# Intelligent lightweight design by forged transmission components

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**Abstract**

Due to the current trend towards lightweight design in automotive industry, also the weight of transmissions has to be reduced. An optimization of the production process is necessary as well as the reduction of input material for economical reasons. Components produced by forging feature high potential for lightweight design due to their excellent properties which can be traced back to the load oriented fibre flow. Further potential for weight reduction is provided by using hollow shafts instead of solid shafts. Various process variants based on forging technology are presented and assessed. Another possibility for weight reduction consists of forged gears. Thus, components may be shortened by using forged gears as no lead-out area of the milling tool is necessary. Additionally, geometries can be produced which can be hardly manufactured economically by machining processes. Furthermore, a concept for burr reduction of machined running gears based on forging technology is presented.

Various examples of series production as well as developments illustrate the potential for lightweight design as well as the economical benefits of forging technology. New material developments are presented within the outlook.

**Kurzfassung**

Aufgrund des aktuellen Trends zum Leichtbau muss bei der Getriebeherstellung mehr denn je auf ein möglichst geringes Einbaugewicht der Einzelbauteile geachtet werden. Gleichzeitig erfordern wirtschaftliche Aspekte eine Optimierung des Herstellprozesses sowie die maximale Einsparung von Vormaterial. Umformtechnisch hergestellte Bauteile besitzen ein hohes Leichtbaupotential aufgrund ihrer hervorragenden Werkstoffeigenschaften, die u.a. auf den beanspruchungsgerechten Faserverlauf zurückzuführen sind. Weiteres Potential zur Gewichtseinsparung besitzt die Ausführung torsionsbelasteter Wellen als Hohlteile. Es werden verschiedene umformtechnische Prozessrouten zur wirtschaftlichen Herstellung von Hohlteilen vorgestellt und bewertet. Leichtbaupotential ergibt sich außerdem bei der Verwendung umformend hergestellter Verzahnungen. So können durch umgeformte

Verzahnungen Bauteile verkürzt und Geometrien hergestellt werden, die zerspanend wirtschaftlich nicht herstellbar sind. Außerdem wird ein umformtechnisches Konzept zur Verringerung der Gratbildung bei der spanenden Herstellung von Laufverzahnungen vorgestellt.

Anhand verschiedener Beispiele aus Serienproduktion wie aus Entwicklung werden das Leichtbaupotential sowie die wirtschaftlichen Vorteile der Massivumformung dargestellt. In einem Ausblick werden neue Werkstoffentwicklungen vorgestellt.

**1. Introduction**

Due to the ongoing discussion on climate change, automotive industry faces essential challenges. The necessary reduction of $CO_2$ emission requires consistent lightweight design in the whole vehicle. Likewise, the trend towards electric cars needs lightweight design for compensating the additional weight of battery systems. Thus, the need for weight reduction is also present regarding transmissions. Besides the design of the transmission itself, the production technology has a significant impact on the weight saving potential of single components. However, lightweight design can only be successful if it is accepted in the market. This implies cost-effective solutions feasible for mass production.

Forging technology can offer both weight saving potential as well as cost efficiency (Fig. 1). Due to the high strength formed components can be designed more sophisticated and with thinner walls leading to a reduction of the weight of the component.

