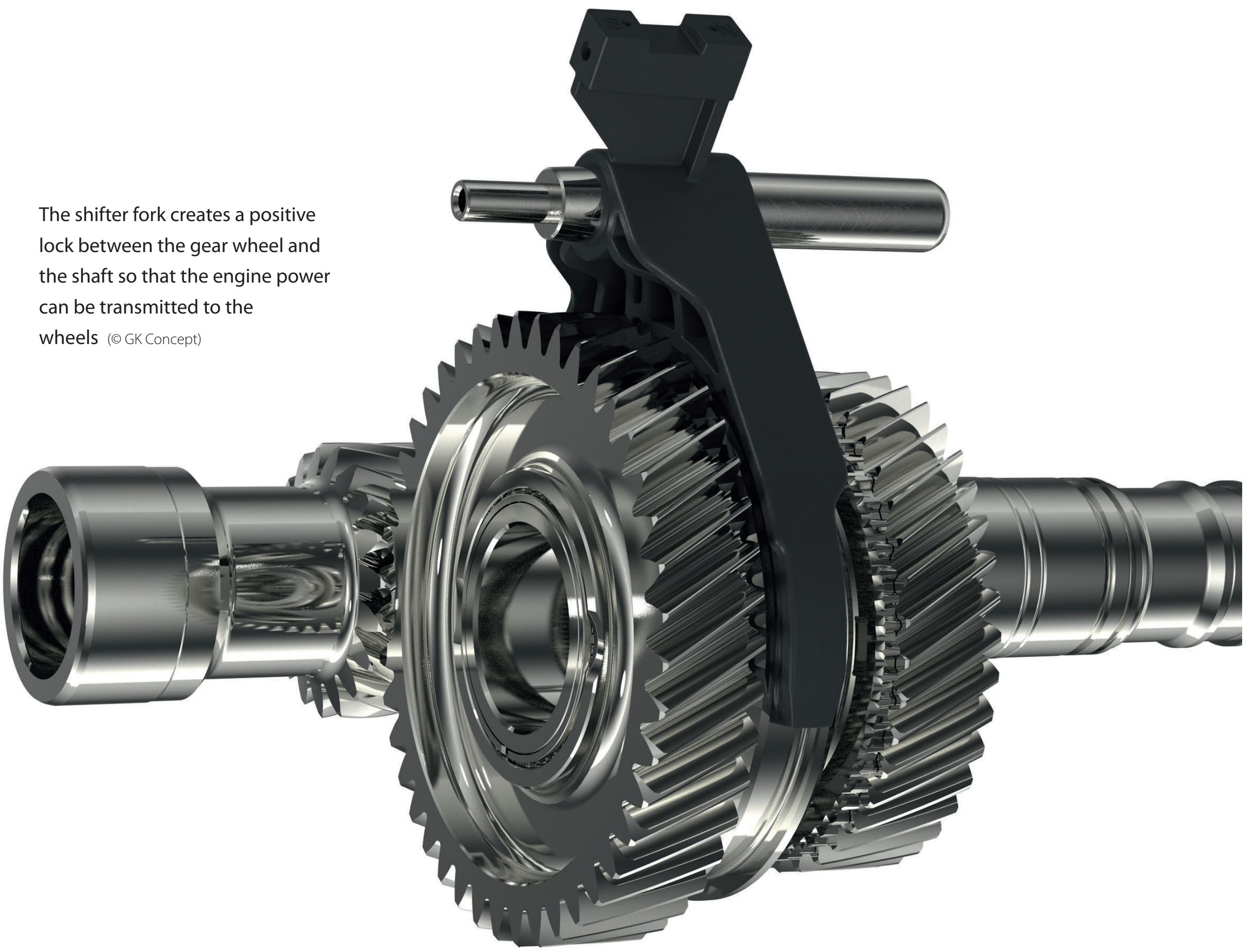
Replacing Metal in the Gearbox

Production-Ready Plastic Shifter Fork Offers a Maximum of Functional Integration

Anyone seeking to replace a metal component by a plastic one, to reduce the number of component parts from eight to three and simultaneously cut both the weight and manufacturing costs needs to take great care to ensure that all specifications are met – especially if the component is used in a hot gearbox and is subject to high mechanical stress. For developing a new shifter fork, GK Concept and its customer Koki Technik were awarded the 2019 GKV/TecPart Innovation Prize.



