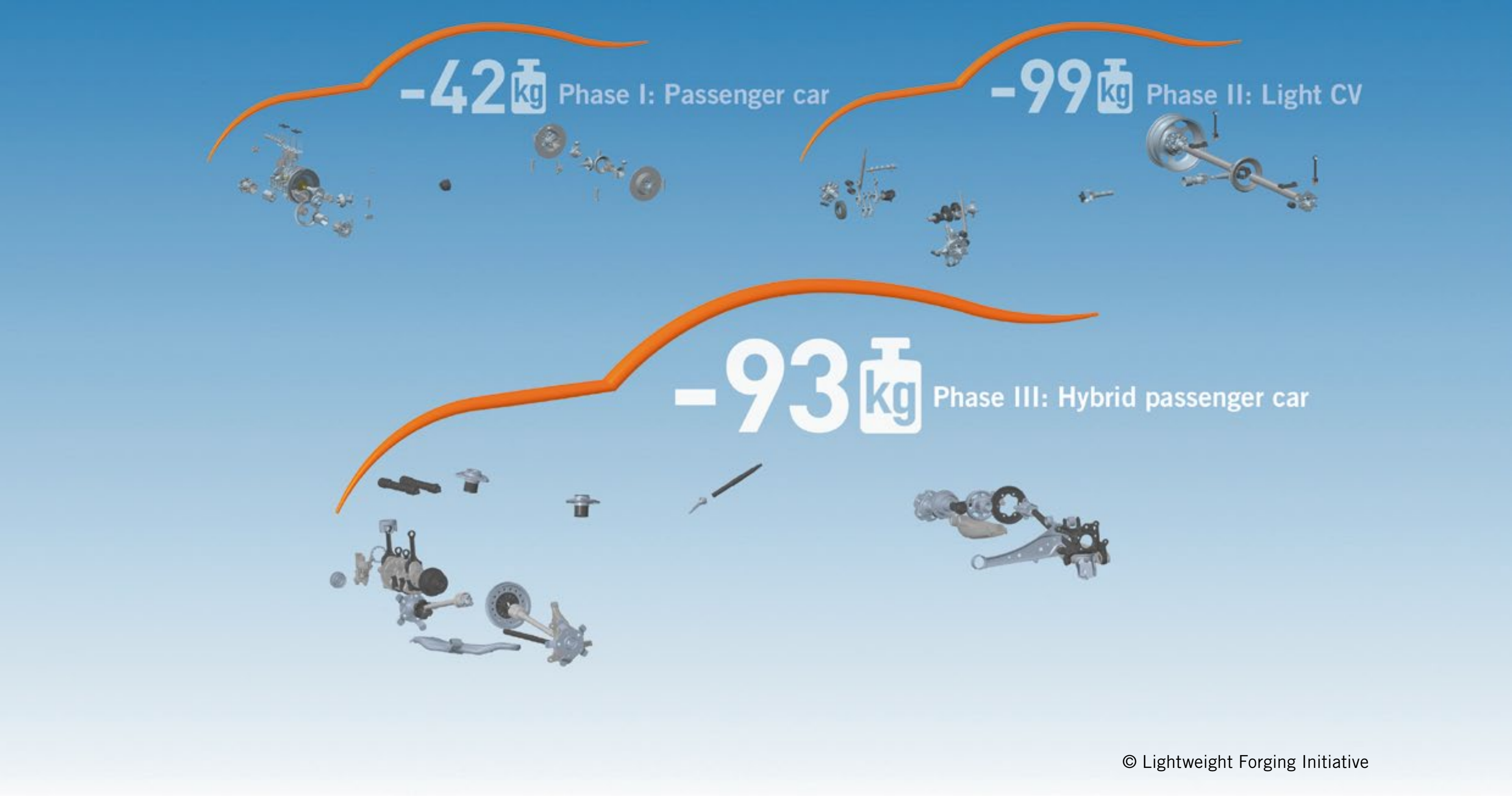

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FORGING AND LIGHTWEIGHT

When one thinks of forging, lightweight is not a word that immediately springs to mind. However, on closer inspection, forging technology proves to be a cost-efficient approach for achieving considerable lightweight design advances in automotive applications that is suited to large-series production. By exploiting the potential offered by forging technology, it is possible to reduce the mass of a medium-sized passenger car by 42 kg and that of a light commercial vehicle by 99 kg [1, 2].