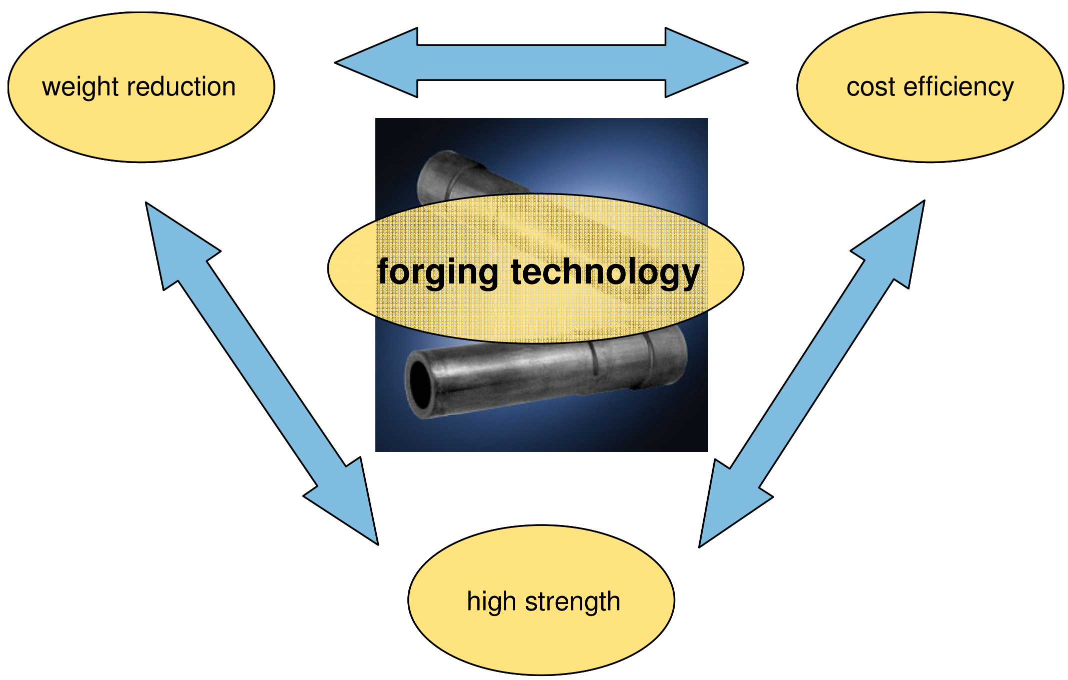


Fig. 1: Advantages of forging technologies for mass production

## 2. Potential for lightweight design by forging

Due to excellent material properties which allow smaller wall thicknesses, forged components exhibit a huge potential for lightweight design. In combination with specific heat treatment processes, the material may be adapted to optimally meet the demands of the component. Therefore, material, component design and forging temperatures have to be coordinated well for achieving ideal component properties and cost efficient production.

One reason for superb mechanical properties of forged components is the fibre flow which is aligned with the geometry of the component. Schuster et al. [1] revealed by various etching methods that the fibre flow is determined by the orientation of elongated inclusions, especially manganese sulphides MnS. While the tensile strength and the yield strength are hardly influenced by the orientation of manganese sulphide inclusions [2], a positive effect on the impact work as well as the fatigue strength can be observed in case of longitudinal orientated manganese sulphides. Cyril et al. [3] observed that the impact work of a 42CrMo4 with a hardness of 50 HRC is reduced by 74 % from longitudinal to transverse orientation of manganese sulfides. For low sulphur contents, the impact work is reduced by 40 %. Schuster et al. [4] examined the impact work for various steels. Specimens have been prepared from the rolled material in longitudinal and transversal direction (Fig. 2a). In case of 30MnVS6 and 20MnCr5 significant differences between the impact energy in parallel and normal direction to the fibre flow has been detected. Similar results can be found for 16MnCrS5 and Cf53, respectively. KLST specimens according to [5] have been used for the experiments. As can be seen from Fig. 2b), the impact energy for the specimens taken parallel to the fibre flow is significantly higher than in perpendicular orientation.

