Forging Solutions

Open Die and Rolled Ring Forging—
the Processes, Applications and Benefits

The Facts About Forging

When buyers must select a process and supplier for the production of a critical metal component, they face an enormous array of possible alternatives. Many metalworking processes are available, each offering a unique set of capabilities, costs and advantages. The forging process is ideally suited to many part applications; however, some buyers may be unaware of the exclusive benefits available only from this type of metal forming. In fact, forging is often the optimum process, in terms of both part quality and cost, especially for applications that require maximum part strength, custom sizes or critical performance specifications.

There are several forging processes available, including impression or closed die, cold forging, and extrusion. However, here we will discuss in detail the methods, application and comparative benefits of the open die and seamless rolled ring forging processes. We invite you to consider this information when selecting the optimum process for the production of your metal parts.

A Historical Perspective

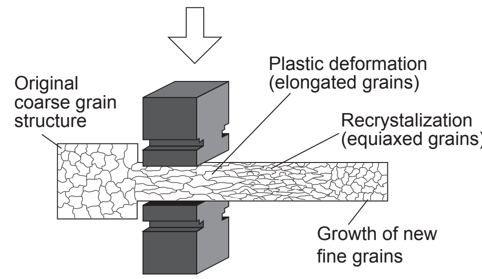
Perhaps the oldest mechnical method of metal-working, forging traces its origins back to the 13th century, B.C.

To keep up with the industry's changing needs, forging has evolved to incorporate the tremendous advances in equipment, robotics, technology, and electronic controls that have occurred in recent years. These sophisticated tools complement the creative human skills which, even today, are essential to the success of every forging made. Modern forging plants are capable of producing superior-quality metal parts in a virtually limitless array of sizes, shapes, materials and finishes.

Forging Defined

At its most basic level, forging is the process of forming and shaping metals through the use of hammering, pressing, or rolling. The process begins with starting stock, usually a cast ingot (or a "cogged" billet which has already been forged from a cast ingot), which is heated to its plastic deformation temperature, then upset or "kneaded" between dies to the desired shape and size.

How the open die forging process affects the crystal structure.



During this hot forging process, coarse grain structure is broken up and replaced by finer grains. Shrinkage and gas porosity inherent in the cast metal are consolidated through the reduction of the ingot, achieving sound centers and structural integrity. Mechanical properties are therefore improved through reduction of cast structure, voids, and segregation. Forging also provides means for aligning the grain flow to best obtain desired directional strengths. Secondary processing, such as heat treating, can also be used to further refine the part.

Forging can create a myriad of sizes and shapes with enhanced properties when compared to castings or fabrications.

The Open Die Forging Process

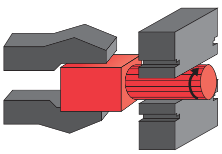
Open die forging involves the shaping of heated metal parts between a top die attached to a ram and a bottom die attached to a hammer, anvil, or bolster. Metal parts are worked at their appropriate temperatures, ranging from 500°F to 2400°F, and gradually shaped into the desired configuration through the skillful hammering or pressing of the workpiece.

While impression or closed die forging confines the metal in dies, open die forging is distinguished by the fact that the metal is never completely confined or restrained. Most open die forgings are produced on flat dies. However, round swaging dies, V-dies, mandrels, pins, and loose tools are also used depending on the desired part configuration and its size.

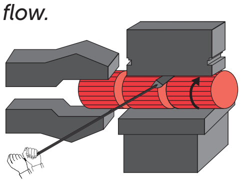
Although the open die forging process is often associated with larger, simpler-shaped parts such as bars, blanks, rings, hollows or spindles, it can be considered the ultimate option in "custom-designed" metal components. High-strength, long-life parts optimized in terms of both mechanical properties and structural integrity are today produced in sizes that range from a few pounds to hundreds of tons in weight. In addition, advanced forge shops now offer shapes that were never before thought capable of being produced by the open die forging process.