During the current Phase III of its project, the Lightweight Forging Initiative – now with an international partner structure [3] – demonstrates which lightweight design potential lies in a split-axle hybrid car (Hybrid Electric Vehicle, HEV) and in sub-systems of a heavy-duty truck.

PROCEDURE AND EVALUATED VEHICLES

Determining lightweight design potential is achieved using a concrete, representative vehicle. This reference is an all-wheel drive, full hybrid SUV with an electrically supported spark ignition engine (ICE) at the front and an electric motor on the rear axle as a split-axle concept. Besides this passenger car application, the segment of heavy-duty trucks is being analyzed based on the evaluation of the sub-systems transmission, propeller shaft and the rear axle.

To specify the lightweight design potential, the vehicles and sub-systems are disassembled into separate components and documented in a database at the automotive research facility fka. Experts from the participating companies then come together in workshops to develop their lightweight design ideas. **FIGURE 1** shows project details and technical vehicle data: 733 lightweight design ideas were generated for the car and 251 for the truck.

OVERVIEW OF THE LIGHTWEIGHT DESIGN POTENTIAL

As part of the study, components in a hybrid car with a total weight of 816 kg were taken into consideration – that corresponds to approximately 51 % of the reference vehicle. More than 3600 com-

The Lightweight Forging Initiative – Phase III: Material Lightweight Design for Hybrid Cars and Heavy-duty Trucks

It is easier to talk about feasible lightweight design potential if this is demonstrated on the basis of a concrete, representative vehicle. In its third project, the Lightweight Forging Initiative with an international partner structure shows which lightweight design potential lies in a split-axle hybrid car and in sub-systems of a heavy-duty truck. The results for the drive shaft, shock absorber, wheel carrier and connecting rod include weight savings of 23 to 35 %.

