Hot Forging on Horizontal Multi-Stage Presses

Machine technology, processes and products

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The significance of forging

Age-old technology
The forging of metals is an age-old technology. As early as 4000 BC, forging was used to process pure metals such as gold, silver and copper from their natural form into jewellery, weapons or objects for daily use. To work the metal back then, stones were used as hammers. Throughout the centuries, the art of forging enjoyed a special status. The production of efficient forged weapons and tools decided on the rise or fall of entire civilisations. From this perspective, it is easy to understand why good blacksmiths enjoyed much respect in ancient times and in the Middle Ages.

Initially, it was mainly individual parts which were produced by forging. The production of coins (Fig. 1) led to a transition to mass production very early on. Coinage is known to have been around as early as 7 BC. Until the 16th/17th century, production continued to be manual, though the tools became increasingly refined. Later, pressing was used to produce coins.

Current forges no longer enjoy the social esteem they did a few centuries ago. The reason for this may lie in the fact that high-strength forgings (hot-forged parts) are mostly hidden from view when in use. Every motor vehicle, for example, contains numerous hot-forged parts, whether these are in the chassis, the brakes or the entire powertrain. Due to their adapted fibre flow and high ductility, hot-forged parts demonstrate safety reserves that render them particularly well-suited to those areas of the vehicle where safety is crucial.

Transition to mass production

Numerous forged parts for vehicles
Combined with the machine technology provided by horizontal multi-stage presses, hot-forged parts can be produced cost-efficiently in large volumes. This book provides information on this machine technology, as well as on the types of parts which are produced by means of hot forging on horizontal multi-stage presses. Details on the process combinations which are possible during production are also outlined.

**Spectrum of parts**

Hot forging on horizontal multi-stage presses enables both simple and complex forged parts to be produced in large volumes and in an extremely economic way. Due to the tool technology and the transport system in horizontal multi-stage presses, they are mainly used to produce rotationally symmetric parts, flanged parts or parts with a round enveloping contour. The manufacture of asymmetrical
The significance of forging

parts is likewise possible, although it is associated with greater development efforts and tool complexity. The spectrum of parts ranges from small nuts (M16) and cams with a weight of only a few grams through to components such as flanges, wheel hubs, gear wheels and outer races for constant velocity joints weighing up to 7.5 kg. Figure 2 shows some example parts. A large proportion of the forgings produced on horizontal multi-stage presses are used in motor vehicle drive systems and in the chassis (Fig. 3). Engine parts made in this way include cams, valve-train gears, balancer shafts and output flanges. For various types of gearboxes, raw parts such as gears, pinions and synchronising gears are produced. Bevel gears for differential gearboxes can be supplied with assembly-ready teeth by means of hot forging and subsequent cold calibration. Drive shafts require joints that enable longitudinal and angular displacement. Such parts are also hot forged, as are wheel hubs.
Besides the motor vehicle industry, forged parts produced on horizontal multi-stage presses are also used in general mechanical engineering applications as well as in pipe engineering. Many bearing rings for various types of bearings are made using hot-forging operations on this type of machine. Flanges for welding and connecting pipes together are likewise produced in this way.

**Market situation**

Apart from a few large forging enterprises and those forges at car makers, forging companies are primarily medium-sized. 77% of the forging companies employ less than 200 employees. A mere 14% have between 200 and 400 members of staff; only 9% have over 400. The company structure of the European forges is shown in Figure 4. The statistics do not, however, differentiate between the various forging processes and the machinery used. It is thus difficult to determine the percentage of hot-forged parts produced on horizontal multi-stage presses. Besides some
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Forges which are operated directly on the site of car makers, the greatest proportion of hot-forging companies is on the open market. Upwards of a certain size, companies are often able to provide comprehensive development services together with forging on horizontal presses.

In general, the larger horizontal multi-stage presses can be found at car makers or in the larger medium-sized businesses. This is because the infrastructure necessary for operating such presses incurs high investment costs. In order to be able to provide smaller series in an economic way, the larger forging companies frequently offer production on conventional vertical forging presses.

Forged parts produced on horizontal multi-stage presses are generally not in an assembly-ready state following the forging process. Fitting surfaces, drilled holes and splines must often be produced in subsequent operations. This may involve a cold-forging operation and/or machining process. At the end of the production chain, the forging company delivers assembly-ready forged parts that have undergone extensive quality inspection.

Figure 5 shows the customer structure for forged parts in 2004. It can be seen that the
majority (53%) of the forged parts went into automotive applications, and thus to automotive manufacturers and their system and component producers. 38% were supplied for general mechanical engineering applications. Other markets, with a total share of 9%, included building and agricultural machinery, as well as the railway industry.

Forced parts mainly supplied to automotive sector

Fig. 5: Customer structure for closed-die forged parts in Europe
Fundamentals of metal forming

As defined in DIN 8580 (a standard from the German Institute for Standardization), metal forming refers to the targeted alteration of the geometry, surface and material properties of a workpiece while maintaining mass and material coherence. In order to process a material by means of metal forming, it must permit plastic deformation of its geometry under appropriate loads by means of outside forces without losing its coherence. This property is a characteristic of metals.

The uniaxial tensile test provides a good example for illustrating the general behaviour of metals which are subjected to force. During this test, which is used to characterise materials, a testpiece is elongated at a slow and continuous rate until necking occurs and the testpiece breaks. The force applied, $F_{\text{tensile}}$, and the resulting elongation of the testpiece, $\Delta l$, are usually related to the initial cross-section, $S_0$, and the initial length, $l_0$, of the testpiece. The engineering stress, $\sigma$, and the engineering strain, $\varepsilon$, are then expressed as:

$$\sigma = \frac{F_{\text{tensile}}}{S_0} \quad \varepsilon = \frac{\Delta l}{l_0}$$

Figure 6 shows a stress-strain curve for a low-alloy steel plotted during a tensile test. It must be pointed out that metals demonstrate both elastic and plastic behaviour. The elastic phase at the start of the curve is marked by a straight line in the stress-strain curve (Hook’s Law). If the material is subjected to load up to its yield point during the elastic phase, it will assume its original form (length) upon
removal of the load. It is only when subjected to a load above the yield point that the material undergoes permanent, i.e. plastic, deformation. Metals barely change in volume during plastic deformation. This means in the case of the tensile test that the cross-section of the testpiece decreases with increasing elongation. If the effective force, $F_{\text{tensile}}$, is divided by the current cross-section surface, $S$, “true stress” can be calculated as follows:

$$k_f = \frac{F_{\text{tensile}}}{S}$$

Plastic flow is referred to as flow stress, $k_f$. The flow stress of a material refers to the stress that is necessary for introducing or maintaining permanent deformation in the uniaxial stress state. In a diagram, flow stress is usually depicted over the logarithmic principal strain, $\varphi$, also known as plastic strain. In order to calculate plastic strain, the change in length, $dl$, is divided by the current length, $l$, as follows:

*Fig. 6: Stress-strain diagram of a low-alloy steel during a tensile test

$R_{\text{el}}$ Upper yield point

$R_{\text{el}}$ Lower yield point

$R_m$ Tensile strength
In each forming increment the logarithmic principal strain is:

\[ \varphi = \ln \frac{l_1}{l_0} \]

The plastic strain is more suited to describing high levels of plastic deformation than the engineering strain, \( \varepsilon \), which is related to the starting length (unfortunately, English notation does not differentiate between elastic and plastic strain. The symbol \( \varepsilon \) is used in both cases. German notation differentiates between elastic (\( \varepsilon \)) and plastic strain (\( \varphi \)). Therefore, German notation is used in this book). During multiple-stage forming processes, the plastic strain values may simply be added up, and thus the total plastic strain of a forming process can be calculated.

The representation of flow stress over plastic strain is plotted as a flow curve. In the area of forging, these curves are recorded in upsetting tests for various parameters such as forging temperature, \( T \), and strain rate, \( \dot{\varphi} (= \frac{d\varphi}{dt}) \). This is because upsetting tests can reach greater plastic strains than can be achieved during tensile tests. As the temperature increases, the flow stress, and thus the (press) force needed for forging, generally decrease (Fig. 7, above). At elevated temperatures (i.e. temperatures above which recrystallisation occurs), the flow stress is also dependent on the strain rate. As the strain rate increases, the force necessary for metal forming increases, too (Fig. 7, below). Taking into account the material state (grain structure, hardness, etc.),
the flow stress for a material is thus a function which depends on the plastic strain, $\phi$, the metal-forming temperature, $T$, and the strain rate $\dot{\phi}$.

