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Rotary Forging

ROTARY FORGING, or orbital forging, is a two-die forging process that deforms only a small portion of the workpiece at a time in a continuous manner. Unfortunately, the term *rotary forging* is sometimes used to describe the process that is more commonly referred to as radial forging, causing some confusion in terminology. Radial forging is a hot- or cold-forming process that uses two or more radially moving anvils or dies to produce solid or tubular components with constant or varying cross sections along their lengths. The differences between rotary and radial forging are illustrated in Fig. 1. Radial forging is discussed in detail in the article "Radial Forging" in this Volume.

In rotary forging (Fig. 1a), the axis of the upper die is tilted at a slight angle with respect to the axis of the lower die, causing the forging force to be applied to only a small area of the workpiece. As one die rotates relative to the other, the contact area between die and workpiece, termed the footprint, continually progresses through the workpiece, gradually deforming it until a final shape is formed. As is evident in Fig. 1(a), the tilt angle between the two dies plays a major role in determining the amount of forging force that is applied to the workpiece. A larger tilt angle results in a smaller footprint; consequently, a smaller amount of force is required to complete the same amount of deformation as compared to a larger contact area. Tilt angles are commonly approximately 1 to 2°. The larger the tilt angle, however, the more difficult are the machine design and maintenance problems, because the drive and bearing system for the tilted die is subjected to large lateral loads and is more difficult to maintain. In addition, a larger tilt angle causes greater frame deflection within the forge, making it difficult to maintain a consistently high level of precision.

Rotary forges can be broadly classified into two groups, depending on the motion of their dies. In rotating-die forges, both dies rotate about their own axis, but neither die rocks or precesses about the axis of the other die. In rocking-die, or orbital, forges, the upper die rocks across the face of the lower die in a variety of fashions. The most common form is where the upper die orbits in a circular pattern about the axis of the lower die. In this case, the upper die can also either rotate or remain stationary in relation to its own axis. Other examples of rocking-die motion include the rocking of the upper die across the workpiece in a straight, spiral, or planetary pattern (Fig. 2).

Applications

Rotary forging is generally considered to be a substitute for conventional drop-hammer or press forging. In addition, rotary forging can be used to produce parts that would otherwise have to be completely machined because of their shape or dimensions. Currently, approximately one-quarter to one-third of all parts that are either hammer or press forged could be formed on a rotary forge. These parts include symmetric and asymmetric shapes. In addition, modern rotary forge machines use dies that are 152 to 305 mm (6 to 12 in.) in diameter, limiting the maximum size of a part. In the current technology, rotating or orbiting die forges are mainly limited to the production of symmetrical parts. Through a more complex die operation, rocking-die forges are able to produce both symmetric and asymmetric pieces.

Workpiece Configuration. Parts that have been found to be applicable to rotary forging include gears, flanges, hubs, cams, rings, and tapered rollers, as well as thin disks and flat shapes. These parts are axially symmetric and are formed by using an orbital die motion. More complex parts can be forged through the use of such rocking-die motions as straight-line, planetary, and spiral. Straight-line die motion is most commonly used to produce asymmetric pieces, such as T-flanges.

Rotary forging is especially effective in forging parts that have high diameter-to-thickness ratios. Thin disks and large flanges are ideally suited to this process because of the ability of rotary forging to produce a higher ratio of lateral deformation per given downward force than conventional forging. There is also very little friction between the dies. Therefore, the lateral movement of workpiece material in rotary forging is as much as 30% more than that in impact forging.

Rotary forging is also used to produce intricate features on workpiece surfaces. Parts such as gears, hubs, and hexagonal shapes have traditionally been difficult to produce by conventional forging because die-workpiece friction made it difficult to fill tight spots properly on the dies.