The shifter fork creates a positive lock between the gear wheel and the shaft so that the engine power can be transmitted to the wheels (© GK Concept)

When drivers of a manual transmission vehicle select first, shift into second and then keep moving up the gears, it is unlikely to register with them that they are using a small component called a shifter fork to do so. And few of them will realize that it is the reason they can change gears in the first place. In their relentless pursuit of lightweight engineering potential, OEM and Tier 1 companies have long since turned their attention on the engine compartment, where heat and chemicals make it particularly challenging to swap a plastic part for a metal part. Especially one that is subject to constant mechanical stress.

Engineering specialist GK Concept GmbH spent around one-and-a-half years doing preliminary and development work on creating a shifter fork made of polyphthalamide (PPA) with a 30 % carbon fiber content. The fork is now ready for mass production, is 35 % lighter than its metal counterpart, meets all specifications and has already passed endurance tests on test rigs. The German Dresden-based development team could not have achieved this success without possessing sound technical knowledge and a certain amount of technical flair, as there were many issues to be addressed, studied in simulations, and resolved with great precision.

Trojan Work at up to 160 °C

What is a shifter fork? In a gearbox, the gears are arranged in pairs on the output shaft that drives the wheels. However, they are not permanently connected to this shaft. A shifter sleeve is needed to manipulate a synchronizer ring to create a positive lock between a selected gear and the shaft, i.e. to engage that gear, so that the power from the engine can be transmitted via the counter shaft. This shifter sleeve itself is moved by the shifter fork (**Title figure**), and anyone with an appreciation of the forces that a car engine can develop will understand just how rugged that component has to be.

When GK Concept was commissioned to examine whether a shifter fork, traditionally made of die-cast aluminum or steel, could also be implemented in plastic, its first priority was to study the load paths and material properties. The fork-ends under an acting force of 1500 N and an operating temperature of about 120 °C would have to undergo less deformation than the maximum permissible value of 0.8 mm. Such low deformation was necessary to prevent the shifter fork from jamming when positioned at an angle and to prevent increased wear on the shifter sleeve and synchronization. In addition, the component had to withstand an abuse load of 2400 N at an elevated temperature of 160 °C without damage (**Fig. 1**).

Which materials would make good candidates for this? Chopped, long, or continuous fibers made of carbon or glass, various thermoplastic matrix materials, or even thermosets? The last of these, despite their very good heat stability, were very quickly rejected due to their brittleness and inadequate strength.

U-shaped polyamide sheets made of continuous fibers, which could have been overmolded, also failed to offer the necessary rigidity (calculated deviation: 3.5 mm). And high-performance polymers, such as PEEK and PAI, offered consistent dimensional stability within the desired temperature window, but were ruled out for cost reasons, because the materials cost EUR 50 and more per kilogram. It would have been uneconomical to use them as substitutes for metal.

Fig. 1. An operating temperature of 120 °C creates harsh conditions. The maximum permissible deformation of the fork-ends under an acting force of 1500 N was well below 0.8 mm (© GK Concept)

Systematic Search for the Right Material Pairing

As they hunted for the right material, the GK Concept team did more than scrutinize data sheets and conduct simulations. They subjected the thermoplastics in question to extensive material tests under the operating conditions to ensure that even storage in an oil bath at 150 °C would not cause any significant deterioration in mechanical properties. In the end, the developers came to the conclusion that PPA with a 30 % content of chopped carbon fibers (0.5 to 5 mm in length) was the right solution (**Fig. 2**).

PPA is stronger and more heat-resistant than most other polymers, has very low water absorption but high creep resistance, i.e. it is stable under constant load, and therefore generally makes a good substitute for metal. It can also withstand continuous temperatures of 150 °C and is chemically resistant – this is important for use in an oily environment.

Boasting a tensile strength of 2400 to 6000 MPa (compared with 1000 MPa for steel), the carbon fibers provide the necessary reinforcement for high-temperature use. Yet, although the shifter fork was designed to optimally transmit and dissipate forces via an increased profile height and mesh-like ribbing, it transpired that the PPA-CF30 was not strong enough initially to meet all mechanical requirements at temperatures exceeding 100 °C. It was essential that the heat-induced changes in geometry would mirror those of an aluminum fork as closely as possible over the full temperature range from –40 to 150 °C in order to ensure that it could be used with the surrounding gear parts.