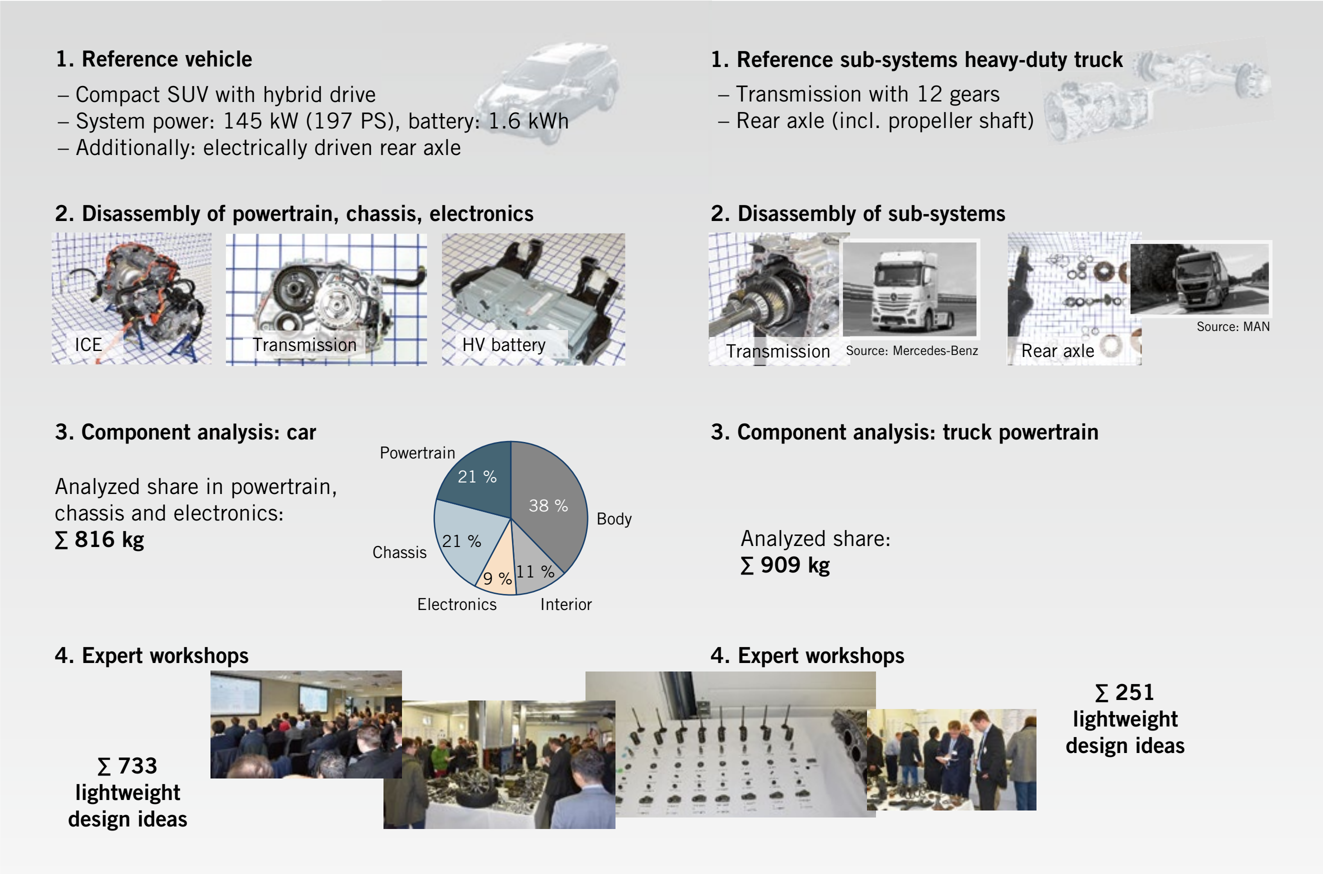


FIGURE 1 Project schedule in four steps as well as vehicle data for a hybrid car and a heavy-duty truck (© Lightweight Forging Initiative)