**Plasticity theory**

Tensile tests, just like compression and upsetting tests, represent a special case in which the material is subjected to load in one direction only. Generally, however, the material must withstand load in several directions, both in the form of tensile and compressive stresses as well as shear stresses. Figure 8 shows a rectangular solid (removed from the workpiece for illustration purposes) with the stresses that occur under multiple-axis load.

**Fig. 7:**
Above: Dependence of the flow stress on the testpiece temperature using the example of 20MnCr5 ($\dot{\phi} = 10 \, s^{-1}$)
Below: Dependence of the flow stress on the strain rate, $\phi$, at elevated temperatures (1200°C) using the example of 20MnCr5
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Fig. 8: Multiple-axis load on the material during forging in x, y, z directions in space. σ_x, σ_y, σ_z stresses along the directions in space; τ_xy, τ_xz, τ_yz, τ_yx, τ_zx, τ_zy shear stresses.

There are various hypotheses which assist in attributing the multiple-axis stress state to the uniaxial one. In these hypotheses, the effective stress, σ_v, is defined and calculated. Very often, the effective stress hypotheses according to Tresca and von Mises are used.

The effective stress according to Tresca (shear stress hypothesis) is as follows:

$$\sigma_v = \sigma_1 - \sigma_3$$

The effective stress according to von Mises (distortion energy theory) is as follows:

$$\sigma_v = \sqrt{\frac{3}{2} \left( (\sigma_1 - \sigma_m)^2 + (\sigma_2 - \sigma_m)^2 + (\sigma_3 - \sigma_m)^2 \right)}$$

with the mean stress, σ_m:

$$\sigma_m = \frac{1}{3} (\sigma_1 + \sigma_2 + \sigma_3)$$

The principal stresses in the principal-stress directions are σ_1, σ_2 and σ_3. It has been proven that, for every possible stress state, the coordinate system can be turned in such a way that three directions perpendicular to each other.
can be found in whose planes no shear stresses act, but only the three principal stresses. The stress which is most tensile is designated as \(\sigma_1\). The stress which is most compressive is termed \(\sigma_3\). Between these two stresses lies \(\sigma_2\).

**Hot-forging technologies**

A principle distinction is made in metal-forming processes between forging and sheet-metal forming (Fig. 9). Forging is frequently sub-divided into cold forging, warm forging and hot forging, depending on the workpiece temperature. The temperature at which a material is forged has a significant influence on the required forces, the plastic strain and thus the complexity of the workpieces to be produced. The forging temperature likewise affects the precision and tool life that may be achieved. Hot forging allows highly sophisticated parts to be produced which have a fibre flow that is adapted to the component geometry and which thus demonstrate good strength properties. The most important hot-forging processes are:

**Important hot-forging processes**
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- open-die forging
- closed-die forging with flash
- closed-die forging without flash.

**Open-die forging**

In open-die forging, tools with a very simple design – often flat upsetting punches – are used, and only part of the material is forged at a time. Open-die forging involves moving the workpiece between the individual forging stages so that after several steps the desired geometry is achieved. The process encompasses forging carried out manually with a hammer to produce art objects as well as that undertaken on hydraulic presses to produce very large shafts and discs for energy and power plant engineering applications. Since the entire open-die forging process is relatively time-consuming, it is only used for small volumes.

**Closed-die forging with flash**

Closed-die forging with flash uses tools which correspond to the geometry of the workpiece to be produced. Once the material has been heated to forging temperature, it is pressed into the desired shape between the upper and lower dies. Excess material, known as flash, flows out of the thin seams between the two halves of the tool (Fig. 10, left). This flash is removed in a separate process step (trimming). Frequently, the closed-die forging process is divided into several stages. The first stages involve material distribution. During the subsequent stages,
the main forging operations take place step by step. Closed-die forging without flash, also known as precision forging, is characterised by the fact that the tools create a completely closed hollow form in which the workpiece is shaped. Thus, no material is pressed into a flash during the forging operation. This means that the starting weight of the slugs corresponds exactly to the weight of the finished forged parts (Fig. 10, right).

The need to continuously optimise forging processes, both from a technological and from an economic point of view, has led to the development of special horizontal machines for closed-die forging without flash that operate with a high stroke frequency and that are equipped to carry out several forging steps. The individual steps are mostly based on some elementary types of forging or combinations thereof (Fig. 11). These include:

• **Upsetting and squaring up**
  These operations involve reducing the height of the workpiece so that its diameter is enlarged. If this is achieved without a limit to the radius, it is referred to as upsetting. If the circumferential surface of the workpiece comes into contact with the tool, it is referred to as squaring up.

• **Forward extrusion**
  In forward extrusion, the workpiece is introduced into a die and pressed through a smaller die opening. This leads to a reduction in the workpiece diameter and to an increase in the total length.

• **Forward can extrusion**
  In forward can extrusion, the workpiece is formed on a die-side punch. The material

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**Closed-die forging without flash**

**Types of forging**
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- **Upsetting**
  - Flat upsetting tool
  - Workpiece

- **Squaring up**
  - Punch
  - Die
  - Ejector
  - Workpiece

- **Forward extrusion**
  - Punch
  - Die
  - Workpiece

- **Forward can extrusion**
  - Punch
  - Die
  - Counterpunch
  - Workpiece
  - Ejector sleeve

- **Backward can extrusion**
  - Punch
  - Workpiece
  - Die
  - Ejector

- **Lateral extrusion**
  - Punch
  - Upper die
  - Workpiece
  - Lower die

- **Piercing**
  - Piercing punch
  - Tool-holding fixture
  - Workpiece
  - Slug

- **Trimming**
  - Trimming punch
  - Flash
  - Die
  - Tool-holding fixture
  - Workpiece
flows forwards around the punch and a cavity is produced. This causes the total length of the workpiece to increase, while its outer diameter remains unchanged.

• **Backward can extrusion**
  Backward can extrusion involves a punch being pushed into the end face of the workpiece. This causes the material to rise between the punch and the die cavity. The total length of the workpiece thereby increases, while its outer diameter remains unchanged.

• **Lateral extrusion**
  In lateral extrusion, the material flows transversely to the main direction of the machine movement into a tool opening with the desired shape. The tool is designed with split dies in order to be able to remove the workpiece after it has been formed.

• **Shearing/piercing and trimming**
  During shearing or piercing operations, the material is separated by cutting. If the material is separated from the inner part of the workpiece, it is referred to as piercing. Trimming describes the removal of material from the outside of the workpiece.

• **Hot sizing/finish forging**
  Hot sizing or finish forging refers to a process in which individual surfaces of the workpiece are formed again following the main forging process. This is carried out in order to meet greater demands on geometrical, positional and dimensional tolerances.
Horizontal multi-stage presses

Producing hot-forged parts in a cost-efficient way depends on a number of different factors. One decisive point is the availability of a suitable forging unit. In determining which forging unit is best, certain criteria need to be considered such as the production volume, the required press force, the number of forging stages and the number of strokes.

In the case of small batch sizes (approx. 100 to 5000 parts per annum), several individual tools are produced and then used on hydraulic presses or hammers for generating hot-forged parts (Fig. 12). The starting material is firstly cut to length by means of sawing or shearing. Subsequent to this, it is then heated to forging temperature in a gas furnace or induction-heating facility. Parts handling is mostly carried out manually. For medium-sized overall production volumes (up to 20,000 parts per annum), linked individual presses or vertical multi-stage presses

Fig. 12: Closed-die forging using a forging hammer
Horizontal multi-stage presses

with an automated transfer system are used (Fig. 13). The presses used can be hydraulically or mechanically driven. Such presses can achieve up to 40 strokes per minute, depending on the length and thickness of the part. The forging slugs produced by sawing or shearing are introduced one at a time into an induction-heating facility. After this, they are removed by a mechanically or electronically controlled transfer beam system and transported to the relevant forging stages.

For medium-sized to large total production volumes (from 20,000 parts per annum), horizontal multi-stage presses can be used (Fig. 14). These forging units are characterised by a very high parts output, which no other type of press is able to match. Depending on the size of the parts, 50 to 200 strokes per minute are possible. Horizontal multi-stage presses have an integrated shearing facility, which enables the induction-heated bars to be sheared to the required slug length. The cross transfer, which is mechanically controlled via cam discs, takes up the slugs and transports them from one forging stage to the next. Generally, precision forging processes are carried
Horizontal multi-stage presses

Suitable for all forging areas

out on such machines so that parts with great levels of accuracy and without flash can be produced at a high degree of material utilisation.