Fig. 2. Clearly visible: the reinforcement of the shifter fork with chopped carbon fibers (© GK Concept)

A Million Windings for the Insert

The question then arose as to which insert shape would provide further stability for the fork area. Possibilities included a round bar, a flat bar or a T-shape, and again different materials. But should an aluminum part be used – or perhaps other carbon fibers? And if the latter: in which form? Inserts milled from panel-shaped semi-finished products would » have an unfavorable fiber orientation, because the tensile strength is always greatest in the direction of the fibers.

The solution was to use carbon rovings wrapped around a core of suitable diameter and embedded in a matrix of epoxy resin. Each fiber was only 5 to 9 µm thick and a million windings were needed to achieve an insert cross-section of 6 x 8 mm (**Fig. 3**). Various fiber orientations around the core were also tested virtually, with an angle of 0° ultimately proving to yield the best performance.

Functional Integration Brings Decisive Cost Advantages

Once GK Concept had determined that the plastic part could be manufactured in such a way as to withstand the operating conditions, it set about optimizing the cost aspects. Purely in terms of the materials, the new shifter fork would still have been more expensive than the standard die-cast aluminum model. This was where the ability of the injection molding process to integrate functions came into its own: the eight different parts of the metal shifter fork could be reduced to just three in the new design.

The design obviated the need for the "flap", a thin polymer layer on the aluminum to protect the shifter sleeve. It also proved much easier to attach two magnets and a pole plate to the upper end of the shifter fork, where they are needed for the transmission control system. Whereas the magnets and pole plate had previously been screw-fastened and covered by a protective cap, they could now be combined into a single article and overmolded, like the shift lever, in the mold – in the past, the metal fork had to be mounted separately. So that left just the three separate parts, namely the shift rod, the magnet assembly and the carbon fiber insert. This made the concept economically attractive, because machining would be completely unnecessary. The article would exit the injection mold ready for fitting.

Coming up with this design was no easy matter: the need to position three inserts left little space left for melt feed, cooling and mechanical parts, such as slide and ejector. The engineers devised an ingenious solution by which the carbon-fiber half-ring "floated" inside the cavity so that it could be overmolded from all sides. The ring is held axially in the opening direction in both mold halves by packages, each comprising six flat ejectors, while an additional ejector package on the moving side takes care of positioning in the radial direction. Once the cavity has been 95 % filled and the insert thus fixed in position by the polymer, the pins retract hydraulically so that the spaces that have been freed up may also be filled. The carbon fibers in their epoxy matrix are then completely surrounded by PPA.

Despite the differences in the materials' shrinkage behavior (0.05 to 0.55 % for PPA-CF30 compared to almost 0 % change in length for the insert), the part is largely stress-free. This is also helped by

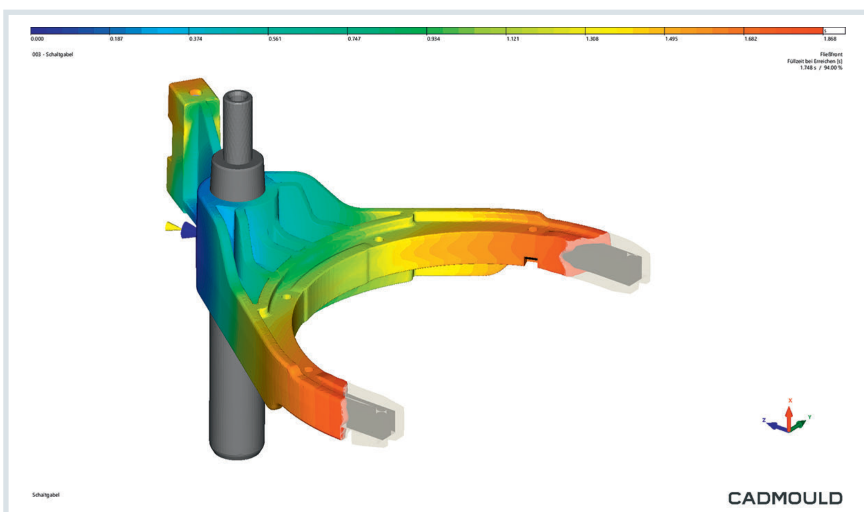


Fig. 3. The filling simulation reveals the simultaneous melt flow into both fork ends. The carbon fiber insert is clearly visible on the right of the figure (© GK Concept)

Company Profile

Founded in 2012, **GK Concept GmbH** quickly set itself up as the Engineering Factory and a competent partner for product and process innovation in the plastics industry. With currently 16 employees, the company has been devising solutions for part and mold design for eight years now and, together with partners, accepts mold making and initial sample production assignments. The core competencies of the Dresden-based development office include kinematic parts and assemblies, lightweight and structural parts, cladding elements made of back-molded textiles and films of

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various types, applications with polyamide sheets, and complex parts and assemblies. For the development of the new shifter fork described here, GK Concept (the two authors can be seen in the figure) together with customer Koki Technik, were honored with the 2019 GKV/TecPart Innovation Prize.