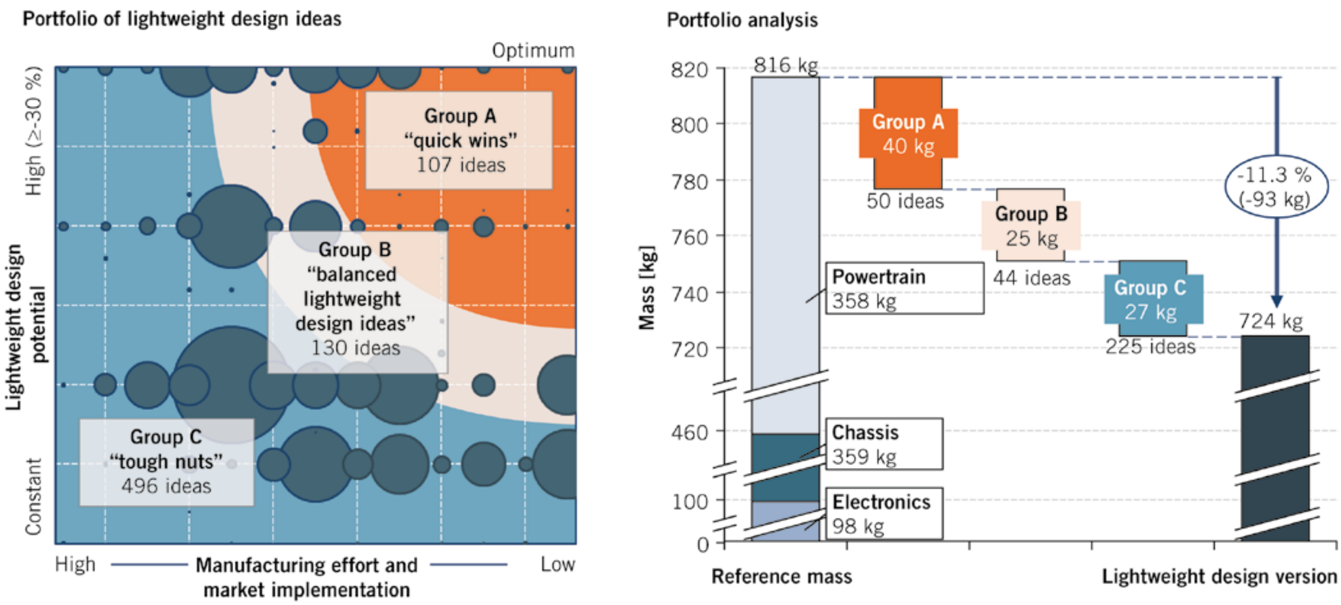


FIGURE 2 Portfolio of lightweight design ideas and the analysis thereof for the hybrid car (© Lightweight Forging Initiative)

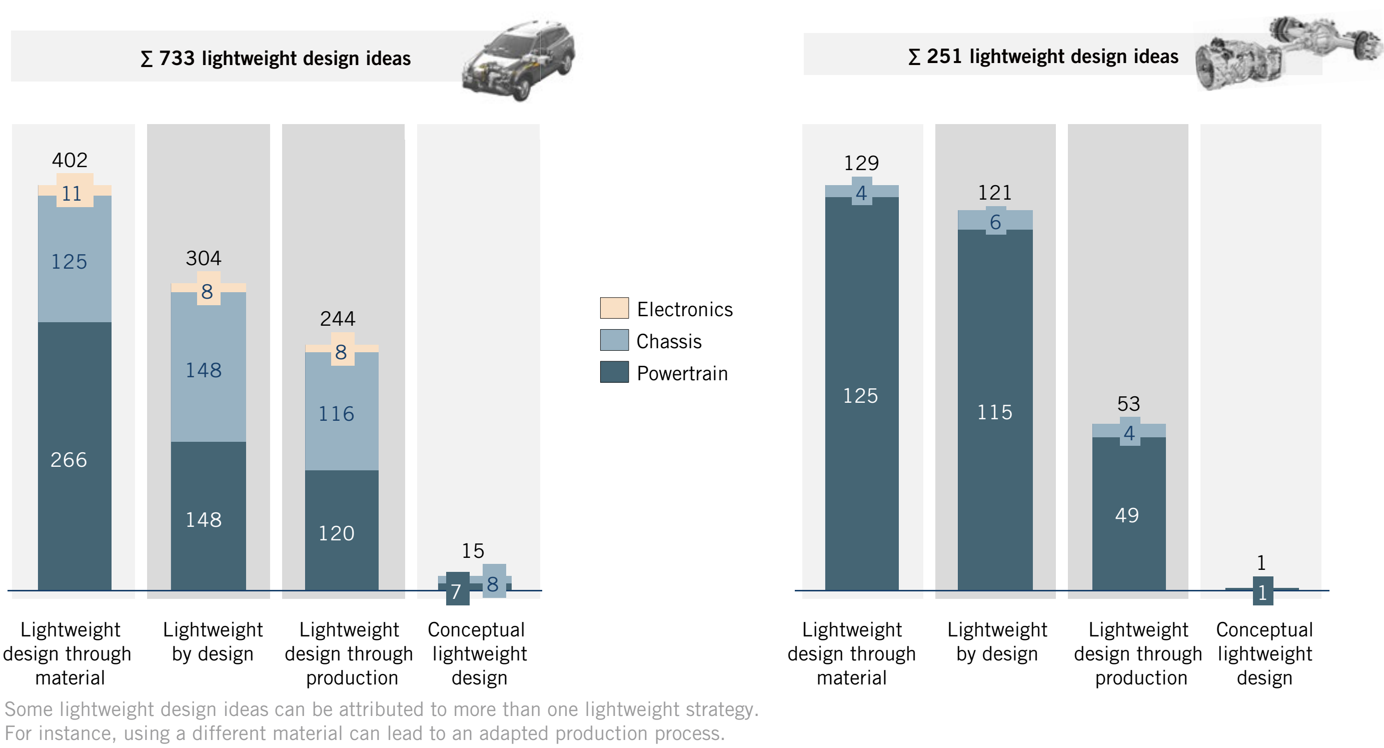


FIGURE 3 Clustering: idea classification according to material or design concepts (© Lightweight Forging Initiative)

ponents from the powertrain, chassis and electronics of the hybrid car were analyzed, and a total of 733 lightweight design ideas were developed. These ideas were then weighed up and classified according to the criteria of lightweight design potential, manufacturing effort and the effort for market implementation. This allows the relevant ideas to be assessed with respect to their lightweight design benefit-cost ratio, **FIGURE 2**.