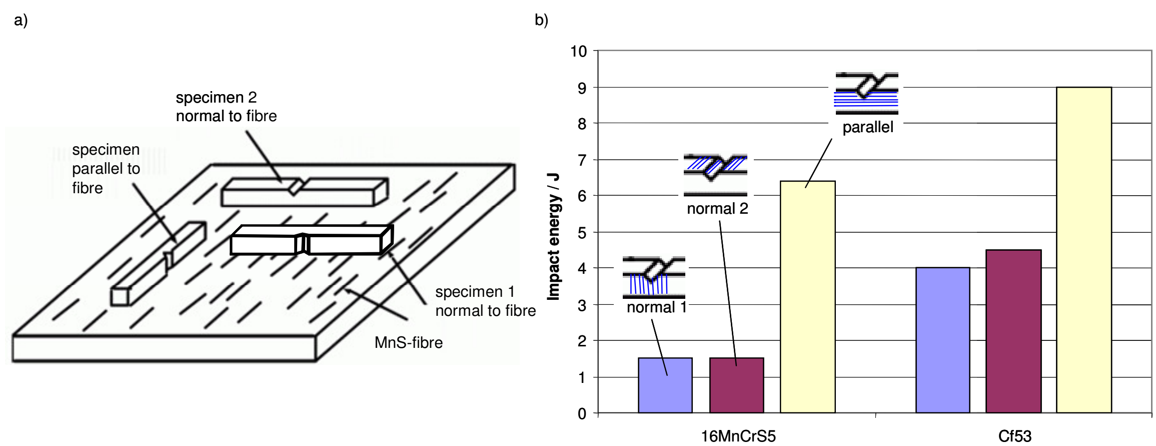


Fig. 2: Influence of fibre flow on impact energy

Regarding fatigue strength, e.g. investigations of Furuya et al. [6] exhibit a reduction from longitudinal to transverse direction of 50 % for a quenched and tempered spring steel. Eventually, it can be concluded that the fibre flow has a significant influence on the mechanical properties of the component. Especially, mechanical properties at dynamic conditions can be significantly affected by the orientation of the fibre flow. Thus, forging processes which lead to a fibre flow aligned with the geometry of the component, improve the mechanical properties of the parts.

**3. Hollow shafts**

The application of hollow transmission shafts is increasing due to the rising demand for weight reduction and due to the increasing demand for double clutch transmissions typically using concentrically running shafts. Hollow design of transmission shafts exhibits a significant weight reduction potential as the mechanical properties like torsional stiffness are hardly influenced by the core material. Thus, from solid to hollow design of shafts in passenger car transmissions, weight reduction of 15 % to 30 % is possible. Fig. 3 shows typical hollow shafts for manual and automatic transmissions, respectively. These examples show the wide range of hollow shafts which can be manufactured economically by forging technology.

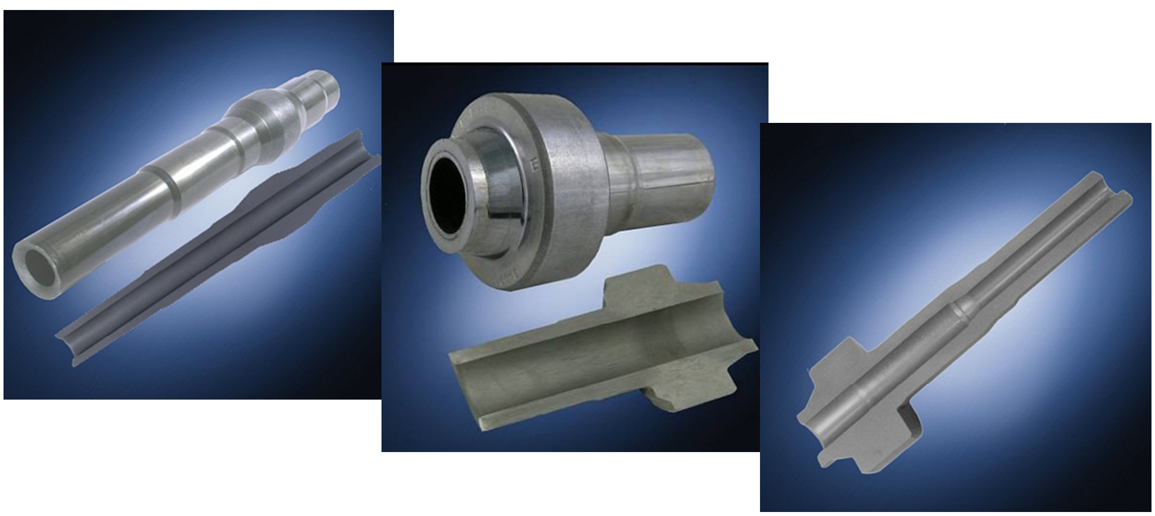

Fig. 3: Hollow shafts for manual transmissions and double clutch transmissions

Regarding the production of hollow shafts basically three process variants exist (Fig. 4). As the available raw material is always bar material, an additional process step like drilling, can extrusion or tube rolling is required leading to higher production costs compared to solid shafts. Conventionally, hollow shafts are produced by forging and subsequent deep-hole drilling. As this process requires maximum material usage and drilling depth, it can be considered as the most expensive process. Another possibility for the production of hollow shafts consists of drilling of the billet and subsequent forging. Thereby, the billet weight as well as the drilling depth can be reduced which results in lower production costs.

The production of a tubular preform is also possible by forging operations, namely can extrusion and piercing. This process requires the smallest amount of material for the billets. In addition, the cost intensive drilling process can be omitted which results in lower costs for manufacturing of hollow shafts. Instead of using bulk material, hollow shaft production starting from tubes seems to be reasonable. But several drawbacks like restricted accuracy and wall thicknesses or high costs prevent a broad application of tubes for hollow shaft production.