The Open Die Forging Process

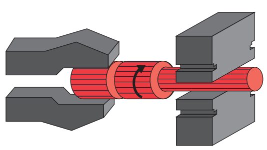
Steps to produce a typical spindle-shaped part:



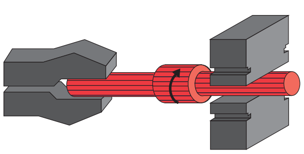
1. Starting stock cut to size by weight is first rounded, then upset to achieve structural integrity and directional grain flow.



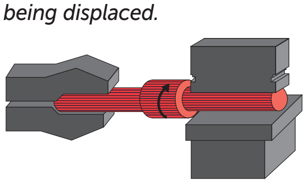
2. A "fuller" tool marks the starting "step" locations on the fully rounded workpiece.



3. Forging or "drawing" down the first step to size.



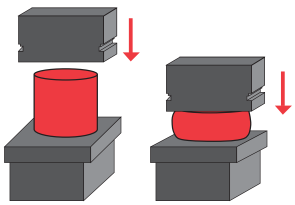
4. The second step is drawn down to size. Note how the part elongates with each process step as the material is being displaced.



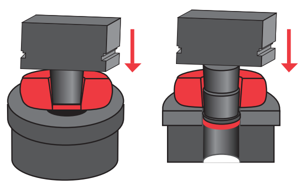
5. "Planishing" the rough forging for a smoother surface finish and to keep stock allowance to a minimum.

The Seamless Rolled Ring Forging Process

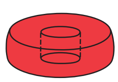
Producing a ring "preform" by the open die forging process:



1. Starting stock cut to size by weight is first rounded, then upset to achieve structural integrity and directional grain flow.

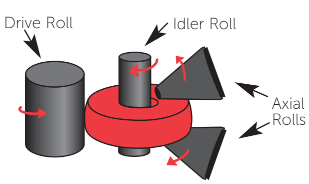


2. Workpiece is punched, then pierced to achieve starting "donut" shape needed for ring rolling process.

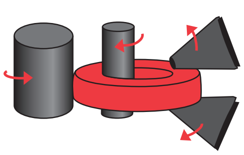


3. Completed preform ready for placement on ring mill for rolling.

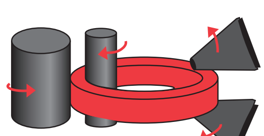
Rolled ring forging process:



4. Ring rolling process begins with the idler roll applying pressure to the preform against the drive roll.



5. Ring diameters are increased as the continuous pressure reduces the wall thickness. The axial rolls control the height of the ring as it is being rolled.



6. The process continues until the desired size is attained.

The Seamless Rolled Ring Forging Process

The production of seamless forged rings is often performed by a process called ring rolling on rolling mills. These mills vary in size to produce rings with outside diameters of just a few inches to over 300 inches and in weights from a single pound up to over 300,000 pounds.

The process starts with a circular preform of metal that has been previously upset and pierced (using the open die forging process) to form a hollow "donut." This donut is heated above the recrystallization temperature and placed over the idler or mandrel roll. This idler roll then moves under pressure toward a drive roll that continuously rotates to reduce the wall thickness, thereby increasing the diameters (I.D. and O.D.) of the resulting ring.

Seamless rings can be produced in configurations ranging from flat, washer-like parts to tall, cylindrical shapes, with heights ranging from less than an inch to more than 9'. Wall thickness to height ratios of rings typically range from 1:16 up to 16:1, although greater proportions can be achieved with special processing. The simplest, and most commonly used shape is a rectangular cross-section ring, but shaped tooling can be used to produce seamless rolled rings in complex, custom shapes with contours on the inside and/or outside diameters.

Advantages of Open Die and Rolled Ring Forging

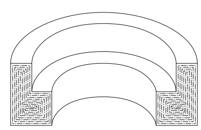
Part Integrity

1. Directional Strength

By mechanically deforming the heated metal under tightly controlled conditions, forging produces predictable and uniform grain size and flow characteristics. Forging stock is also typically preworked to refine the dendritic structure of the ingot and remove porosity. These qualities translate into superior metallurgical and mechanical qualities, and deliver increased directional toughness in the final part.