Overall, the study identified a lightweight design potential of 93 kg for the hybrid car, which corresponds to approximately 11 % of the component mass analyzed. The ideas can then be categorized into quick wins, balanced lightweight design ideas and tough nuts, depending on the potential weight savings and implementation effort.

In the case of the commercial vehicle powertrain that is the second focus of the Phase III project, a total of 460 components with an overall weight of 909 kg were analyzed during a design benchmark. Of this total weight, 290 kg stems from the transmission as well as 619 kg from the propeller shaft and rear axle. As part of the expert workshop, more than 250 lightweight design ideas based on technical possibilities were developed. The resulting lightweight design potential adds up to a total of 124 kg, which is approximately 14 % of the component mass analyzed.

The ideas can be categorized as lightweight design achieved either by material, design or production concepts. However, these concepts are not completely clear cut and sometimes they are mutually dependent, **FIGURE 3**.

LIGHTWEIGHT DESIGN WITH MATERIAL INNOVATIONS

Modern, high-strength steels can make a significant and cost-efficient contribution to reducing the weight of individual components and thus of the total vehicle weight. The steel manufacturers and forging companies of the Initiative [3] proposed the use of around 20 different high-strength steels which allow weight-reduced, leaner component design. These steels encompass a broad spectrum of composition, metallographic structure and properties. Some of the suggested precipitation-hardening ferritic-perlitic (Dispersion Hardening Steels, DHS) and Quenched-and-Tempered (Q+T) high-strength steels as well as those provided with a bainitic structure after cooling from the forging temperature are shown in the material pedigree, **FIGURE 4**, together with their strength and ductility properties. To achieve the desired mechanical-technological properties, a meticulous steel production process according to the state of the art is necessary on the one hand. On the other hand, targeted further processing that takes both the part and the material into account is required. This may take the form of hot, warm or cold forging, for instance. Such high-strength steels allow higher loads, performance and durability, even when it comes to parts subject to dynamic loads such as crankshafts, connecting rods, gearwheels and bearings.

High-strength dispersion-hardening steels such as 38MnVS6 and 46MnVS6, which achieve their mechanical properties through controlled cooling from the forging heat and without an additional heat treatment process, are suggested by Saarstahl, Sidenor and Georgsmarienhütte for components such as connecting rods, crankshafts and wheel carriers. In some cases, the strengths of such dispersion-hardening steels can exceed those of conventional tempered steels, for instance that of 42CrMo4.

High-strength bainitic steels sometimes achieve even higher strengths through controlled cooling from the forging heat and, at the same time, improved ductility properties. **FIGURE 4** shows several bainites. In **FIGURE 5** as well as in the subsequent article in the next issue of ATZ [4], several bainites for concrete applications are suggested. The percentage in **FIGURE 5** states how much heavier the series part is compared to the lightweight design proposal.

TimkenSteel presents steels with comparatively high Charpy energy values with high strengths. In the case of such high strengths, the cleanliness level of the steels takes on a critical role. TimkenSteel states that it thus uses its "Ultrapremium Clean Steel" technology during the production process.

The highest tensile strengths are achieved by spring steels, for example 55Cr3, the thermo-mechanically rolled 54SiCrV6 suggested by Saarstahl, 60SiCrV7, or the Solam M2050 S-Cor demonstrated by ArcelorMittal with a strength of up to 2050 MPa. Such steels enable weight reductions in vehicle components such as cross bars or springs.