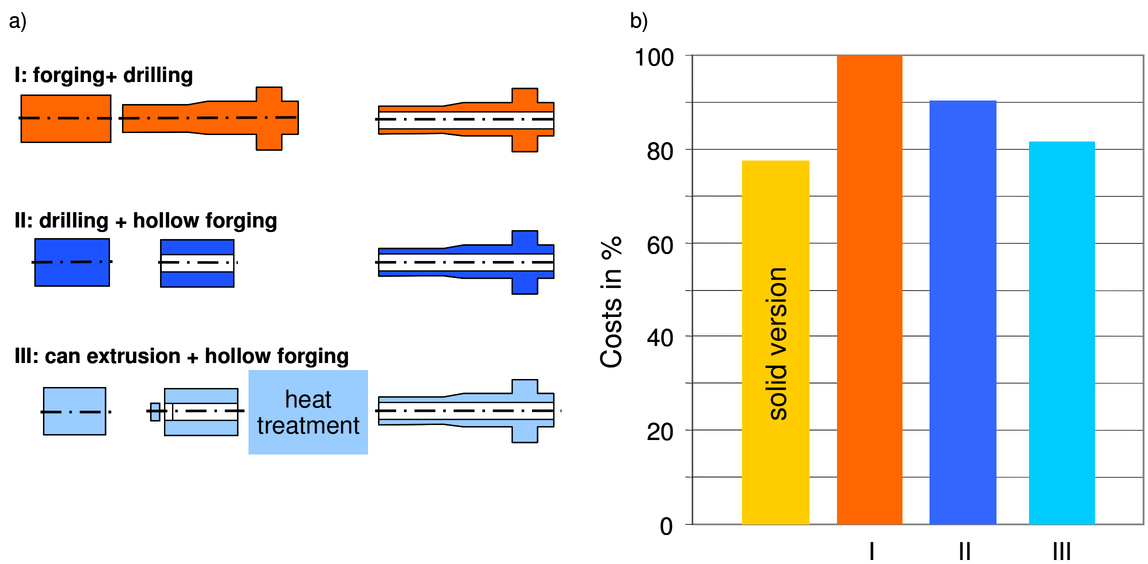


Fig. 4: a) typical process variants for hollow shaft production; b) comparison of production costs relative to solid version

In addition to the economical benefit of forged hollow shafts compared to drilled shafts advantages arise as more internal contours with bigger weight saving potential can be realised. Fig. 5 shows a drilled and a forged version of a hollow shaft. While the strength of the drilled shaft is reduced by the outside undercut, the design of the hollow forged version leads to increased strength due to a bigger shaft diameter. The weight reduction of the outside undercut of the drilled version is relatively small compared to the forged internal cavity. The costs for the drilled version are high due to the big drilling volume while the forged shaft can lead to reduced costs as a result of material savings. This example points out the weight saving potential of shafts produced by hollow forging which goes beyond the possibilities of the conventional manufacturing process consisting of forging and deep-hole drilling.

Fig. 6 illustrates the variety of geometries of hollow shafts which can be produced by forging processes. As flanges, form flanges as well as one or two-sided tapers are possible, the majority of shafts for transmissions can be produced economically by forging processes.