**Machine concept of horizontal multi-stage presses**

Horizontal multi-stage presses can be used for cold-, warm- and hot-forging operations. The presses used for cold forging draw their material mostly from coiled wire, and are designed for the greater flow stress of such materials with respect to stage forces, the tool assembly space and the shearing forces. Oils are usually used as lubricants. By contrast, horizontal multi-stage presses for hot forging – and for warm forging with certain workpiece geometries – generally work with bar stock. The lubricant used during hot forging is either pure water or water mixed with corrosion inhibitors and wetting additives.

The following text focuses in particular on the use of horizontal multi-stage presses for hot
Machine concept of horizontal multi-stage presses

Horizontal multi-stage presses consist of a machine base that has usually been cast in one piece. The press ram is driven within the machine base by means of a crankshaft and a connecting rod, and it executes an oscillating, horizontal movement. The tools fixed to the press ram are mostly punches and are held by a suitable tool-holding fixture. These work together with the tool parts mounted on the press base, usually the dies, in order to form the part during several forging stages (Fig. 15). Three to four forging stages are customary on hot-forging presses. Depending on the given geometry of the part, the following forging stages are required:

- upsetting
- preforming
- finish forming
- trimming and/or piercing and hot sizing.
24 Horizontal multi-stage presses

As the press ram is arranged horizontally, the large volumes of lubricoolant used for cooling the tools are able to flow off downwards after use. Even bar ends and piercing slugs or separated flash gravitate downwards, and are thus removed easily. The good parts are also routed downwards following the last forging stage.

Horizontal multi-stage presses used in hot forging are linked with peripheral units to form a fully automated forging line (Fig. 16). This forging line mainly consists of a bar-stock feeding facility, an induction-heating unit, the horizontal multi-stage press itself and an unloading belt for controlled cooling of the workpieces. As a rule, the entire facility can be operated by one or two employees.

Principle of operation/machine kinematics

The machine kinematics of horizontal multi-stage presses corresponds to those of conventional (vertical) crank presses. Both types of presses demonstrate a small ratio between the length of the connecting rod and the ram stroke. This leads to a very rapid forging process. Furthermore, due to the brief contact time, the thermal load on the tools is low. The
rapid forging process also generates a relatively large time gap for transferring the workpieces.

**Machine drive**
The electric motor for the press drive system is located outside of the actual machine base. It drives the flywheel, which is equipped with a clutch-brake combination. The task of the brake is to bring the press ram to a standstill quickly should there be a fault with the press or the forging process. This is intended to prevent damage occurring to the machine or to the tools. A gear transfers the energy from the motor to the crankshaft which, in turn, drives the press ram via a connecting rod (Fig. 17). All other movements of the multi-stage press are derived directly from the crankshaft by means of power take-offs via auxiliary shafts. The synchronised, positively controlled movements of the shearing blade, the transfer system, the punch, the punch monitoring system, the punch-side holding pin and the ejector on the die side are thus always guaranteed.

**Fig. 17:**
*Drive system of a horizontal multi-stage press*
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Bar-stock feeding system
A bar-stock feeding system is used to draw the raw material bars directly out of the induction-heating facility. This feeding device, which is usually designed with four feed rolls, conveys the bar stock up to the bar stop of the shearing station within the work cycle of the machine. The feed rolls are adapted to the diameter of the bar stock. Due to the pressure which they subject the bars to, they remove a large proportion of the adhering scale that arises in the ambient atmosphere during induction heating.

Shearing station
The sheared slugs required for forging the workpieces are produced directly in the multi-stage press by means of hot shearing. The shearing facility consists of a fixed blade attached to the die block, a clamping piece, as well as a movable shearing slide with a shear blade and a slug holding pin (Fig. 18). The shearing slide is driven by a radial cam. Firstly, the bar is pushed until it reaches the bar stop, upon which it is then fixed by the clamping piece. The shearing slide moves forwards, shears the material and transports it to the first forging station. During the transport phase, the slug continues to be held by the cutoff holding pin until it is taken up by the punch-side holder pin of the first station. Decisive factors for the quality of the finished parts include the highest possible consistency in slug length, and thus also slug weight, as well as the lowest possible slug deformation. Also of importance is the quality of the shearing surface on the end faces of the slugs.

Transfer system
In order to achieve a high number of strokes, a reliable transfer system for transporting the workpieces from one forging stage to the
next is an absolute prerequisite. The transfer facility consists of a rail with several adjustable upper and lower grippers, which in turn are mounted on gripper supports (Fig. 19). The grippers are arranged in front of the dies. Their purpose is to hold the workpiece in a perfectly centred way at the particular forging stage until the workpiece is pushed into the die by the punch. While the press ram moves into the forward dead-centre position (forging), the cam-controlled grippers are driven back by one forging stage, ready for taking up the next workpiece. During the backward stroke of the press ram, the workpiece is brought into a transport position in front of the die block by means of a die-side ejector and a punch-side holding pin. It remains fixed there until the gripper takes up the workpiece or the workpiece is pushed into the gripper. A cross-transfer system transports all workpieces forward by one forging stage.

**Transfer-system components**

**Fig. 19:** Transfer facility

**Transport of the workpiece**
Ejectors and holding pins
The ejectors and the holding pins integrated in the tool fix the workpiece in a defined position in front of the die-block face following completion of a forging operation so that it may then be taken up by the transfer facility. The workpiece is held between a punch-side holding pin and a die-side ejector. The time of ejection can be individually adapted at each forging stage to the part being produced by means of adjustable and exchangeable radial cams (Fig. 20). Prior to the subsequent forging stage, the workpiece is clamped between the ejector and the holding pin while the grippers open. Following this, the workpieces are pushed into the die by the punch or the holding pin and are then forged. An additional task of the die-side ejector lies in introducing cooling water precisely at those sites of the die that are subjected to strong abrasive wear due to elevated temperature loads.

Cooling system
Due to the high workpiece temperatures and the high number of strokes of the presses, a great deal of thermal energy is transferred to the tools during the forging operations. This thermal transfer arises from the heated bar slug itself as well as from the forging energy,
90% of which is converted into heat. In order to prevent high levels of abrasive wear on the tools, a cooling system is required that also serves as a carrying medium for the various lubricant additives. What is known as a cooling bridge is used to introduce the cooling medium into the forging process. From this bridge, nozzles and water outlets direct the cooling water onto the tools. On the die side, the tools are also cooled from the inside. The die and the ejector need to withstand particularly high thermal loads. Drilled holes in the machine base allow the cooling water to be routed to the ejector, which directs the water onto the die upon ejecting the part.

**Tool-changing systems**

In order to achieve a high level of efficiency within the forging process, it is essential that the tool change is carried out rapidly. To do this, the tools from all forging stages can be removed together as one block from the press via a tool-changing facility, and then

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**Fig. 21: Tool-changing system**
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**Automatic or manual tool change**

Transferred to a rack that has been placed nearby. The tools to be changed are removed from another rack and transported into the machine (Fig. 21). There, the tool block is clamped manually or automatically via a hydraulic tool clamping system. If necessary, the cross-transfer system with grippers for each stage can also be completely changed. If it is only individual tool elements which need to be changed, the process can be carried out manually.

**Monitoring equipment**

Besides the safety equipment that is incorporated into multi-stage presses, as prescribed by occupational health and safety regulations, comprehensive monitoring systems are also integrated in order to prevent injury to people as well as damage to tools and the machine itself. Proximity switches are thus used to monitor the opening and closing of the grippers, for example. Workpieces which remain adhered to the punch are not taken up by the transfer system, and are thus not transported further. During the forging operation on the next workpiece, the tool would then have two workpieces to deal with, thereby leading to an overload for tool and machine. For this reason, punch sensors are moved in front of the punch upon each stroke in order to detect any workpieces adhering to it and, if necessary, to bring the machine to a standstill prior to the next stroke.

**Peripheral equipment**

The high yield of horizontal multi-stage presses requires that they be linked with peripheral equipment further up and down the chain. Examples of such peripheral units include the bar magazine, the heating facility.
Peripheral equipment

and the cooling belt. These peripheral units need to be designed to precisely meet the volume output, the maximum bar diameter as well as the maximum permissible starting weight of the multi-stage press. Equipment for heat-treating and shot-blasting the parts may either be assigned directly in line with the forging machine in continuous operation or be used for several presses in batch operation.

Bar magazine/stock reel

The raw material is usually in the form of round rolled bar stocks. Where the diameter of the raw material is smaller, rod wire from a coil can be used. Following the incoming inspection, the raw material is held in intermediate storage before being introduced into the feed unit. When using rod wire, a vertical or horizontal stock reel is used. Bar stocks, usually with lengths of between 6 m and 9 m, are laid in bundles on a material cart where they are then separated. From there, they are transported to the heating facility.