Weight savings achieved by using high-strength steels are not only possible in the case of forgings. Rather, the use of forged steels that can withstand higher loads also represents an alternative to cast parts. Hence, Deutsche Edelstahlwerke suggest substituting cast truck brake disks, which have a weight of 35.5 kg, with a stainless, wear-resistant, high-carbon concentrated and nitrogen-alloyed steel. In this application, Sidenor sees lightweight design potential in the use of the wear-resistant Mn-alloyed steel 1.3401 (X120Mn12).

In **FIGURE 5** (top left), the lightweight design potential of a differential input shaft applied in the analyzed hybrid SUV is presented. The hollow shaft, which is currently produced from a CrMn case-hardening steel known as SCr420H, has a weight of 1182 g. As a high-strength alternative to such CrMn carburizing steels, Georgsmarienhütte worked together with Hirschvogel to develop a micro-alloyed bainitic steel known as 16MnCrV7-7 (1.8195). This steel can also undergo case-hardening and retains a stable fine grain structure up to a carburizing temperature of 1050 °C. It is also characterized by a higher hardenability value. This high-strength steel, which is used for the differential input shaft, enables an optimized thinner-walled design, thereby promising a weight reduction of 307 g.

The analyses carried out within this Initiative also demonstrate that considerable weight savings could be achieved in the case of tubes, such as those assem-

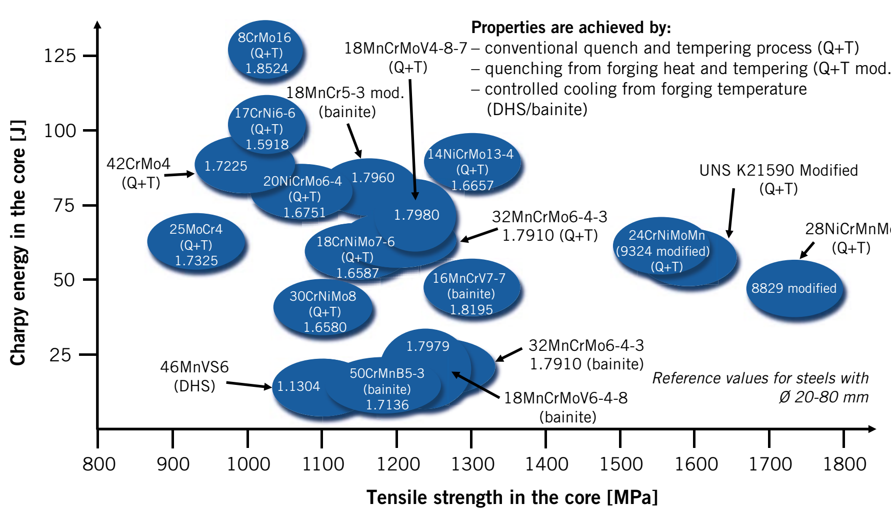


FIGURE 4 Material pedigree of high-strength stainless steels (© Lightweight Forging Initiative)

bled in shock absorbers. For this reason, Benteler suggests replacing a tube made of the steel E235+CR, which has a yield strength of at least 235 MPa, with the high-strength, ferritic-bainitic multiphase steel FB590, which has a yield strength of 500-600 MPa. In this way, the wall thickness of the outer tube can be reduced from 2.8 to 2.0 mm, thereby achieving a corresponding lightweight design potential of 250 g, **FIGURE 5** (bottom left).

ArcelorMittal proposes the use of ferritic-perlitic steels or its bainitic steel Solam B1100 as a lightweight alternative to cast materials, for example for the steering knuckle. The presented weight savings have been estimated by means of FEM simulations carried out on the part. By using the bainitic forging steel, it is possible to achieve a weight of 4100 g instead of the 5060 g of the cast part – simply through controlled cooling from the forging heat and without a costly heat treatment process. The steel manufacturer Sidenor suggests the use of its steel Micro1100 (44MnSiVS6) to reduce the weight of the steering knuckle shown in **FIGURE 5** (top right). By cooling the steel directly from the forging heat, a ferritic-perlitic grain structure is generated which demonstrates a tensile strength of 1100 MPa. Sidenor sees in this a lightweight design potential of approximately 20 %.