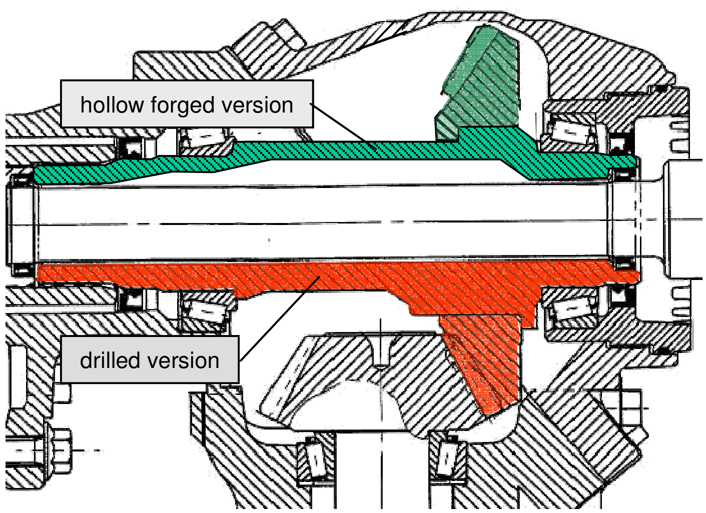


Fig. 5: Hollow shaft versions based on drilling and hollow forging

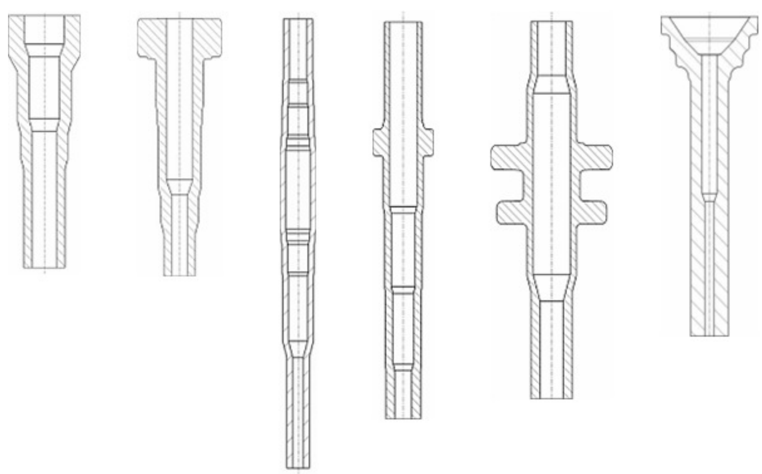

Fig. 6: Possible design versions of hollow shafts

Compared to typical input or main shafts of double clutch or manual transmissions components like the stub shafts shown in Fig. 7 are characterised by thin walls, big hole diameters and thin flanges. Thus, these components have not been produced up to now by cold forging which is very cost-effective for thick walled or solid transmission shafts. The stub shaft shown in Fig. 7 has been produced by a highly economic automated multi stage cold forging process. Hence, an alternative to the traditional production process based on tubes has been established.

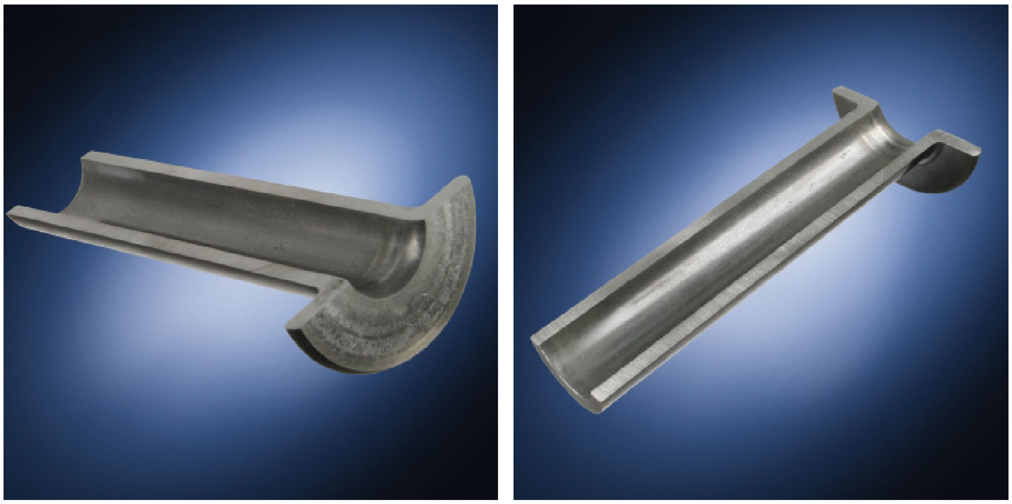

Fig. 7: Thin-walled stub shaft, produced by highly economic multi stage forging process

**4. Forged gears and splines**

Forged gears represent another possibility for cost-effective lightweight design. Forging can be used to produce both gears and splines regarding on the tolerance requirements. The high productivity of forging processes permit cost-savings when producing gears or splines in large quantities. Netshape or near netshape forging reduces machining efforts leading to additional cost reduction potential. For example, spline gears require tolerances IT8 according to DIN5480 which can be achieved using state of the art forging. With additional effort like intermediate machining for eliminating volume fluctuations of the raw parts quality IT7 can be achieved. The specification of tolerances according to the function of the component instead of general tolerances can lead to even more economical solutions of forged gears. In case of part dimensions which are replicated directly within the shape of the tool, tolerances of IT5 or IT6 can be achieved, e.g. pitch and profile of forged gears. Regarding the potential for lightweight design, forged gears offer various advantages which are discussed below.