Heating system

The raw material is heated to temperatures of between 1100°C and 1250°C in the heating system. At these temperatures, the material demonstrates considerably reduced flow stress and higher ductility compared with its behaviour at room temperature, and thus can be formed into a complex part over several forging stages. Heating is carried out by induction under normal atmospheric conditions. The raw material is transported through several induction coils which are adapted in size and power to the material to be processed (bar stock diameter) and to the material throughput. The alternating current flowing through the induction coils generates an electromagnetic alternating field in the insides of the coils. This in
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turn induces circular currents that decrease exponentially towards the centre of the bar stocks. This leads to the outer parts of the bar being heated in particular (skin effect). The bar stocks are heated through to the inside by means of thermal conduction (Fig. 22).

Fig. 22: Principle of induction heating
Above: Workpiece (1) with induction coil (3) and magnetic field (2)
Below: Current distribution in the workpiece along the diameter
j Induced current
δ Current penetration depth
d Diameter

The consistency of the final temperature is seen as a significant quality criterion of heating systems. Decisive for this is the temperature difference both in the bar stock cross-section as well as across the entire bar length. One advantage of induction heating is that scaling of the material may be kept low due to the rapid heating process.

Low levels of scale

Unloading and cooling line
Following the last forging stage, the workpieces fall downwards and are transported out of the multi-stage press by means of a conveyor belt. If suitable steel types are used (i.e. quenched and tempered steels or micro-alloyed dispersion-hardening steels), or if suitable cooling units such as furnaces or covering
hoods (with case-hardening steels) are used, it is possible to carry out heat-treatment processes in a cost-efficient way directly after the forging operations have been completed. This has the advantage that the workpieces do not need to be heated again. To achieve this, it is necessary to cool the workpieces in a controlled way and relatively quickly from the forging temperature to temperatures of approx. 600°C to 750°C and, if necessary, to hold them within this temperature range for a certain time. This endows the workpieces with the desired strength and hardness, as well as with a certain toughness, depending on the grain structure. Cooling is carried out either on special cooling belts, which may be equipped with ventilating fans or covering hoods, or else in suitable continuous furnaces. In the latter case, the workpieces may either be cooled using an adjustable air stream or held within a certain temperature range. It is important that the workpieces are evenly distributed on the conveyor belt so that they are all cooled uniformly.

Heat treatment subsequent to forging …

… requires controlled cooling
Forging process and tools

The movement of the press ram enables the tools to form the workpiece into its final geometry. The various forging stages determine the grain flow and plastic strain generated in the workpiece. Thus, the forging tools which are used have a considerable influence on the quality of the parts produced. On horizontal multi-stage presses, the tool set-up for one forging stage consists of several individual forging tools which are stacked. The tool sets for the single forging stages are in turn grouped together to form a complete tool set (Fig. 23). Each tool set is designed for one particular forging operation. As a rule, the following forging stages are involved: upsetting, material distribution, finish forging (precision forging without flash) and separating (piercing and/or trimming).

Tool life and thus costs are greatly influenced by the design of the individual forging stages,
known as the sequence of forging stages, as well as by the design and production of the individual tools. Besides the forging unit used, tools thus also play a key role in producing high-quality hot-forged parts in series production in a cost-efficient way. When designing tools, experienced tool designers as well as process and material specialists are required. Besides this, an absolute must is the continuous support provided by computer-aided engineering tools such as FEM, CAD, CAM and CAQ. It is not only the three to four tool sets for the forging stages which need to be adapted to the particular slug diameter or to the workpiece, but also the feed rolls, the shear blades, the grippers, the punch sensors and, in some cases, the cooling water jets, too.

**Process design**

Process design involves determining the individual forging stages needed for producing the finished part. These are summarised in a sequence of forging stages. Depending on the workpiece geometry to be produced, the following forging operations may be carried out: upsetting or squaring up, forward extrusion, forward and backward can extrusion, lateral extrusion, piercing or trimming, and in some cases hot sizing, too.

**Sequence of forging stages**

The sequence of forging stages details which geometry the workpiece must demonstrate after each forging stage has been completed. A sequence of forging stages involving four stages is shown in Figure 24. The geometry and the tolerance requirements which the finished part needs to fulfil form the starting point for determining the surfaces to be machined and for providing them with a machin-
Forging process and tools

In collaboration with the customer, the geometry of the part is modified in order to take process limitations into account. These include, for example, draught angles, minimum wall thicknesses, minimum radii and holes, as well as any necessary material overflow. The following boundary conditions are taken into account to outline the individual forging stages:

- bar diameter
- material
- surface requirements
- strength requirements
- number of pieces
- number of stages
- interval between stages
- press force
- machine transfer.

Process limits and volume consistency have to be taken into account as well. Process limits are set by material-related values such as the maximum plastic strain and degree of upsetting, by tool-related values such as the internal pressure, as well as the sliding movement between tool and workpiece. All these values greatly influence tool life. The sequence of forging stages is used as a basis for designing the individual forging tools.

**Fig. 24:** Sequence of forging stages for an outer race of a constant velocity joint
FEM process simulation
The sequence of forging stages is verified by means of FEM process simulations (FEM; Finite Element Method). FEM simulations are used to determine at a very early stage of the development and planning process whether problems will arise when forging the material. Furthermore, they allow substantiated statements to be made on possible forging defects that may occur, such as folds, overlapping, as well as underfilling of the die, or material separations (Fig. 25). Besides this, the simulation also serves to estimate the press forces and thus the loads that the tool and machine must withstand.

The material volume is divided into individual workpiece elements for the FEM process simulation. These workpiece elements are described by means of a material model in terms of yield conditions and flow law. The material model can describe the material either as elastic-plastic or rigid-plastic. In the case of hot forging, the elastic elongation of the material compared to the plastic deformation can be neglected. Thus it is generally rigid-plastic material models which are used. The yield condition describes at which stress state the material deforms plastically. Flow curves, as shown in Figure 7 (see p. 13), serve as the basis for this. The flow law provides information on how the material will deform at the given stress state. The simulation program calculates the material flow on the basis of a balance between deformations and boundary conditions such as tool geometry and tool movement. The degree to which the die is filled, the fibre flow and other parameters such as the temperature and stresses in the workpiece can be derived from this.

The selected boundary conditions such as the friction law and the values of the friction co-
Forging process and tools

efficiencies between the workpiece and the individual tool elements also have a significant influence on the simulation results. Besides simulating the actual forging process, modern FEM programs also have the capacity to calculate the grain structure which will be generated by the forging process. This provides the opportunity to optimise the workpiece properties by means of suitable process design prior to actual production operations. It is also possible for the simulation to model the load which the tools must withstand with respect to prevailing stresses, the material fatigue arising as a result of mechanical and thermal influences, as well as the abrasive load on the tool surface.

Through simulation it is possible to check the feasibility of producing a part in advance in a relatively simple and cost-effective way. If forging defects happen to be revealed, it is still possible at this point to undertake modifications to the geometry of the tool and to alter the sequence of forging stages in order to ensure that the parts are subsequently produced with zero defects.

Increased computing power and high-performance software packages provide readily accessible results. They are also responsible for having ensured that FEM process simulations are nowadays an indispensable part in the development of forging processes on horizontal multi-stage presses.

Process steps during hot forging on horizontal multi-stage presses

The procedure for a four-stage forging process, including the typical steps involved, will be outlined in the following text. In the case of three-stage forming processes, the first two stages – upsetting and material distribution – are combined, or else one stage is omitted.
**Shearing**

Prior to the actual forging process, the heated raw material bar stock is conveyed from the feed rolls into the shearing stage. Here, the bar stocks run on an adjustable bar stop, which ensures that a consistent slug length is achieved. The actual shearing system consists of the movable shear blade, the fixed blade, the carrier, the cut-off holding pin and the clamping piece. The shear blade, driven by a radial cam, cuts the shearing slugs. The blades must be adapted to the particular bar diameter in each case in order to avoid deformation of the slugs. The cutting edges of the blades are frequently armoured (welded) with special heat-resistant materials, and they have a recess in order to guarantee an appropriate blade clearance. The shearing operation is aimed at producing slugs that are as cylindrical as possible, that demonstrate a consistent weight as well as good end-face qualities.

**1st forging stage – upsetting**

During the first forging stage, the slug is usually only upset. A distinction is made between upsetting that is carried out between two flat upsetting punches and squaring up or closed-die upsetting. Generally speaking, free upsetting serves to remove the oxide layer on the outside of the slug. The slight deformation which occurs during the upsetting operation causes the brittle oxide layer to flake off and fall downwards away from the slug. This enables good surface qualities, low machining allowances and a longer tool life to be achieved.