Lightweight design proposals for the connecting rod were submitted by ArcelorMittal, Deutsche Edelstahlwerke, Georgsmarienhütte, Nippon Steel, Nissan, Saarstahl, Schmiedetechnik Plettenberg, Schuler and TimkenSteel. Based on analyses by Mahle [5], TimkenSteel estimates a lightweight design potential of up to 35 % through the use of the high-strength steels 36/46MnVS6Mod for forged connecting rods, **FIGURE 5** (bottom right). When taking only the conrod shaft into account, Georgsmarienhütte and Schmiedetechnik Plettenberg predict that the use of the high-strength dispersion-hardening steel 46MnVS5 or the bainitic steel 16MnCrV7-7 will lead to a lightweight design potential of 10 to 15 %.

LIGHTWEIGHT DESIGN IN THE TRANSMISSION: MATERIAL AS THE KEY FACTOR

Transmissions for converting torques and speeds are also used in hybrid powertrains on both axles. Besides numerous geometrical and forging technology proposals relating to the transmission parts used, the choice of material naturally offers a great source of lightweight design potential, too. If gearwheels can withstand higher loads on the flank and tooth root, and if shafts can endure greater torsional and bending loads, then the entire system design can be rendered smaller and thus lighter. Where necessary, however, the press fit of gearwheels on shafts also needs to be taken into account. To estimate the lightweight design potential achieved with material optimizations, the Institute of Product Engineering (Ipek) at the Karlsruhe Institute of Technology (KIT) was commissioned to set up a model of the transmission using a spreadsheet. Data on load and load-bearing capabilities form the input values for this model, which estimates the system weight via the transmission topology.

By varying the load-bearing values, it is possible to estimate the effectiveness of material optimizations on the lightweight design potential of the transmission. **FIGURE 6** shows the calculation for the transmission on the rear axle. The various material input values are listed successively and with the 20 % increase that seems possible through the use of ultraclean carburizing steels by TimkenSteel [6]. Correspondingly, the table calculates possible weight savings and reduced assembly spaces. In this way, lightweight design reserves are uncovered by increasing the load-bearing capacities, ideally in combination with one another. Hence, it is definitely worth looking into improved steel materials in order to achieve advances in lightweight design in the transmission, too.