Workpiece Materials. Any material, ferrous or nonferrous, that has adequate ductility and cold-forming qualities can be rotary forged. These materials include carbon and alloy steels, stainless steels, brass, and aluminum alloys. In the past, cold-forged production parts were primarily steels with a Rockwell C hardness in the mid-30s or lower. Generally, harder materials

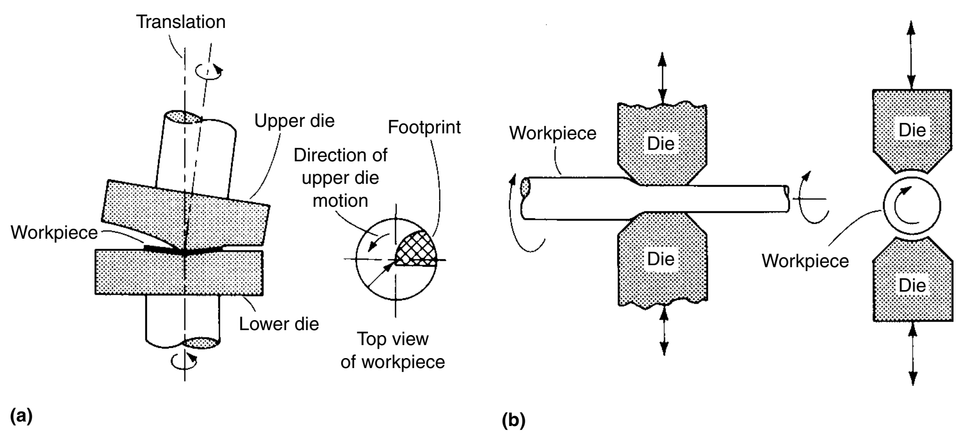

Fig. 1 Differences between rotary and radial forging. (a) In rotary forging, the upper die, tilted with respect to the lower die, rotates around the workpiece. The tilt angle and shape of the upper die result in only a small area of contact (footprint) between the workpiece and the upper die at any given time. Because the footprint is typically only approximately one-fifth the workpiece surface area, rotary forging requires considerably less force than conventional forging. (b) In radial forging, the workpiece is fed between the dies, which are given a rapid periodic motion as the workpiece rotates. In this manner, the forging force acts on only a small portion of the workpiece at any one time.

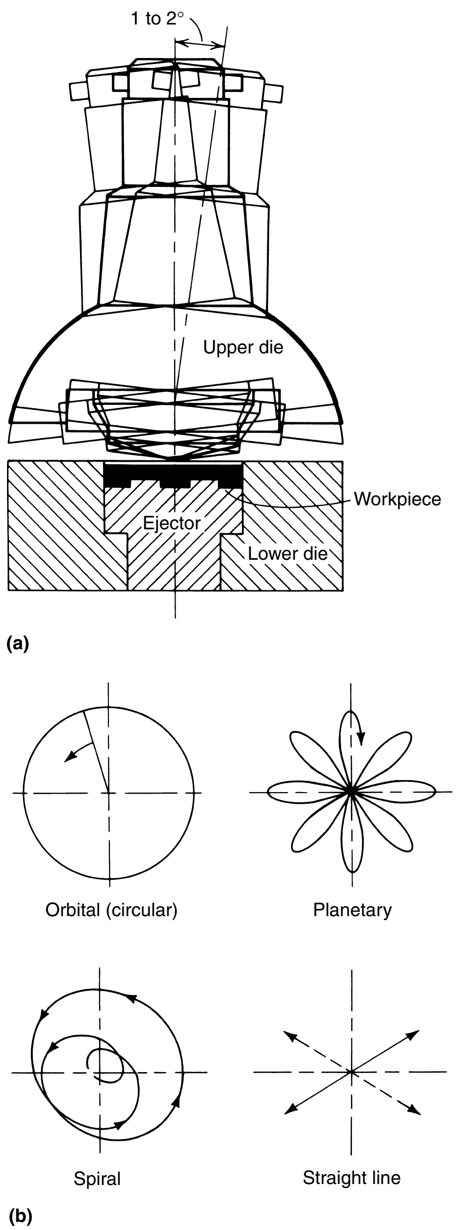

Fig. 2 Schematic of (a) rocking-die forge and (b) sample patterns of upper die motion

should be annealed before forging or should be warm forged.

Warm rotary forging is used when the material has a Rockwell C hardness greater than the mid-30s or when an unusually large amount of lateral movement in the workpiece is required. Materials are heated to a point below their recrystallization temperature; for steels, this is generally in the range of 650 to 800 °C (1200 to 1470 °F). Because the working temperature is below the recrystallization temperature, the inherent structure and properties of the metal are preserved.