In the case of workpieces with more complex geometries, process steps such as squaring up in a die or forward extrusion may be used in the first forging stage if these are no longer
Forging process and tools

Fig. 26: Combined upsetting and squaring up
a) The slug is transferred to the first stage and is pushed against the ejector by the punch.
b) The ejector remains stationary so that the slug can be upset and the scale thereby removed.
c) The ejector is pushed into the die subsequent to the descaling stroke.
d) The descaled slug is squared up in the die.

possible in the following stages, as laid down by the sequence of forging stages. This means, however, that the oxide layers cannot be removed, and thus greater machining allowances generally need to be taken into account.

Certain systems allow a combination of both upsetting and squaring up to be carried out (Fig. 26).

2nd forging stage – material distribution
The second forging stage involves preforging the workpiece. It is during this stage that the greatest levels of plastic strain are achieved. Depending on the course of the subsequent stages, the workpiece geometry after the preforging operation either already roughly corresponds to the workpiece geometry to be produced, or it is initially pressed into a simple preform which demonstrates optimum volume distribution for the forging stages that follow. Usually, preforging is an operation without flash, i.e. the header punch arranged on the ram side enters the die and thereby forms the workpiece.

3rd forging stage – finish forging
During the third forging stage, the workpiece is given its final shape, except for those areas which are to be separated during the subse-
sequent stage. The levels of plastic strain are generally significantly lower than those during the preforging stage. Small radii and areas with thin wall thicknesses are shaped. Generally, the highest press forces need to be applied during the finish-forging stage.

4th forging stage – piercing and trimming
During the final forging stage, the parts are usually pierced or trimmed. In the piercing process, the workpiece is supported by means of a die with an appropriate recess. A piercing punch presses the floor of a cavity that was preformed out of the workpiece during the previous stages. The workpiece is then drawn out of the die upon the return stroke of the punch and is stripped off the punch by a stripper. It then falls onto the conveyor belt which transports it out of the machine. The piercing slug is pushed through the die and falls through a passage onto another conveyor belt that removes material waste (piercing slugs, flash, under-length slugs from bar ends). In the case of parts with complex outer geometries such as spiders or multiple-arm flanges, production with flash (similar to closed-die forging with flash) may be necessary. This flash is likewise separated from the workpiece during the last stage. Furthermore, the fourth forging stage may be used to hot-size the parts. Hot sizing is
Forging process and tools

used to form certain surfaces to meet tighter tolerances.
Figure 27 shows the sequence of forging stages which is necessary for producing a gear wheel with six waves.

Tool design

Tools represent the heart of forging operations and are of great significance with respect to the cost-efficiency of the production process. Tool precision, reliability and service life are all considerable cost factors, and thus tool development, design and engineering are among the core competences required in operations using horizontal multi-stage presses.

Tool structure

The tools are stacked for the individual forging stages and arranged in a basic tool block (Fig. 28). This fixes the precise position of the punch holder and die to each other. The punch holder, which enters the die, is usually fixed to the press ram. Holding pins are inte-
grated into the punch side to fix the workpiece prior to the forging operation and to hold it in front of the punch during the return stroke. Pusher rods, which extend through the tool structure, activate the holding pins. These pusher rods can be moved via radial cams that are integrated in the machine. On the die side, forging tool elements are located in a die holder. Depending on the load and the forging pressures which arise, the tools are pre-stressed using shrinkage rings. Ejectors are arranged on the die side to move the workpiece out of the die into the transport position.

It is important to cool all those tool elements that are in contact with the workpiece. To achieve this, the die or the ejector is often provided with drilled holes and ducts in order to be able to apply coolant to the areas that are subjected to high loads. At the same time, it is also important to have ducts to allow the water vapour generated during the forging operations to escape from the die cavity.

**CAE (Computer-Aided Engineering)**

Nowadays, it is not only 2D CAD systems (CAD; Computer-Aided Design) which are used for designing forging tool elements, but also 3D CAD systems, too. These enable a continuous data flow to be achieved, right from the design phase and simulation stage through to production using CAM systems (CAM; Computer-Aided Manufacturing). CAM systems are used during the preparation stage to generate the programs for the CNC machine tools (CNC; Computerised Numerical Control). The geometry data forms the basis for quality assurance surveillance using CAQ systems (CAQ; Computer-Aided Quality Assurance). Using this geom-
For forging process and tools

Geometry data, testing programs are developed on the computer and the permissible tolerances are determined both for the forging tools and for the workpieces. In order to minimise the standstill times of the presses, the movement of the transfer system used to transport the workpieces is also modelled on the computer. This enables possible problems such as collisions or workpieces falling off due to the grippers releasing them too soon to be monitored in advance.

Tool materials

The tools which come into contact with the workpiece during hot-forging processes on horizontal multi-stage presses need to withstand high thermal and mechanical loads and significant levels of abrasive wear. In addition, the intensive use of cooling water causes a very pronounced repeated change in temperature. This leads to the generation of thermal-shock cracks. For this reason, high-alloy tool steels (hot-forging tool steels) are used as tool materials. These are usually alloyed with chromium, nickel, molybdenum or vanadium in order to achieve adequate toughness at the highest possible hardness values and a great level of wear resistance (Table 1). For those tool parts which do not come into direct contact with the hot workpiece, it is possible to use more reasonably priced conventional tool steels, as here it is only good strength and hardness properties that are decisive.

Depending on where and how the tools will be used, a compromise must be made between hardness and toughness. Hardness ranges of between >40 HRC and 60 HRC are usually chosen. In order to increase wear resistance,
the forging tools may be additionally hardened by means of carburisation or nitriding. The choice of parameters with respect to the heat treatment can have a considerable influence on tool life.

### Tool production

A complete tool set consists of the stack of tools needed for each of the forging stages. These are known as stage tool stacks. Each stage tool stack comprises approx. 15 to 25 individual parts, depending on complexity. They are machined from sawn slugs of rolled steel bars or from rolled steel slabs.

### Soft machining

The tool components are machined in the soft state. Due to the low strength values prevailing during this phase, the machining tools are able to achieve high metal-removal rates and a long tool life. Tool parts with low dimensional tolerances are provided with an allowance in order to compensate for the distortion that occurs during the hardening process. The changes to the dimensions that arise during the hardening process are subsequently compensated for when the surfaces undergo hard machining.

### Machining

<table>
<thead>
<tr>
<th>Material number</th>
<th>DIN-designation (DIN = German Institute for Standardization)</th>
<th>AISi reference</th>
<th>Chemical composition in % (typical values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2344</td>
<td>X 40 CrMoV 5 1</td>
<td>H13</td>
<td>C 0.40, Cr 5.20, Mo 1.30, V 1.00, Co –</td>
</tr>
<tr>
<td>1.2365</td>
<td>X 32 CrMoV 3 3</td>
<td>H10</td>
<td>C 0.32, Cr 3.00, Mo 2.80, V 0.50, Co –</td>
</tr>
<tr>
<td>1.2367</td>
<td>X 38 CrMoV 5 3</td>
<td>H11</td>
<td>C 0.37, Cr 5.00, Mo 3.00, V 0.60, Co –</td>
</tr>
<tr>
<td>1.2885</td>
<td>X 32 CrMoCoV 3 3 3</td>
<td>H10A</td>
<td>C 0.32, Cr 3.00, Mo 2.80, V 0.50, Co 3.00</td>
</tr>
</tbody>
</table>

Table 1: Tool materials for hot forging
Heat treatment

Following soft machining, the tools are heat-treated in order to adapt the material properties to the subsequent operating conditions. The tool components which come into contact with the workpiece are usually hardened. This involves initially bringing the tool to a temperature which causes the carbon to completely dissolve in the iron crystals (austenitic range), and which is dependent on the material quality. The heating process is not continuous, but is carried out in temperature stages. Continuous heating poses the hazard of stress cracks, as the steels demonstrate reduced heat conductivity due to the high proportion of alloys. In order to achieve even temperature distribution throughout the tool, it is thus necessary to hold the material for a certain time at each temperature stage and also upon reaching the hardness temperature. This ensures that the tool is evenly heated through to the core. The length of time it takes to achieve this even temperature distribution depends on the geometry and wall thickness of the tool.