As forging processes lead to an uninterrupted fibre flow which follows the outer shape of the gears as well as strain hardening, forged gears feature advantageous mechanical properties like an enhanced fatigue limit. By exploiting these beneficial mechanical properties it would be possible to design smaller components leading to weight reduction. Additionally, forged splines enable a different design of components as typical restrictions from machining like lead-in or lead-out areas are not necessary. Thus, components can be produced shorter which reduces the weight of the part. For example, producing the splines of the link shaft by cold forging instead of machining (Fig. 8a), lead to a reduction of length of approx. 25 % and a weight reduction of approx. 15 %. This could be achieved by omitting the lead-out area for the machining process.

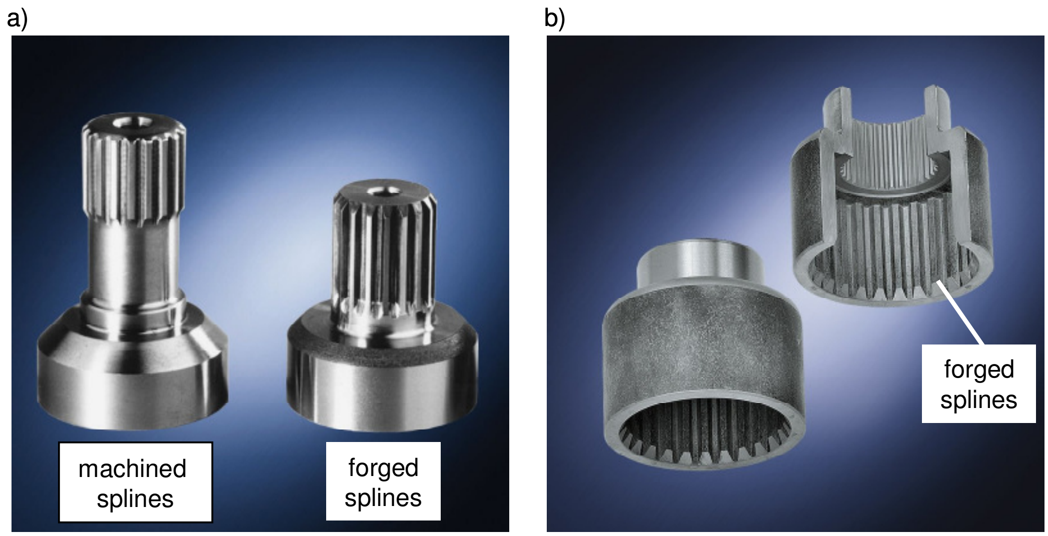


Fig. 8: a) End piece with machined and forged splines; b) connector flange with forged splines

As hardly any lead-out area is necessary the forged splines of the bigger diameter of the connector shaft in Fig. 8b extend to the bottom of the cup. This connector shaft made from C35 between gearbox and drive side is produced by a three stage cold forging process with backward extrusion of the bigger spline. Several component designs can be achieved economically only by forging technology. E.g. the three arm flange in Fig. 9a) with a spline in a blind hole is produced by warm forging, intermediate machining and cold extrusion of the spline. This geometry cannot be produced by machining economically. The sliding shaft (Fig. 9b) with internal teeth on the bottom of the cup is manufactured by a three stage cold forging process. As there are hardly any lead-in and lead-out areas the overall length of the splines can be used.

a) b)