2. Structural Strength

Forging provides structural integrity that is unmatched by other metalworking processes. By consolidating the ingot center, forging eliminates internal voids and porosity. The process also breaks up and eliminates the dendritic structure that is inherent in the original cast ingot. Predictable structural integrity reduces the need for part inspection requirements, simplifies heat treating and machining and ensures optimum part performance under field service conditions.



Cross section of continuous grain flow of custom forged contoured ring.

3. Impact Strength

Parts can also be forged to meet virtually any impact requirement. Proper orientation of grain flow assures maximum impact strength and fatigue resistance. The high-strength properties of the forging process can be used to reduce sectional thickness and overall weight without compromising final part integrity.

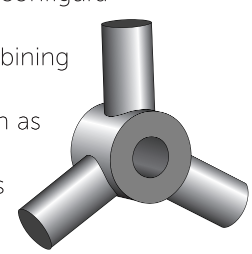
Part Flexibility

1. Variety of Sizes

Limited only to the largest ingot that can be cast, open die forged part weights can run from a single pound to over 1,000,000 pounds. In addition to commonly purchased open die parts, forgings are often specified for their soundness in place of rolled bars or castings, or for those parts that are too large to produce by any other metalworking method.

2. Variety of Shapes

Shape design is just as versatile, ranging from simple bar, shaft and ring configurations to specialized shapes. These include multiple O.D/I.D. hollows, single and double hubs that approach closed die configurations and unique, custom shapes produced by combining forging with secondary processes such as torch cutting, sawing and machining. Shape designs are often limited only by the creative skills and imagination of the forging supplier.



3. Metallurgical Spectrum

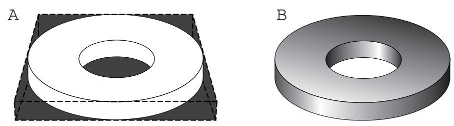
Metallurgical properties can be greatly varied through alloy selection, part configuration, thermal mechanical working, and post-forming processes.

4. Quantity and Prototype Options

Virtually all open die and rolled ring forgings are custom made one at a time, providing the option to purchase one, a dozen or hundreds of parts as needed. An added benefit is the ability to offer open die prototypes in single piece or low volume quantities. No better way exists to test initial closed die forging designs, because open die forging imparts similar grain flow orientation, deformation and other beneficial characteristics. In addition, the high costs and long lead times associated with closed die tooling and set-ups are eliminated.

Economic Advantages

1. Material Savings
Forging can measurably reduce material costs since it requires less starting metal to produce many part shapes. For example, with a torch cut part (A), all corner stock and the full center slug are lost, even though you pay for the excess material. With a forging (B), the part is shaped to size with minimal waste.

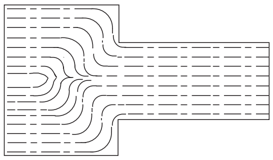


2. Machining Economies
Forging can also yield machining, lead time and tool life advantages. Savings come from forging to a closer-to-finish size than is capable by alternate metal sources such as plate or bar. Less machining is therefore needed to finish the part, with the added benefits of shorter lead time and reduced wear and tear on equipment.

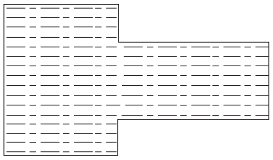
3. Reduced Rejection Rates
By providing weld-free parts produced with cleaner forging quality material and yielding improved structural integrity, forging can virtually eliminate rejections.

4. Production Efficiencies
Using the forging process, the same part can be produced from many different sizes of starting ingots or billets, allowing for a wider variety of inventoried grades. This flexibility means that forged parts of virtually any grade can be manufactured more quickly and economically.

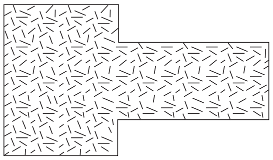
Grain Flow Comparison



Forged Bar:
Grain flow is oriented to improve ductility, toughness, and increase fatigue resistance



Machined Bar:
Unidirectional grain flow has been cut when changing contour, exposing grain ends. This renders the material more liable to fatigue and more sensitive to stress corrosion cracking.



Cast Bar:
Cast bars typically do not have a desired grain structure.