Warm rotary forging results in an increased forging capability compared to cold rotary forging. However, some disadvantages are inherent in higher-temperature forging. The work-hardening effects on the material that are associated with cold working are not as prominent, even though the working temperature is below the recrystallization temperature. In addition, as with any forging process, higher working temperatures result in increased die wear. Dies not only wear at a faster rate but also must be fabricated from more durable, more expensive materials.

Advantages and Limitations

Advantages. The primary advantage of rotary forging is in the low axial force required to form a part. Because only a small area of the die is in contact with the workpiece at any given time, rotary forging requires as little as one-tenth the force required by conventional forging techniques.

The smaller forging forces result in lower machine and die deformation and in less die-workpiece friction. This low level of equipment wear makes rotary forging a precision production process that can be used to form intricate parts to a high degree of accuracy.

Rotary forging achieves this high level of accuracy in a single operation. Parts that require subsequent finishing after conventional forging can be rotary forged to net shape in one step. The average cycle time for a moderately complex part is 10 to 15 s, which is a relatively short time of deformation from preform to final part. In addition, it is unnecessary to transfer the workpiece between die stations; this facilitates the operation of an automatic forging line. A cycle time in the range of 10 to 15 s will yield approximately 300 pieces per hour. The resulting piece is also virtually flash free. Therefore, rotary forging results in a much shorter operation from start to finish.

Tooling costs for rotary forging are often lower than those for conventional forging. Because of the lower forging loads, die manufacture is easier, and the required die strength is much lower. Die change and adjustment times are also much lower; dies can be changed in as little as 15 min. These moderate costs make the process economically attractive for either short or long production runs, thus permitting greater flexibility in terms of machine use and batch sizes.

Because impact is not used in rotary forging, there are fewer environmental hazards than in conventional forging techniques. Complications such as noise, vibrations, fumes, and dirt are virtually nonexistent.

The smaller forging forces allow many parts to be cold forged that would conventionally require hot forging, resulting in decreased die wear and greater ease in handling parts after forging. This is in addition to the favorable grain structure that results from the cold working of metals.

Disadvantages. Rotary forging is a relatively new technology (compared to other forging methods), and one disadvantage in the past was determining whether or not a piece could be produced by rotary forging. However, current design tools, such as finite element modeling (FEM), now can be used to evaluate die geometries. In the past, the design process (like that for other forging processes) was basically one of trial and error. A set of dies would be constructed and tested for each part not previously produced by rotary forging in order to determine whether or not the part was suitable for rotary forging. This obviously creates a greater initial capital investment than that required in machining, which does not require specific die construction. The benefit of the new FEM method is to allow evaluation without trial-and-error die testing.

Depending on the material as well as the specific shape and geometry, parts that are usually machined may not be suitable for rotary forging for a variety of reasons. For example, the material may experience cracking during the forging process; the finished part may undergo elastic springback; or there may be areas on the workpiece that do not conform to the die contour, leaving a gap between die and workpiece, such as central thinning.

Finally, a major problem lies in the design of rotary forge machines. The large lateral forces associated with the unique die motion make the overall frame design of the machines more difficult. These large forces must be properly supported by the frame in order for the forge to maintain a consistent level of accuracy. Conventional forges present a less troublesome design problem because they do not experience such a wide range of die motion.

Machines

As previously discussed, rotary forging machines are classified by the motion of their dies. These dies have three potential types of motion: rotational, orbital, and translational. Rotational motion, or spin, is defined as the angular motion of the die about its own axis. Rocking, or orbital, motion is the precession of a die about the axis of the other die without rotation about its own axis. Rocking patterns that are currently in use include orbital (circular), straight-line, spiral, and planetary. Translational motion, or feed, is the motion of a die in a linear direction indenting into the workpiece. Machines with three different combinations of these motions are illustrated in Fig. 3.

In rotating-die machines, the upper, or tilted, die has rotational and translational motion, while the lower die has only rotational motion (Fig. 3a). Depending on the specific machine, both dies can be independently driven or only the lower die is power driven while the upper die (the follower) responds to the motion of the lower die.