After an even temperature has been reached, accelerated cooling is carried out in hardening oils, salt baths or using a stream of nitrogen (quenching). The characteristic critical cooling rate for each steel needs to be reached in order to ensure that the austenite completely transforms into martensite (tempered martensitic structure). Due to its high degree of supersaturation in the atomic lattice, the dissolved carbon leads to atomic strains in the grain structure. Following austenitizing and quenching, the tool is as hard as glass and brittle, and would lead to failure by fracturing under the given load cases. Repeated heating to temperatures of 450°C to 650°C (tempering) causes these atomic strains in the grain structure to be relieved. A tempered grain structure and an
optimum balance between surface hardness and toughness are reached in order to achieve the best possible wear-resistance properties. In so doing, it is necessary to allow the tools to cool to room temperature following each tempering operation. High-quality tool steels are usually tempered at least three times. In order to increase the surface hardness and the wear resistance, the tools can undergo nitriding or carbonitriding in addition to the initial hardening operation.

**Hard machining**

Besides conventional hard-machining processes involving grinding, the past few years have seen an increase in turning and HSC milling (HSC; High Speed Cutting) operations. This development is a result of the modern cutting materials available today such as CBN (CBN; Cubic Boron Nitride) and fine-grain cemented carbides. These processes enable the distortion caused by heat treatment to be compensated for in a simple and cost-effective way. Hard machining at high cutting speeds and low feeds leads to surface qualities which lie in the range of $R_a = 0.8$ to $3.2 \, \mu m$. It is thus sometimes possible to put the tools into operation without the need for manual finishing operations such as polishing.

**Use of pre-assembled tool sets**

**Pre-assembly**

Due to the high hourly machine costs of horizontal multi-stage presses, the running time of these facilities needs to be maximised for financial reasons. In order to reduce the standstill times during tool changes, the tools undergo pre-assembly outside of the machine. This involves stacking the tools for the indi-
Forging process and tools

Individual forging stages and then mounting and adjusting them in a holding block (Fig. 29). This facilitates any necessary adjustment work to the individual tool parts. During the tool change, the entire block containing the used tools is removed from the machine by means of a crane. A crane is likewise used to introduce the new tool set into the machine where it is then clamped in position by means of clamping bolts.

Tool lubrication and cooling
Tools used during the hot forging of steel are subjected to high loads. Besides the mechanical loads which arise during the forging process, the tools also need to withstand high thermal alternating stresses. Furthermore, the contact with the forged part leads to abrasive load on the tool surface.

If tools are permanently used at temperatures of above approx. 600°C, the tool material undergoes a continual reduction in strength due to tempering effects. This means that the hard martensitic grain structure produced during the hardening operation transforms into softer components such as bainite, ferrite and...
Use of pre-assembled tool sets

pearlite. The tools are thus cooled in order to prevent this (Fig. 30). Via spray nozzles which are mounted near the tools, the active tool elements, in particular the punch, are sprayed with cooling water. Frequently a nozzle ring is mounted in front of the die in order to cool the walls of the die, too. Furthermore, in the case of deep die cavities, it is necessary to provide the ejectors with ducts through which the die wall can be cooled during ejection of the workpiece. When designing the tools, it is necessary to also provide openings in the die to allow the water vapour generated during the forging process to escape. This prevents the punch and die from becoming overloaded and the die cavity from not being filled completely.

The coolant used is water with salts, corrosion inhibitors and stabilizers added to it. The additives serve to improve wettability between the coolant and the tools, while the corrosion inhibitors protect the tool and machine. The coolant not only cools the tool surface but also ensures that the heat is distributed evenly.

Fig. 30: Cooling of the tools

Cooling measures

Cooling medium: water with additives
Forging process and tools

Heat distribution function

within the entire tool assembly space. Uneven thermal expansion of tool blocks on the die and punch sides would otherwise lead to deviations in part accuracy.

The tool surface is heated during the actual forging process when it comes into contact with the forging material, which has a temperature of approx. 1200°C. This leads to high compressive stresses occurring on the tool surface. Subsequent cooling, by contrast, leads to tensile stresses on the tool surface. This frequent alternating stress can cause fatigue on the tool surface, resulting in thermal cracks.

Methods for increasing tool life

Depending on geometrical factors, the forging material, the temperature and the configuration of the sequence of forging stages, high partial contact pressures can occur during the forging process. These can amount to levels several times greater than the flow stress of the forging material if the material slides along the tool during the forging process. Abrasive wear results particularly if scale, i.e. oxidised hard material, is introduced into the tool. This wear load can only be counteracted to a limited extent with the use of lubricants. In order to reduce the level of abrasive wear, it is thus necessary to increase the hardness of the tool surface, for example by means of nitriding. During the nitriding process, the tools undergo conventional hardening before being treated in nitrogen-emitting gases (temperatures of between 480°C and 540°C) or in salt baths (temperatures of between 520°C and 570°C). Nitrogen diffuses into the tool surface and strains the dislocation gliding planes on an atomic level, thereby increasing the material hardness. A very high nitriding depth of up to several tenths of a millimetre may be achieved by

Hardening by nitriding
treating the tools in a salt bath. The nitriding depth depends on the duration of the particular treatment.
If increased levels of scale are drawn into the individual forging stages, it is important to pay particular attention to the upsetting operation when optimising the forging process. In such a case, it is necessary to vary the degree of upsetting, i.e. the ratio of the starting length of the slug to the length of the upset part, in order to improve spalling of the scale around the circumference of the slug. Another simple option is to reduce the forging temperature so that scale formation is minimised from the outset. To do this, however, the forging process needs to permit a lower forging temperature.
An optimally designed sequence of forging stages ensures that those forging operations which lead to high abrasive loads on the die and punch are distributed across several forging stages so that the tools used for each particular forging stage achieve a similar tool life. The efforts involved in the tool change are thereby reduced, and the operating time of the machine can be increased.
A briefer contact time between the tool and workpiece always leads to lower heat input into the tool surface. The effect of the temperature on the tool surface is thereby reduced. For example, there are fewer burns on the surface structure, and the levels of thermal alternating stress are lower (Fig. 31). Due to this, the tool life is correspondingly higher. In order to achieve a brief contact time between tool and workpiece, a high press-ram speed at the front dead centre needs to be aimed for. However, as this is mainly predetermined by the press kinematics, it can only be varied by the frequency of the strokes. One drawback of shortening the contact time is that the time...
interval needed for cooling the tools is also reduced. It is necessary here to find the best possible compromise.

One way of improving the wear resistance of the tools and of the shear blades in particular is to apply high-alloy welding filler materials, known as stellites. These are applied using laser welding or tungsten inert-gas surfacing at coating thicknesses of between 2 and 3 mm. In some cases, even coating with PVD or CVD coatings (PVD stands for Physical Vapour Deposition, CVD for Chemical Vapour Deposition) may be advisable. These very thin (<10 µm) and extremely hard (~3000 HV) coatings are unable to significantly reduce the thermal load of the tool material, however. Furthermore, the tool material must also demonstrate an appropriate basic hardness in order to prevent the PVD and CVD coatings from spalling.
Production process

Due to the high stroke frequency achieved with horizontal multi-stage presses, and to the fact that the forging processes carried out on these machines are designed in such a way that every stage is occupied, no other machine type achieves such a high performance. Thus, depending on the machine size, it is possible to produce up to 12,000 parts per hour or, theoretically, a throughput of up to 36 tons of steel per hour. In order to achieve these values, sophisticated logistics systems must be in place with respect to material supply and transport as well as to the further processing of the workpieces.

Workpiece materials

Hot forging is suitable for almost all metallic materials. It is primarily steels that are processed. These can be subdivided into unalloyed and low-alloy steels. Insofar as the requirements placed on the part demand that another material be used, it is also possible to employ high-alloy steels, too. For the plumbing and pipe-fitting industry, various brass alloys are processed on horizontal multi-stage presses. Even though the forging of aluminium alloys is also possible in principle, it is not currently carried out due to the unfavourable behaviour of aluminium during the hot-shearing process. Frequently used steels are listed in Table 2. Besides unalloyed and low-alloy steels, case-hardening steels, quenched and tempered steels and dispersion-hardening steels are also used. Case-hardening steels are generally easy to machine following hot forging and subsequent isothermal cooling or subsequent annealing. The surface-hardening treatment by means of carburising, hardening and temper-
Production process

In a production process at approx. 200°C, machining is carried out only after the parts have been machined. Gears, for example, are frequently produced from case-hardening steels. These steels are characterised by tooth flanks which are extremely hard and which have a high load-bearing capacity, as well as by a tooth base that can withstand impact loads.

In the case of quenched and tempered steels, it is possible to use certain heat treatments to adapt their mechanical and technological properties (such as tensile strength, elongation at failure, toughness, and even machinability, too) within a wide range to the particular application. Drawbacks of these heat-treatment processes, however, are the efforts and costs that they involve. Using steels with microalloying elements such as vanadium, titanium or niobium makes it possible to achieve the properties of quenched and tempered steels by means of controlled cooling from the hot-forging temperature. Such steels are referred to as dispersion-hardening steels.