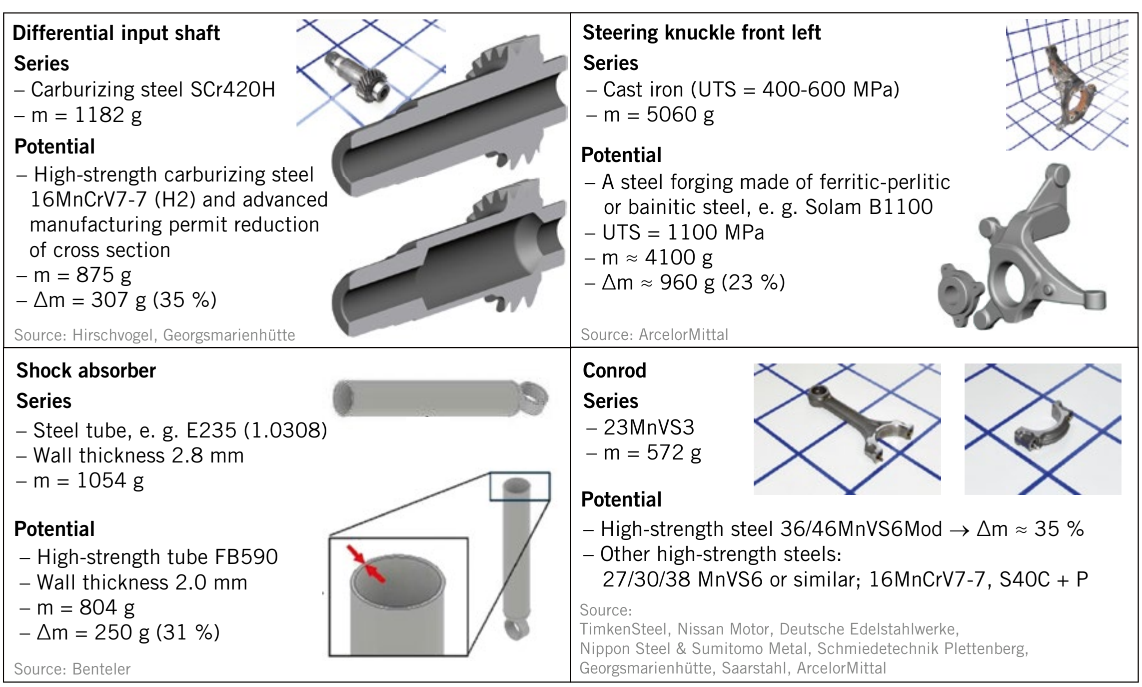
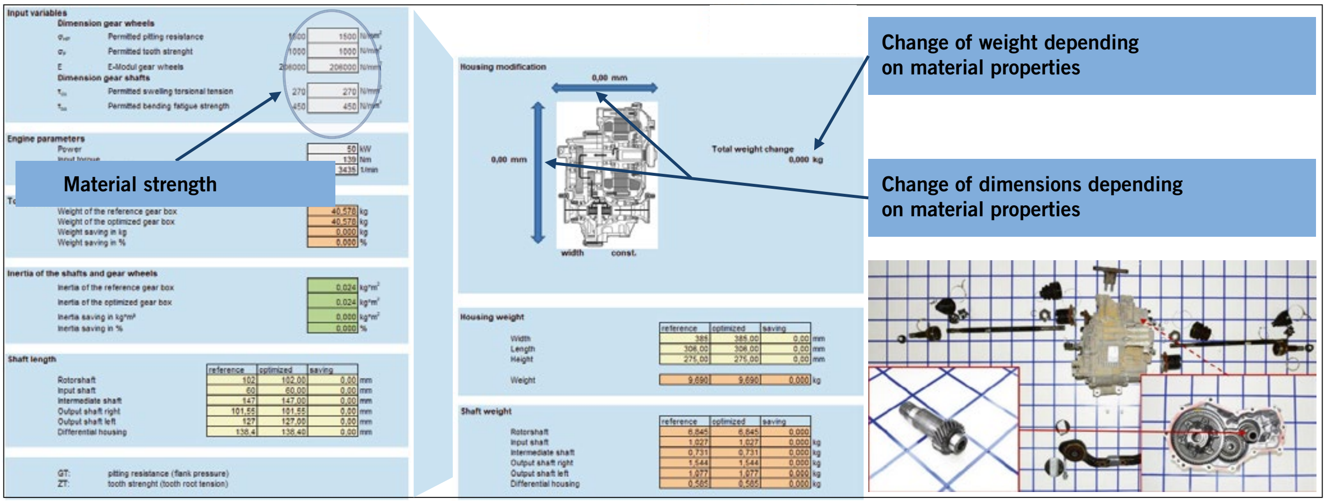


FIGURE 5 Lightweight design potential through the use of high-strength steels for four examples – drive shaft, shock absorber, steering knuckle and conrod (© Lightweight Forging Initiative)



Tooth flank strength [MPa]	Tooth root strength [MPa]	Torsional strength [MPa]	Bending strength [MPa]	Δ Weight [g]
1500 → 1800	1000	270	450	-129
1500 → 1800	1000 → 1200	270	450	-1216
1500 → 1800	1000 → 1200	270 → 324	450	-1722
1500 → 1800	1000 → 1200	207 → 324	450 → 540	-1875

FIGURE 6 Calculation of the lightweight design potential achieved with higher-strength case-hardening steels using the example of a rear-axle transmission in the split-axle powertrain (© Lightweight Forging Initiative)

CONCLUSION

Steel is the most important and a far advanced material for the automotive industry. Nevertheless, it can be seen that new insights continue to be generated which enable both the performance and the cost efficiency of steel materials (for example through controlled cooling from the forging heat) to be increased even further. The examples outlined here demonstrate this in an impressive way. However, it is becoming increasingly important to involve all partners of the process chain – from the steelworks and the forging company up to the manufacturer of the finished component – in achieving optimizations during a joint development process.

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