In rocking-die forges, the upper die always has rocking motion. In addition, the upper die has both translational and rotational motion (Fig. 3b) or has neither motion (Fig. 3c). In cases in which the upper die does not have translational motion, the lower die has the ability to translate.

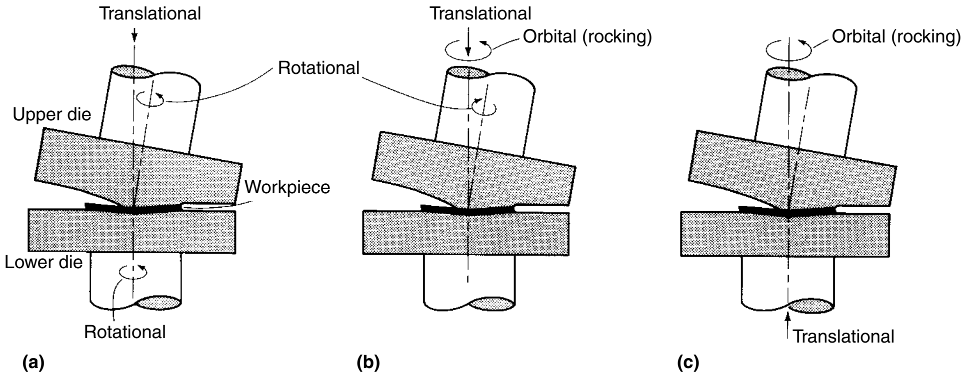

Fig. 3 Examples of die motion in rotary forging. (a) Upper die has both translational and rotational motion, while lower die rotates. (b) Upper die has translational, rotational, and orbital (rocking) motion; lower die is stationary. (c) Upper die has orbital (rocking) motion only; lower die has translational motion.

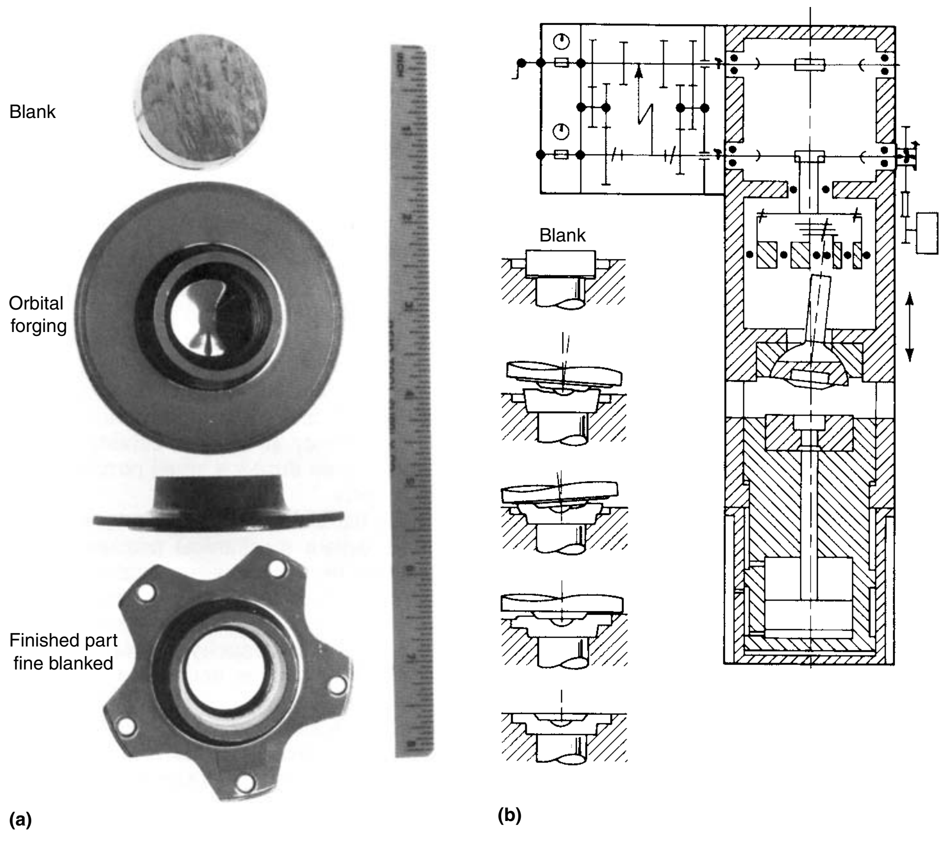

Fig. 4 (a) Rotary-forged aluminum alloy 6061 bearing retainer used in bicycle hubs. (b) Schematics of the rotary forge used to produce the bearing retainer and the workpiece deformation process (left)