Table 2: Frequently used steels for producing hot-forged parts

<table>
<thead>
<tr>
<th>Material number</th>
<th>DIN-designation (DIN = German Institute for Standardization)</th>
<th>Excerpt of the chemical composition (typical values)</th>
<th>Mechanical properties (heat-treated, in bars &lt; Ø 16 mm)</th>
<th>Properties</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0037</td>
<td>1.1191 Ck45</td>
<td>0.20</td>
<td>370 235 25</td>
<td>Unalloyed structural steel</td>
<td>Parts with no special requirements</td>
</tr>
<tr>
<td>1.7218</td>
<td>25CrMo4</td>
<td>0.25 0.70 1.00 0.25</td>
<td>900 700 12</td>
<td>Quenched and tempered steel</td>
<td>Nuts, fasteners</td>
</tr>
<tr>
<td>1.7227</td>
<td>42CrMoS4</td>
<td>0.42 0.75 1.10 0.22</td>
<td>1100 900 10</td>
<td>Quenched and tempered steel</td>
<td>Transmission shafts, chassis, gears</td>
</tr>
<tr>
<td>1.5231</td>
<td>38MnSiVS5</td>
<td>0.38 1.40 20.3 0.10</td>
<td>820 550 12</td>
<td>Dispersion-hardening steel</td>
<td>Chassis, wheel hubs</td>
</tr>
<tr>
<td>1.7131</td>
<td>16MnCr5</td>
<td>0.16 1.2 0.90</td>
<td>780 590 10</td>
<td>Case-hardening steel</td>
<td>Gears, camshafts</td>
</tr>
<tr>
<td>1.3505</td>
<td>100Cr6</td>
<td>1.0 0.35 1.5</td>
<td></td>
<td>Bearing steel</td>
<td>Cams, bearing rings</td>
</tr>
</tbody>
</table>

...quenched and tempered steels...

...dispersion-hardening steels...
Heat treatment

High price, they nevertheless represent a cost-effective alternative to conventional quenched and tempered steels, as the heat-treatment process can be omitted. Parts that need to withstand high contact pressures and a high level of sliding wear such as bearing rings or cams are produced from special materials alloyed with chromium. These are known as bearing steels (e.g. 100Cr6).

Heat treatment

Hot forging endows workpieces with their geometry. The final component properties such as strength and toughness are only achieved, however, by a combination of hot forging and subsequent heat treatment. There are many different types of heat treatment to choose from in order to achieve an optimum combination of properties as required for the particular application. Common heat-treatment processes include:

- **Normalising**
  This is used to achieve an even and fine grain structure.

- **Hardening and tempering**
  This is a heat-treatment process which involves hardening and tempering in order to achieve a predetermined strength value while attaining high levels of toughness.

- **Quenching and tempering from forging heat**
  Under certain circumstances, quenching and tempering are possible using hot-forging temperatures. Direct quenching of the workpieces from the forging heat allows the hardening process in a furnace to be omitted. The subsequent conventional tempering operation ultimately serves to set the defined strength and toughness properties.
Production process

- **Soft annealing**
  This refers to the process of reducing the hardness of a workpiece to below a given value, e.g. for subsequent cold forging.

- **Treating for strength**
  Annealing to achieve a certain tensile strength.

- **Treating for ferrite-pearlite microstructure**
  Annealing to achieve a certain grain structure. Besides improving machinability, this heat treatment causes a reduction in the distortion behaviour of ferrite-pearlite grain structures during case hardening subsequent to machining.

- **Controlled cooling from the forging heat**
  For certain parts, the required properties can be directly achieved by means of controlled cooling from hot-forging temperatures. Micro-alloy dispersion-hardenning steels, for example, are particularly suited to this type of heat treatment.

**Shot blasting**

Generally, all workpieces are shot-blasted prior to final inspection and dispatch. This removes any scale generated during the previous operations as well as any traces of flash material. The blasting agent consists of steel grains of various sizes (from 0.1 mm) and shapes (round or angular). In order to be able to use the most suitable steel mix for each particular application, it is common to work with compositions consisting of various grain sizes and to vary the duration of the shot-blasting operation. The parts can be shot-blasted on a continuous conveyor, on a troughed belt or on an overhead conveyor.
Quality properties and tolerances

A significant advantage of forged workpieces lies in the grain flow of the material, as it follows the workpiece geometry and is thus optimally adapted to the particular load case. In contrast to machined workpieces, the grain flow in forged parts is not interrupted. The grain flow can be made visible in metallographic cross-section by means of etching. Figure 32 shows the fibre flow in a universal joint. The strength and toughness properties in the direction of the grain structure are better than those transverse to it. An uninterrupted grain flow enables a higher fatigue strength to be achieved than is possible with machined workpieces.

As a rule, forged parts achieve accuracies of between IT 14 and IT 16 according to the ISO tolerance classifications. When carrying out hot-forging operations on horizontal multi-stage presses, smaller tolerances within the range of between IT 11 and IT 13 are achieved and, under certain circumstances, even IT 10 is not impossible. Such tolerances cannot be obtained, however, without considerable technological efforts. These involve achieving lower tolerances in the raw material, ensuring that the heating temperatures are kept within a narrow range, providing thermally stable conditions in the machine and within the forging process, as well as using precision forming tools which demonstrate the lowest possible...
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Quality requirements

Due to the high investment costs of horizontal multi-stage presses and all the associated peripheral equipment, such facilities have high costs. Such considerations generally lead to increased production costs. In general, though, it is only certain workpiece dimensions that are critical to function which are produced to such tight tolerance values. The applicable dimensions must be agreed upon by the manufacturer and the customer in each individual case. If particularly tight tolerances are not required, allowances of between 0.5 and 2.0 mm are customary on the surfaces in question. An additional advantage is that any skin decarburisation of the forged parts, which is caused by induction heating of the bars in air, may be minimised. The demands placed on the workpieces with respect to material and dimensions are determined by the customer. Meeting these demands is guaranteed by means of a quality management system. The criteria which need to be monitored are established in close collaboration with the customer in advance of the project. The scope of the quality inspection may include not only geometrical values (Fig. 33), but also strength properties and crack detection.

Cost considerations

Due to the high investment costs of horizontal multi-stage presses and all the associated peripheral equipment, such facilities have high
hourly machine cost rates. Due to the fact that these machines are often only operated by one or two employees, it is clear that the key to achieving cost-efficient operation does not lie in reducing labour costs but in consistently utilising the machine operating time to the full. Irrespective of the wage level, horizontal multi-stage presses only operate efficiently in companies where it is possible, from a technical and organisational point of view, to maximise the operating time of the machine. Great efforts are thus made to minimise scheduled standstills for tool changes, maintenance and repair as well as unscheduled ones arising from tool failure or organisational problems, for example.

As it is very time-consuming to adapt horizontal multi-stage presses and the entire forging process to a different part, production is only feasible from an economic perspective with batch sizes of 20,000 parts and above. In the case of smaller batch sizes, production on manual or automated hammers or presses often represents the more cost-effective solution.

**Combination with other production processes**

In general, hot-forged workpieces undergo subsequent operations to make them into assembly-ready components. In designing production processes and process chains, various types of processes need to be weighed up, taking technological and economic aspects into account. The advances being made in individual processes such as machining or cold forging result in the need to periodically revise and, where necessary, adapt existing process chains. Examples of this include the production of outer races for constant velocity...
Production process

joints by means of hot forging and machining, or the subsequent direct heat treatment of certain steels from hot-forging temperatures.

**Machining**
Machining enables very tight tolerances and optimum surface qualities to be achieved (Fig. 34). A distinction is made between machining in the soft, unhardened state and machining in the hardened or quenched and tempered state. The development of modern cutting materials has led to the possibility of turning, milling and broaching workpieces with hardness values of up to 60 HRC and above with a cost-effective tool life.

In the case of milling and turning, HSC technology is used. This is characterised by high cutting speeds and low cutting depth in each cut. The advantage of hard machining lies in the fact that it is a cost-effective way of compensating for the workpiece distortion that arises during the hardening process.

**Cold forging**
Hot-forged parts can be further processed by means of conventional cold forging. If high levels of accuracy are demanded of particular
component surfaces, it is possible to cold-calibrate the workpieces (Fig. 35). This involves forging the workpieces which have been previously coated with molykote, for example, with high press forces in a tool that is pre-stressed with several shrinkage rings. In general, only small levels of plastic strain occur, i.e. the changes to the workpiece geometry are only negligible, while the accuracy and surface quality are greatly enhanced. Bevel gears for differential gearboxes are typical parts which can be produced by hot forging with subsequent cold calibrating. By using both forging processes, the geometry of the tooth flanks can be produced ready for assembly. This is due to the fact that the levelling of roughness peaks on the workpiece surface leads to a high percentage of contact area.

