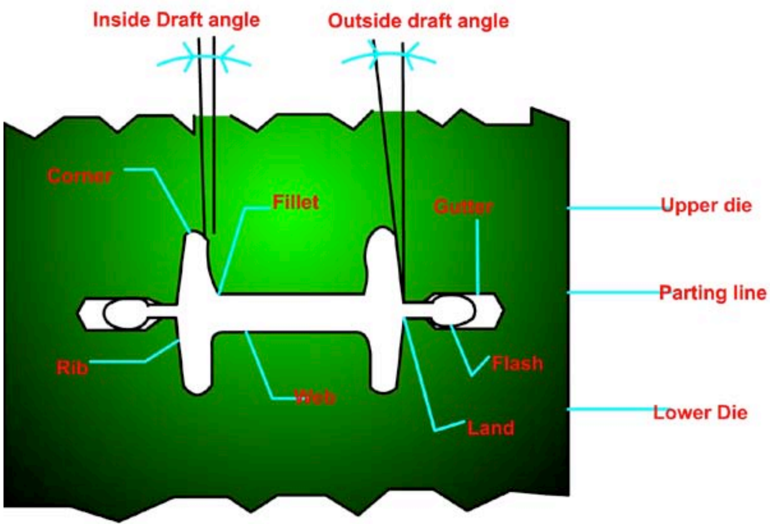

Fig.1.5.2: Parameters of impression die forging

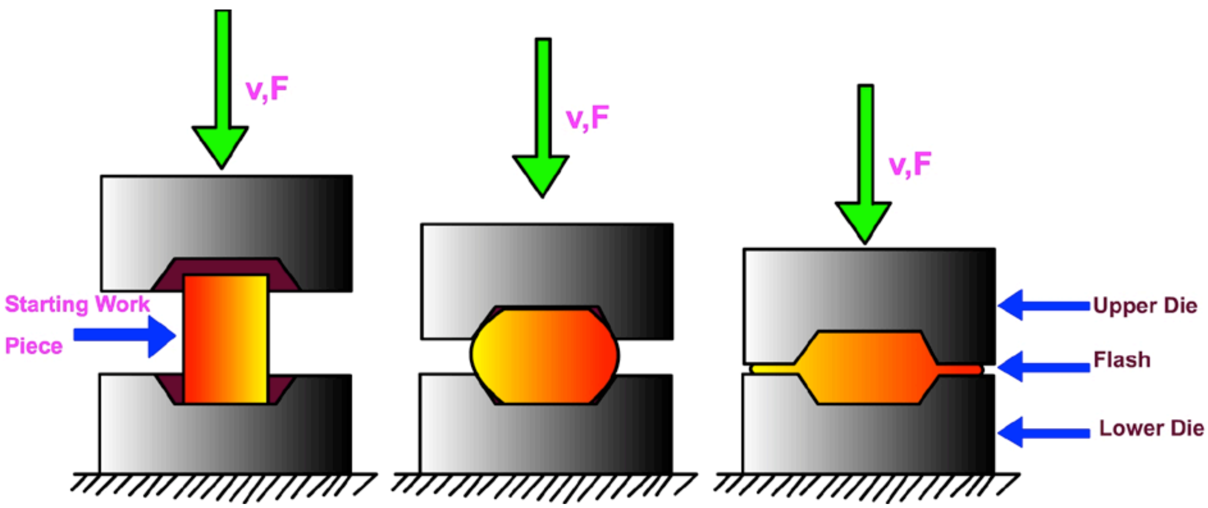

Fig.1.5.3: Stages of closed die forging process

1.5.1 Forging load for impression die forging:

Predicting the forging load for impression die forging is rather empirical due to the complexities of material flow involved.

One empirical relation for forging load, given by Schey is as followed:

$F = C_1 Y_f A_f$, where $C_1$is a shape factor or constraint factor which depends on the complexity of the forging process. $Y_f$is the flow stress of material at the given strain,A_f is the projected area of the forging.

<u>Typical values of C_1:</u>

Simple upsetting	1.25 to 2.5
Flashless forging (Coining)	5 to 8
Complex forging with flash	8 to 12

From the above equation, one can determine the capacity of forging press, as the force predicted by the empirical equation is the highest.

1.6 Precision die forging:

Near-net-shape forming is possible through precision die forging, in which high dimensional accuracy, elimination of after-machining and complex shapes of parts are achieved through precision dies and higher forging loads are achieved.

Alloys of aluminium, titanium, magnesium are commonly precision forged. Ferrous materials are difficult to precision-forge because of die wear, higher temperatures of forging, excessive forging loads requirement.