The selection of machine type is primarily based on the construction and maintenance of the machine. In general, the machines that use more involved die movement are more difficult to maintain, particularly because of the loss of accuracy due to die and frame deflection.

Rocking-die machines are able to produce parts in a larger variety of shapes and geometries (particularly asymmetric parts). However, because of the large amount of die and frame movement, these parts may not be as precise as those produced with rotating-die machines. In addition, rocking-die machines require more frequent maintenance in order to retain their original level of accuracy.

Rotating-die machines are commonly used to forge symmetric parts. Included among these types of machines is the rotary forge that has the simplest die motion, in which both dies have rotational motion and one also has translational motion. In this case, the forging force always acts in one direction; therefore, the press design is simplified, and the minimal amount of frame deflection results in maximum precision. In addition, any error in the part is uniformly distributed around the circumference of the part, thus facilitating the alteration of die design to compensate for the error.

Dies

Rotary forging dies will typically produce 15,000 to 50,000 pieces before they must be refinished. Naturally, die life depends on the material being forged and on the complexity of the piece.

Because rotary forging dies experience a much lower forging force than normal, they are generally small and are usually made of inexpensive materials, typically standard tool steels. Therefore, die cost is lower than in other conventional forging methods. Lubrication of the dies, although not essential, is suggested in order to increase die life.

Both dies can be changed within 15 min. Complete job change and adjustments require approximately 30 min. This makes rotary forging particularly attractive for short production runs.

Examples

Example 1: Rotary Forging of a Bicycle Hub Bearing Retainer. A rocking-die forge was used to produce the bearing retainer shown in Fig. 4(a). This part is used in bicycle hubs.

The material of construction was aluminum alloy 6061. The aluminum was first saw cut from 33.3 mm (1 5/16 in.) diameter bar stock into 19 mm (0.75 in.) thick pucks. The material was heat treated from an initial hardness of T4 to a hardness of T6. The puck was then placed on the lower die, and the upper die, using an orbital rocking pattern, deformed the material to fill the lower die mold. A schematic of the forge and the workpiece deformation is shown in Fig. 4(b).

After the deformation was complete, the upper die was raised, and the piece was ejected from the lower die. The resulting part had an outside diameter of 88.9 mm (3.5 in.). The retainer was then fine blanked to the final shape.

The production rate was approximately 6 to 7 parts per minute. This process is noticeably faster and less expensive than the conventional alternative of turning these parts down from 88.9 mm (3.5 in.) diameter preforms, which involves a large amount of material waste. In addition, the rotary-forged pieces exhibit a higher density and a more beneficial grain structure as a result of the cold working of the material.

Example 2: Warm Rotary Forging of a Carbon Steel Clutch Hub. A rocking-die press with a capacity of 2.5 MN (280 tonf) was used to warm forge a clutch hub. The medium-carbon steel (0.5% C) blank was first heated to a temperature of 1000 °C (1830 °F) and then placed on the lower die. Both upper and lower dies were preheated to approximately 200 °C (390 °F) and maintained in the range of 150 to 250 °C (300 to 480 °F) during forging. The lower die was raised until die-workpiece contact was made, and the upper die was rocked in an orbital pattern. Water-soluble graphite was sprayed onto the dies as a lubricant. The working time for forging was approximately 1.5 s per piece. The working load was approximately 0.75 MN (84 tonf), or approximately one-tenth the load required for conventional hot forging.