**Joining**

Often, process limitations mean that parts cannot be produced from one workpiece. In such cases, the parts can be produced by joining two workpieces together which may have been produced by different processes. Common joining operations include welding processes such as friction welding and flash-butt welding as well
Production process

Very widespread is the joining of synchronising gear rings with hot-forged speed gears for vehicle gearboxes. This is because such parts have a functional undercut that makes it extremely difficult to produce them with assembly-ready dog teeth from one workpiece (Fig. 36). Hot-forged parts are also frequently joined with tubular parts. Input shafts for commercial vehicles, for example, consist of hot-forged flanged parts which are joined with tubes by means of friction welding. Likewise, in order to achieve weight savings, a great number of camshafts are produced from forged and machined cams as well as a tube by means of various joining processes (assembled camshaft).

Special processes

Double-part production
Double-part production refers to the manufacture of two parts made of the same material from one bar slug. Particularly in the case of
annular or tubular parts, it is possible to produce an inner and an outer ring from one slug, for example. The parts are separated from each other during the penultimate or the final forging stage by means of piercing and by using a special stripping device. Double-part production is used in particular for producing inner and outer races for all types of bearings. Besides increasing productivity (two parts per stroke), this process also achieves better material utilisation. In addition, it is very cost-effective if the production volumes are the same for both parts.

**Rotation during transfer**

By means of a special rotating device on the grippers, it is possible to turn the slug by 90° during the transfer. After the slug has been rotated in this way, its longitudinal axis is no longer parallel to the press-ram movement but is in the direction of the cross transfer. This enables workpieces to be produced which demonstrate an undercut related to the longitudinal axis or which require a fibre flow that is now parallel to the ram. Furthermore, the rotating device allows workpiece geometries to be produced which would otherwise only be possible with complex tool technologies or high material use.
Examples of products

Nuts and cams

Figure 37 shows a selection of nuts and cams produced on horizontal multi-stage presses by means of hot forging. Besides standard nuts, special nuts such as locknuts, collar nuts and weld nuts are frequently produced, as well as nuts for particular applications such as hub axle nuts and gearbox nuts. In order to produce these parts, three-stage presses are often used. The production sequence consists of free upsetting, main forging into the desired shape and piercing. A similar production sequence is also used to produce raw cam parts for assembled camshafts.

Universal joints

Due to the high volumes possible on horizontal multi-stage presses, tripods and spiders (Fig. 38) for universal joints as well as for propeller and drive shafts are typical parts produced on this type of forging machine. These are mainly produced with flash.
As the flash does not surround the entire circumferential surface, but is only located between the individual journals, the end faces of the journals can sometimes be produced ready for installation. The removal of this small amount of flash as well as any piercing of the parts that may be necessary are carried out at the same time during the third forging stage of the process. Subsequent cold calibration enables tight geometrical, dimensional and positional tolerances to be generated.

**Bearing rings**

Figure 39 shows bearing rings made from 100Cr6. The inner and outer rings are produced together in a double-part production process. During the fourth forging stage, they are separated and the smaller of the two rings is pierced in the centre. Both can be produced without flash on their outer contour. This is beneficial with respect to subsequent operations. These parts frequently serve as preforms for additional processes such as ring rolling.

**Assembly-ready end faces**

**Without flash**
Examples of products

during which they are then made into larger parts with greater diameters.

Raw gear parts and bevel gears

Raw parts for gears used in the engines of passenger and commercial vehicles and gearboxes (Fig. 40) are very often produced by means of
hot forging with subsequent soft machining. This is followed by the induction hardening of functional surfaces (teeth). Depending on the requirements with respect to running noise and service life, they subsequently undergo hard finishing by means of shaving or lapping. Bevel gears are generally preforged by means of hot forging so that the material distribution of the teeth is optimally prepared for the cold-forging process. The teeth can then be cold-forged until they are assembly-ready, with accuracies of between IT 6 and IT 8. Following this, the part is then finished mechanically in the concave region and, where appropriate, in the drilled hole.

Flanges

Among the parts belonging to the large family of flanges are three-armed flanges, wheel hubs and flange shafts. Flange shafts are used for the output of manual and automatic gearboxes, as well as for the input and output of differential gearboxes. Besides highly accurate concentric running properties, adequate balancing of the shafts is also important in order to prevent vibrations in the powertrain. During the
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hot-forging process, a surrounding groove can be introduced in order to accommodate a seal (Fig. 41).

**Outer races for constant velocity joints**

Outer races for constant velocity joints, as shown in Figure 42, serve to transmit torque from the input shaft to the wheels. Balls roll in the ball tracks to ensure that torque is transmitted evenly at variable angles between the input and output shafts. The outer races for constant velocity joints are hot-forged during a four-stage forging process. Following cooling and heat treatment, the parts are soft-machined. The races then undergo induction surface-hardening treatment. The distortion which arises in the races during this process is machined away by hard-finishing operations. Another solution is to pre-correct the distortions during soft machining, thereby omitting the hard-finishing operation subsequent to hardening.

Fig. 42: Hot-forged raw part for an outer race of a constant velocity joint (left), and an outer race of a constant velocity joint with a soft-machined inner contour (right)
Outlook

Continuous developments in the hot forging of metallic workpieces – a process which has its roots in the age-old tradition of hammer forging – will secure the future of products which are competitive both from a technological and economic point of view. It is not only new, even more efficient forging machines that will play a significant role in this, but also the continuing process optimisations and ambitious product innovations of hot-forging companies. Great development potential lies in the ongoing optimised planning and implementation of process combinations. This involves exploiting and combining the particular process-specific advantages of hot forging, warm forging and cold forging as well as the benefits of machining operations in order to achieve an optimum production process for the desired part.

New, more cost-efficient materials which nevertheless fulfil the demands placed on the parts are currently being developed. Materials which involve lower process costs due to the omission of heat-treatment processes and additional operational steps are also the focus of current research and development efforts. Furthermore, in view of the trend towards lightweight construction in vehicles and the associated increase in production volumes, the forging of certain aluminium alloys on horizontal multi-stage presses can be reckoned with in the future.

Enhanced machine and tool technologies together with the use of advanced planning tools should enable ever more sophisticated geometries to be produced and significant reductions in part tolerances, and thus in machining allowances, to be achieved. To reach this object-

Process combinations

New materials

Enhanced machine technology
ive, a close working relationship is necessary between the forging company and the customer in the sense of a development partnership. Only then it is possible to meet customer requirements while at the same time allowing for an optimised cost structure.

The high strengths and safety reserves that are associated with the optimum grain flow of hot-forged parts enable these to be transformed into precision lightweight components. Thus hot-forged precision parts produced on horizontal multi-stage presses will continue to make an important contribution to weight optimisation in future, too, and will thereby play a key role in reducing automotive fuel consumption.
The company behind this book

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SEISSENSCHMIDT AG, headquartered in Plettenberg, Germany, was founded in 1846 and has established itself as an outsourcing partner to the international automotive industry. Previously a producer of parts for the railway industry, for heating systems and for cement construction, SEISSENSCHMIDT has been active as a supplier in the automotive sector for four decades now. The company’s success story as an automotive supplier began in 1965 with its investment in the first fully automatic horizontal multi-stage hot-forging press.

For large-series production, SEISSENSCHMIDT employs a broad range of fully automatic horizontal multi-stage presses that is unmatched worldwide and with which it achieves an output of up to 9000 forged parts per hour. The forging enterprise accompanies its customers from the design stage right through to the production of the assembly-ready part. State-of-the-art technology is used during each development phase.

The range of services provided by SEISSENSCHMIDT also encompasses conventional hot forging and heat treatments. In addition, cold forging is offered for producing parts with extremely low allowances and tolerances from hot-forged raw parts. SEISSENSCHMIDT Components Processing GmbH & Co. KG, a subsidiary of the SEISSENSCHMIDT AG, provides comprehensive capacities for carrying out various machining processes. The entire service spectrum is rounded off with a high level of competence in the area of logistics.

The subsidiaries, SEISSENSCHMIDT Corporation in the US and SEISSENSCHMIDT Precision Components Kft. in Hungary, as well as numerous representations abroad, ensure that the company has an excellent international presence.

SEISSENSCHMIDT delivers precision components for drive and chassis applications to almost all the renowned automotive manufacturers and leading system suppliers.

The production programme includes precision components for gearboxes, engines, differentials, suspensions, drive shafts and other application areas within the drive system and the chassis.