1.7 Flashless forging

It is a closed die forging process in which the work volume is equal to die cavity volume, with no allowance for flash. Excess material or inadequate material will lead to defective part. If billet size is less then underfilling takes place. Over sized billet leads to die damage or damage to the press.

A variant of closed die forging is **isothermal forging**. In this process, the die is heated up to the same temperature of the billet. This helps in avoiding die chilling effect on work piece and lowering of flow stress. This process is suitable for complex parts to be mass-produced.

Coiningis a special type of closed die forging. Complex impressions are imparted to both surfaces of the blank from the die. Forging loads involved are very high – as high as 6 times the normal loads. Minting of coins is an example of this process.

Coining, when used for improving surface finish of products is called sizing.

Piercing: It is a process in which a punch makes deep indentations to produce cavity on workpiece. Work piece may be kept inside a die or may be free. Higher forming loads are required.

Heading: Heads of bolts, nails are made by heading, which is an upsetting process. Special types of machines are used for heading.

1.8 Roll forging:

In this process, the bar stock is reduced in cross-section or undergoes change in cross-section when it is passed through a pair of grooved rolls made of die steel. This process serves as the initial processing step for forging of parts such as connecting rod, crank shaft etc. Finished products like tapered shafts, leaf springs can also be made.

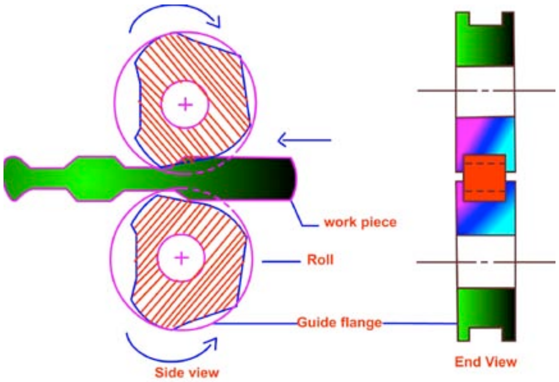

Fig.1.8.1: Roll forging

A particular type of roll forging called **skew rolling** is used for making spherical balls for ball bearings. In this process, the cylindrical bar stock is fed through the gap between a pair of grooved rollers which are rotating. Continuous rotation of the rolls and the stock gives raise to formation of a spherical shaped blank, which is subsequently finished to required dimensions.

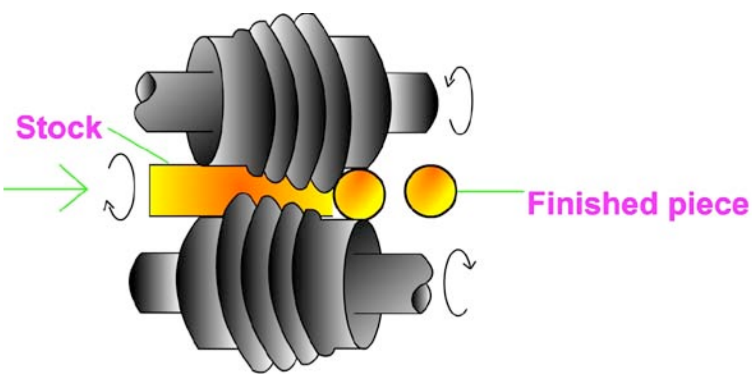

Fig. 1.8.2: Skew rolling process

1.9 Rotary forging:

In this process the punch is given orbital rocking motion while pressing the workpiece. As a result of this the area of contact between work and punch is reduced. Therefore lower forging loads are sufficient. The final part is formed in several smaller steps. Example of parts produced by this process include bevel gears, wheels, bearing rings.

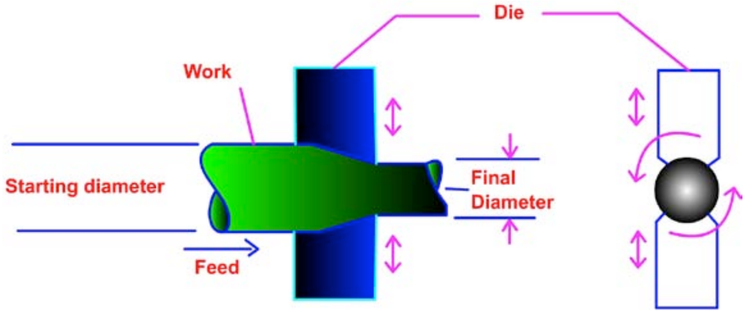

Fig. 1.9: Swaging

Hubbing: It is a pressing operation in which a hardened steel block, with one end machined to the form, is pressed against a soft metal. This process is used for making mold cavities. Hardened steel form is called hub. Hubbing is advantageous because it is easy for machining the positive form than machining the negative cavity.