Comparative Analysis

When Compared To...	Open Die and Rolled Ring Forged Metal Parts Deliver...
Machined Bar	• Contoured grain flow yielding greater impact and directional strength • Cost savings in material and reduction of waste • Less machining and longer tool life • Broader material options and size ranges
Weldments/Fabrications	• Superior and more consistent metallurgical properties • Reduced labor, rejection and rework/replacement costs • Stronger parts due to the elimination of welds • Single-piece design and inspection efficiencies • Simplified production requirements
Castings	• Directional grain flow and superior final part strength • Structural integrity and product reliability • Reduced process control and inspection requirements • Greater near net part design flexibility reducing machining time
Centrifugal Castings	• Continuous grain flow for the optimum combination of fatigue strength and toughness • Cost savings with the elimination of die, mold and set-up costs • Sound, quality, rejection-free parts
Torch Cut Plate	• Significantly greater size and grade flexibility • Elimination of porosity and laminations • Reductions in waste and material costs • Controlled directional grain flow yielding optimum strength, toughness and fatigue resistance
Closed Die/ Impression Die Forging	• Single and low volume quantity options • Prototypes with comparable properties • Near net shapes with short lead times and the elimination of tooling costs

Material Grades and Secondary Processes

Alloys

Practically all ferrous and non-ferrous alloys can be forged, however each metal has unique characteristics. Some of the most common metals include:

- Alloy Steel
- Aluminum
- Beryllium
- Brass
- Bronze
- Carbon Steel
- Copper
- Magnesium
- Nickel
- Stainless Steel
- Titanium
- Tool Steel
- Zirconium
- Custom grades

Modern steel mills offer the strongest, cleanest materials in the world. Their diverse capabilities also allow the development of custom-melt materials uniquely suited to any application.

Secondary Processing

Adding secondary processing to your forging adds value and oftentimes reduces overall costs. In conjunction with proper alloy selection and forging practices, heat treating, machining, sawing, torch cutting and testing options allow forged parts to be produced to almost any desired shape, size or property.

Of specific note are custom, near net shaped parts not normally associated with the open die process. Combining the creative skills of the forgemaster with the use of simple, loose tooling or secondary processing such as torch cutting, sawing and machining, uniquely shaped parts of the highest quality can be produced.

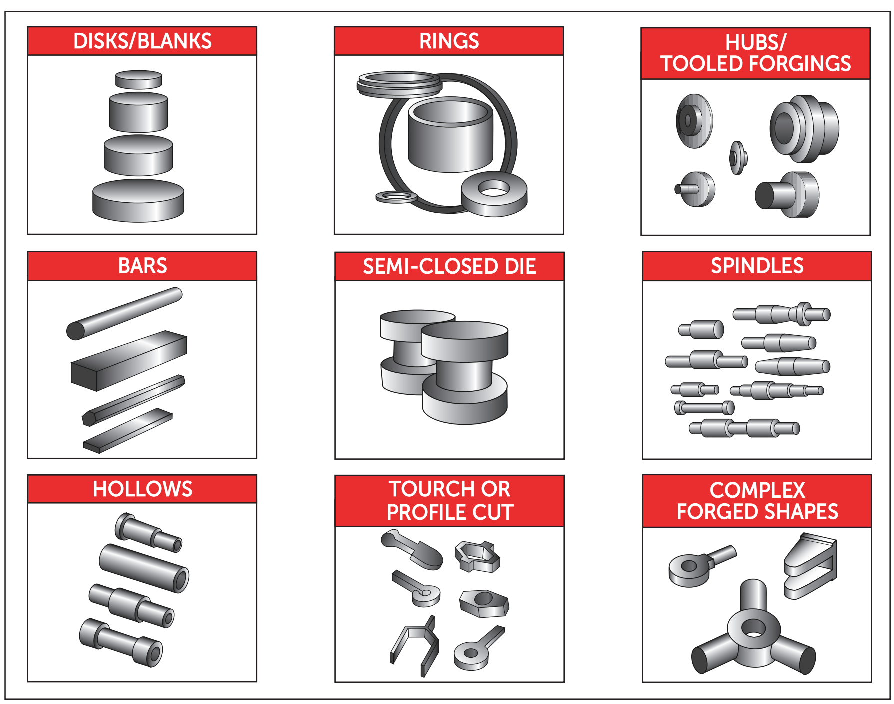
Applying the Forging Process

Applications

Forged metal parts are used in nearly all metalworking industries. Some of the major industry applications include:

- Aerospace
- Automotive
- Agriculture
- Construction
- Defense
- Gear/Power Transmission
- General industrial euipment
- Mining
- Nuclear
- Oil and gas
- Power generation
- Warehouse / Service centers

For advice on whether the forging process is appropriate for a specific part, consult an experienced forging specialist. Below are examples of common forged parts.



Making The Decision

Forgings can deliver better part strength compared to other metalworking processes -- such as machined bar, torch cut plate, weldments, fabrications, or castings -- due to the elimination of porosity, contoured grain flow, and fine grain size. The ability to forge near net shape parts saves cost, time, machining labor, and material for low quantity orders or special sizes. Forgings are also ideal for high quality, restricted mechanical properties, and safety critical applications. This is why forging is almost always the preferred method where quality and safety are a concern. When selecting a forging supplier you should consider the following:

Technical Services

Does the potential supplier offer technical assistance to improve the quality of your finished part and at the same time reduce production time and costs? Does the source utilize advanced metal and part testing technologies? Can the supplier provide application assistance using advanced simulation capabilities utilizing finite elements analysis?

Metallurgy

Are experienced metallurgists, several with advanced degrees, available to assist you with your selection and application of optimum alloys for your forged metal part? Does the supplier maintain the largest inventory of metal alloys? Can the supplier also provide custom-melt and specialty alloys?

Production Capabilities

What are the parameters—in terms of forging sizes, shapes and alloys—of the supplier's capabilities? Can all your open die and rolled ring forging requirements be met by the supplier? Does the vendor offer near net, semi-closed die and custom shaped forgings? Ask for a current equipment list, and determine whether the source has today's most advanced forging presses, ring mills, metallurgical capabilities and other systems. Can the supplier also provide in-house secondary services such as machining, torch cutting, heat treating and testing?

Quality Control

Is the supplier ISO 9001:2008, DNV and PED Certified? Is the source an American Bureau of Shipping certified and Lloyds Registry approved forging supplier?

Are the supplier's inspectors Level III Certified to SNT-TC-1A? Is supplier ASNT Certified? Does the source perform chem checks on both incoming materials and outgoing forged parts?

Experience

How long has the supplier been in the forging business? What type of forged parts does the source deliver? Has that supplier produced similiar components? Can the potential vendor meet your specific requirements for part quality, delivery and cost?

If you have any questions or concerns, reach out to a Scot Forge technical sales expert or industry specialist. We will discuss your specific needs and the value working with an employee-owned company like Scot Forge can provide.

About Scot Forge

Scot Forge is proud to be a 100% employee-owned manufacturer of custom open die forgings and seamless rolled rings. Starting as a small hammer shop in Chicago in 1893, Scot Forge has over 120 years of experience.

Our capabilities include eight hydraulic open die presses, four ring mills, six pneumatic hammers, one bar planishing mill and one hydraulic upset press. We produce parts that weigh from 1 lb. to 100,000 lbs. in carbon, alloy, stainless steel, tool steel, copper, aluminum, nickel, and other ferrous and non-ferrous materials. Shapes that are readily forged include bars (round, square, flat or hex), blanks, rings, hubs, step-down shafts, hollows, and contoured custom shapes achieved by torch cutting and other secondary processing. We also feature Tartan Bars®—sound-center, rolled-surface round bars—a unique product manufactured only by Scot Forge.

We offer all downstream value-added processes including saw cutting, heat treating, contour torch cutting, destructive testing, metallurgical analysis and Level III nondestructive testing.

Scot Forge is certified to ISO 9001:2008 , AS9100C. Further pursuance of aerospace products has led to Nadcap accreditation in both Nondestructive Examination and Heat Treatment. Other accreditations include OSHA SHARP, ABS, DNV, Lloyd's Register and the European Pressure Equipment Directive (PED).

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References used: Forging Industry Association trade publications.