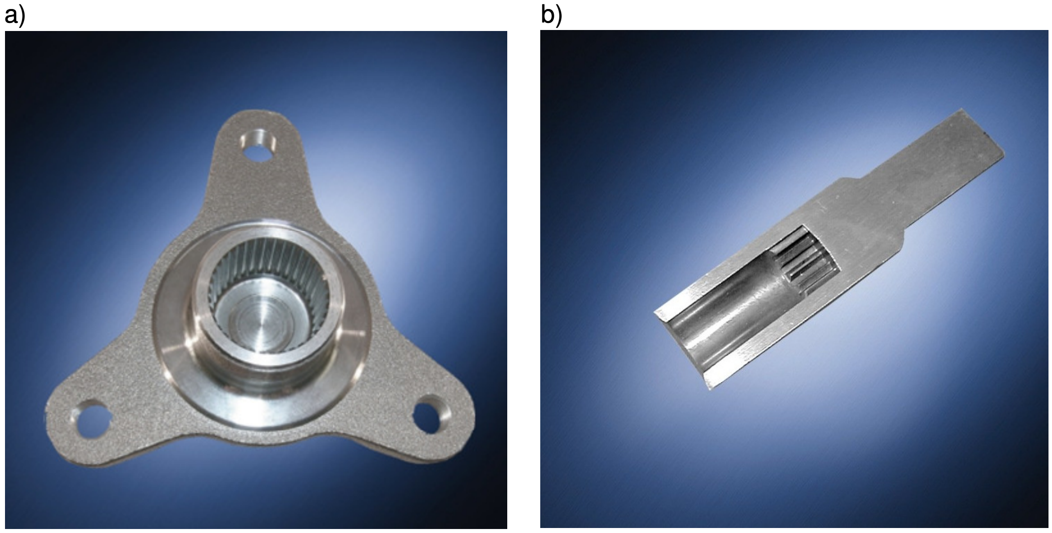

Fig. 9: a) Three arm flange with forged splines; b) sliding shaft with forged splines

An additional advantage of the absence of the lead-out area of the milling tool is represented by a smooth transition from spline to cylindrical shaft which leads to a reduction of the notch stresses. This fact is illustrated in Fig. 10 which compares simulation results of machined and forged splines. In this simulation, the splines have been loaded with a torsional load. The resulting equivalent stress is lower in case of the forged splines.

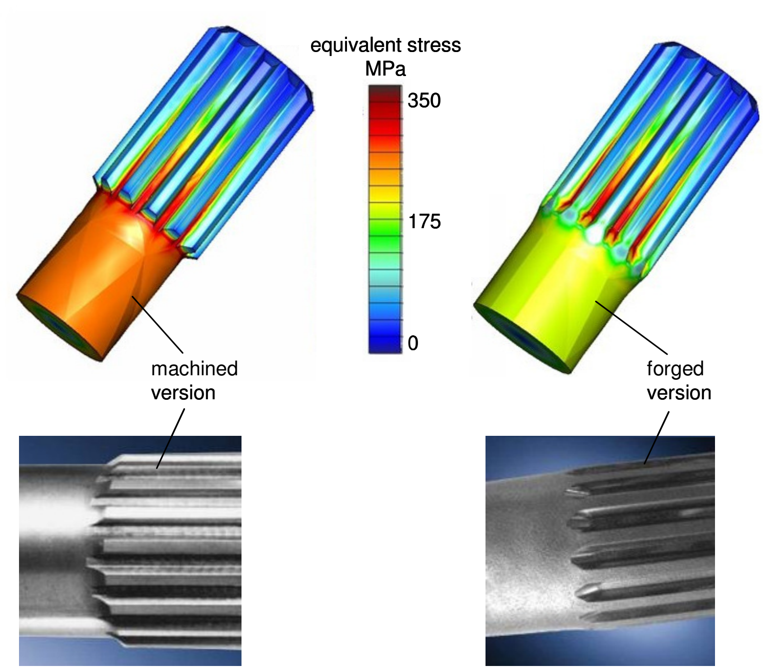


Fig. 10: Comparison of machined and forged splines

In order to transmit high torques within a restricted space Hirth gears are very well suited. Especially in axial direction, Hirth joints require less space as conventional splines. The maximum torque which can be transmitted can be even increased by a radial connection of the teeth (Fig. 11). Nowadays netshape forging of Hirth gears is possible. When forging Hirth gears the tooth position relative to the component is not limited: Hirth gears can be forged even in recesses. Additionally a wide range of tooth flank angles as well as crowning in axial and radial direction can be produced. Besides offering a high degree of design freedom, forging represents an economical production at high volumes. Thus, Hirth joints become an interesting machine element for automotive applications.

Fig. 11: Various components with face gears (Hirth gears)

Regarding running gears, usually tighter tolerances are required due to high rotational speeds which can only be met by grinding, honing or lapping. An exception is represented by differential bevel gears which rotate relatively slow. Thus, quality requirements are less restrictive which enables forging of ready to assembly running gears. Concerning running gears with high quality requirements due to noise issues, pre-forged gears may reveal cost-saving potential under certain conditions: in case of large gears the reduction of the billet weight and the machining volume, hence a decrease of machining time and tool wear, could be preferable on a total cost basis compared to entire machining of the gears out of bulk material.