The quenching, tempering, and finish machining processes associated with conventional hot forging are not required for the rotary-forged part. After forging, the piece is merely cooled and then blanked to final dimensions. The surfaces of the piece have the same smoothness as the two dies. Flange flatness deviation and thickness variation are less than 0.1 mm (0.004 in.). An additional benefit of the lower forging temperature (conventional hot forging of these parts is done at 1250 °C, or 2280 °F) is a reduced grain size, which improves the strength of the part. A comparison between conventionally and rotary warm forged hubs is shown in Fig. 5. The rotary-forged hub requires a smaller billet weight, thus decreasing the amount of material waste. The rotary-forged hub also has closer tolerances than the conventionally forged hub, demonstrating the precision of the rotary process.

The higher temperatures associated with warm rotary forging cause more rapid die wear than that found in cold rotary forging. In this example, the dies, made of AISI H13 tool steel with a hardness of 50 HRC, exhibited noticeable wear after only 50 pieces had been forged.

Example 3: Rotary Forging of a Copper Alloy Seal Fitting. A rotating-die machine was used to cold forge a naval brass seal fitting. This fitting is used in high-pressure piping, such as in air conditioners or steam turbines.

The initial preforms were 86.4 mm (3.4 in.) lengths of 44.5 mm (1.75 in.) outside diameter, 24.1 mm (0.95 in.) inside diameter tube stock.

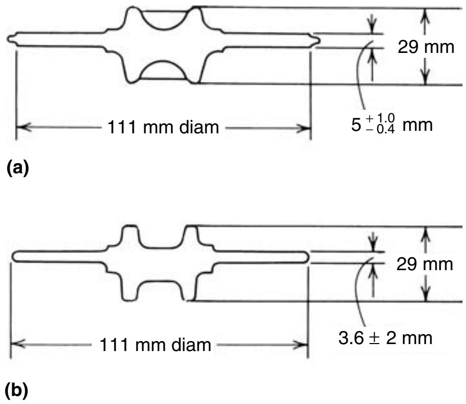

Fig. 5 Comparison of (a) conventionally forged and (b) rotary hot forged carbon steel clutch hubs. Billet weight: 0.63 kg (1.39 lb) for conventional forging, 0.44 kg (0.97 lb) for rotary forging

As shown in Fig. 6, the tube preform was fitted over a cylindrical insert that protrudes from the lower die. The upper die was lowered until indentation was made. Die rotation then began. The workpiece was deformed to fit the dimensions of the lower die and then ejected. The rotary-forged product was 39.7 mm (1 9/16 in.) long with a minimum inside diameter of 23.6 mm (0.93 in.) and a maximum outside diameter of 55.6 mm (2 3/16 in.). Minimal machining was required to bring the part to final dimensions.

The machine used to produce these fittings is a rotating-die forge in which both dies rotate only about their own axis. The upper die is motor driven, while the lower die merely follows the rotation of the upper die after contact is made. The dies are constructed of A2 tool steel heat treated to a hardness of 58 to 62 HRC. The expected life of these dies is approximately 20,000 pieces.

In conventional processing, these fittings would be machined from 75 mm (3 in.) solid bar stock. This results in a large amount of wasted material, and machining time is approximately 17 min per piece. The tube stock used for rotary forging is more expensive than bar stock, but material waste is minimal. In addition, rotary forging requires only 20 s per piece, with an additional 3 to 4 min per piece needed for subsequent machining to final form.

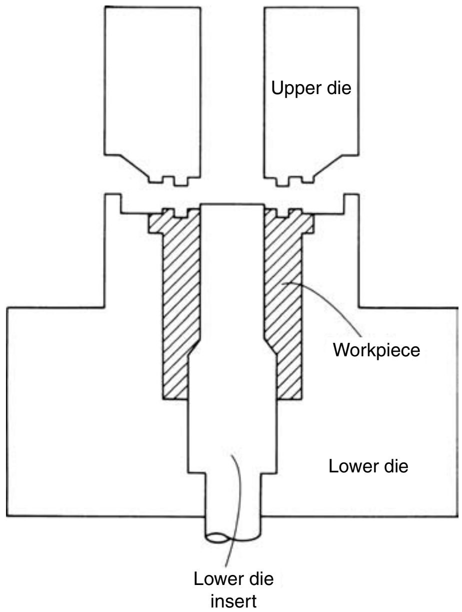

Fig. 6 Schematic of rotary forging setup for the forming of a copper alloy seal fitting used in high-pressure piping

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