➘ www.gkconcept.de/en

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Service

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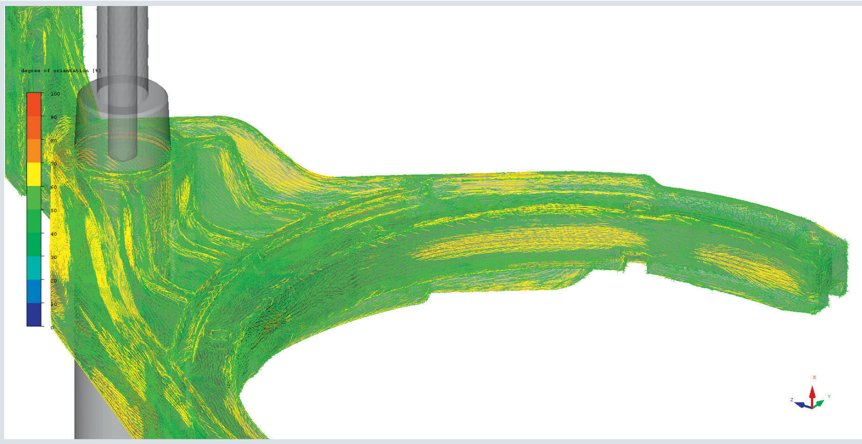

Fig. 4. The high degree of orientation of the fibers increases the load-bearing capacity of the part and reduces shrinkage in the direction of the fibers (© GK Concept)

the fact that the melt is fed highly uniformly into both ends of the fork from the sole gate near the gear shaft. This gives rise to a high degree of fiber orientation in the fork arms and so reduces shrinkage in the fiber direction (**Fig. 4**).

Endurance Tests on Automotive Test Rigs Already Passed

The ingenious combination of part design, material selection, structural simulation, mold design and process simulation made it possible to produce a shifter fork weighing just 99 g, which is 35 % less than the original model weighing 143 g. As each gear pair has its own shifter fork, the weight savings add up, e.g. in a six-speed transmission.

The cost aspect of replacing the metal is interesting. The PPA-CF30 version achieves its greater efficiency primarily through functional integration. In terms of material price alone, it is costlier than aluminum; in terms of processing costs, the two curves approach each other and, just at the point where previously external parts would be integrated, the new model becomes much cheaper. This reduces the necessary mold investment by a whopping 60 %, with a cost saving of no less than 10 % showing up in the overall calculation. The lead time is also shorter because fewer individual parts have to be requested and ordered.

The plastic shifter fork has already passed endurance tests on automotive test rigs. Its use in series production is therefore only a question of time.

Conclusions

The engineering for the plastic shifter fork presented a number of challenges in the form of high ambient temperatures, the presence of chemicals and considerable mechanical stress – especially as the cost aspect also had to be taken into consideration. The team at GK Concept solved these conscientiously, developing a product that is production-ready, and is lighter and cheaper than previous metal versions. ■

Successor for Basotect UF

Insulation for Buildings and Trains

BASF SE, Ludwigshafen, Germany, has developed a successor for its melamine resin foam Basotect. The material called Basotect UF+ will replace the previous grade Basotect UF.

According to the company, the new development has improved emission properties than its predecessor and is also suitable for additional applications.

The lightweight and flexible foam reportedly is suited for the insulation of rail vehicles as well as of heating, ventilation and air-conditioning (HVAC) technology in buildings. At the same time it reduces the noise level of the facilities. As stated in a press release, Basotect UF+ provides low thermal conductivity, a low density of 7 kg/m^3 without release of mineral fibers during processing.

The lightweight and flexible foam is suited for the insulation of rail vehicles as well as of heating, ventilation and air-conditioning technology in buildings (© BASF)

The new material meets the fire safety requirements for industrial applications (e.g. ASTM C141) and in the transportation sector (HL3 according to EN 45545). It is flame retardant even without additives and can be used up to temperatures of 240 °C.

To the product presentation:
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