However, in conventional manufacturing of running gears by machining, forging technology could provide further benefits for cost-effective production. During machining of gears usually the occurring burr and sharp edges at the lead-out area of the milling tool are undesired. Thus, the edges of the machined gears are often chamfered within an additional and costly process step. This may be omitted by a new concept for the production of chamfers. Instead of chamfering the gears after machining, the chamfers can be produced by forging before machining the gears. Forging of chamfers is possible as the tolerance requirements of the chamfers are less compared to flanks of the gear teeth. By preforged chamfers the exit angle of milling tool can be changed in order to minimize the formation of burr. Eventually, this concept may minimize or even prevent burr making the cost-intensive mechanical removal process dispensable. Apart from the initial alignment of the rotational position during soft machining, the existing production concept does not need to undergo any changes.

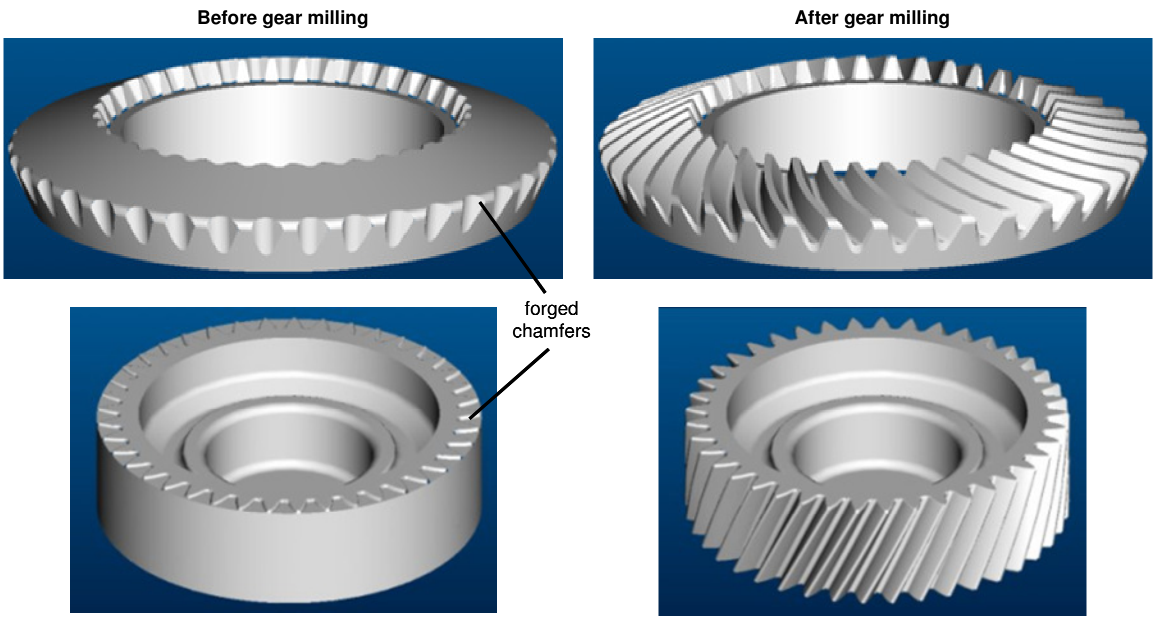


Fig. 12: Concept of preforged chamfers for running gears

**5. Conclusions and outlook**

Forging technology offers many opportunities for cost-efficient production of lightweight components. As forging processes enable the orientation of the fibre flow according to the geometry of the part enables, excellent mechanical properties like increased fatigue life are provided. Efficient forging processes for production of hollow shafts enable advanced lightweight design at reasonable costs. Forging of hollow shafts allows part geometries which cannot be produced, or only with high difficulty, by machining processes and exhibits additional potential for weight reduction. Forging of gears and splines can omit the lead-in and lead-out area of machining tools which is beneficial for a tighter design of components, thus a reduction of weight. Hirth joints, especially with features which cannot be machined can be produced economically by forging processes in series production.

For the development of innovative and excellent products, an early interaction between customer and supplier is necessary. Thus, the Hirschvogel Automotive Group provides its longtime experience to all customers worldwide and offers assistance from the first design concept up to assembly-ready components in large scale production. Various new developments support to supply the customers with innovative and excellent products. For example, a new steel grade H2 has been developed. The steel H2 offers high hardenability which is achieved by low cost alloying elements. Thus, H2 steel could be a cost-efficient alternative to 18CrNiMo7-6 or other high-alloyed case hardening steels. While fundamental investigations have been accomplished, the development of a series production part in cooperation with customers is necessary to activate the economic potential of H2 steel.

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