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**LIGHTWEIGHT AUTOMOTIVE
DESIGN – THE POTENTIAL OF
FORGING**

There are several developments in the steel industry with respect to materials in wire and bars [1] as well as in forging companies, all with the aim of supporting customers in their lightweight design efforts [2]. However, each individual development provides merely an isolated solution, perhaps with only negligible transferability to other areas of application. This is because solutions are developed in each case for the specific requirements in a vehicle and, even then, the results may not be published at all.

A field analysis of the issue of “Lightweight Automotive Design” pinpoints the most important projects to date, ❶. It becomes clear that the activities have different initiators (steel industry, individual steel manufacturers or suppliers, OEM). However, the majority of projects deals exclusively with the car body or with lightweight design solutions based on sheet metal; this is also reflected in how lightweight design is perceived in the industry [3]. Lightweight design potential in the powertrain and chassis is rarely

focussed on, and if it is considered, then only by means of a solution approach at system level, for example downsizing. Lightweight design potential achieved through material or through forging operations has not been analysed to date in any large pre-competitive joint project. The steel manufacturing and forging industry has thus set itself the task of demonstrating design, material and production engineering solutions, the success of which may be measured with respect to lightweight design, cost and implementation potential.

**CONTENT AND PROCEDURE
OF THE LIGHTWEIGHT DESIGN
POTENTIAL STUDY**

15 forging companies and nine steel manufacturers have joined forces in the “The Lightweight Forging Initiative” [4] under the auspices of the German Forging Association (Industrieverband Massivumformung e. V. – IMU) [5] and the VDEh steel institute [6]. Without drawing on public funding, the companies are making multilateral financing available to enable the first working step of the initiative to be taken, namely a lightweight

THE LIGHTWEIGHT FORGING INITIATIVE AUTOMOTIVE LIGHTWEIGHT DESIGN POTENTIAL WITH FORGING

Forging processes (hot, warm and cold) are used to produce several important components in automotive engineering applications. When awarding contracts, the lowest price is often the decisive criterion; innovations are either not enquired about, or part and system development is already so far advanced at the time of the enquiry that it is too late to incorporate lightweight design proposals. The Lightweight Forging Initiative was set up to highlight to the professional world the contributions which forging makes to the automotive megatrend of lightweight design.

design potential study. This is carried out by the automotive engineering research institute, Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka). This is by far the largest pre-competitive joint project of these two industries to date.

A vehicle with only low mileage was procured as a reference (significant series volume, middle class estate car, diesel, double-clutch transmission, all-

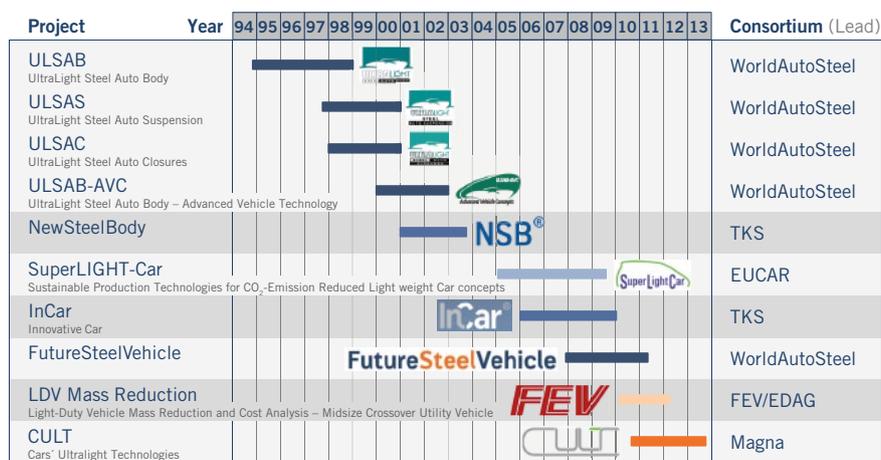
wheel drive) and systematically disassembled by the fka. The parts were documented in a database (images, weight, dimensions and material). During several workshops, experts of the participating companies came together to work on lightweight design proposals. All proposals were classified with respect to their lightweight design potential, the estimated cost development and the anti-

pated implementation efforts, and then recorded in the database. In this way, quantifiable results may be assessed in several dimensions in the database. ② provides an overview of the procedure.

OVERALL LIGHTWEIGHT DESIGN POTENTIAL OF THE REFERENCE VEHICLE

The overall results of the lightweight design study conducted by The Lightweight Forging Initiative are shown in ③. From a forging perspective, it is primarily parts from the powertrain (injection, engine, transmission, transfer gearbox, drive shafts) and the chassis which are open to lightweight design ideas. Some potential is also seen in the car body, mainly in the area of the fastening elements.

The lightweight design ideas thus concentrate on a reference basis of 838 kg, which is approximately 48 % of the entire vehicle. It should be mentioned that some vehicle components contributing greatly to weight cannot be produced by forging. For this reason, parts such as the engine block, cylinder head, gearbox housing and large-area basic chassis parts made



① Overview of large automotive lightweight design projects (Sources: Lightweight design potential study of The Lightweight Forging Initiative, fka)

from sheet metal were not analysed for their lightweight design potential, as the possibilities offered by forging cannot be employed in a cost-efficient way.

In total, a lightweight design potential of 42 kg was identified. The lightweight ideas submitted identified an average lightweight design potential of 10 % for the components analysed.

Idea classification according to cost impact and implementation efforts is shown in 4. The experts estimate that some ideas will lead to both a reduction in weight as well as costs (quick wins). Other ideas demonstrate a lightweight design potential which is expected to involve somewhat higher costs and increased development efforts.

As part of the lightweight design potential study, 399 ideas were generated based on the parts in the reference vehicle. These may be categorised as ideas relating to material, design or concept. From these, a small selection shall be outlined in the following. To provide a well-rounded picture of what the industry can achieve, individual lightweight design solutions will also be presented which were not developed specifically for the reference vehicle, but were already being used in other applications.

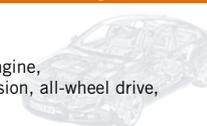
The lightweight design ideas described do not claim to be fully developed solutions. On the one hand, a differing level of development efforts has flowed into these proposals. On the other hand, some proposals will be faced with system requirements which are not known among the participating steel manufacturers and forging companies. One thing which all the proposals have in common, however, is that they should not be viewed as a criticism of the engineering achievements of those who developed the reference vehicle. Rather, they should reveal possibilities with respect to design, material and production engineering for generating lightweight design, as well as provide impetus and allow conventional procedures to undergo scrutiny. The lightweight design potential stated as a percentage in the following relates to the optimised weight (this means, the serial component is x % heavier than the optimised part).

MATERIAL LIGHTWEIGHT DESIGN POTENTIAL

There are many new developments in the area of steel materials for forgings.

1. Determining the total vehicle weight

Reference vehicle:
125 kW / 170 PS
2.0 l turbo-DI Diesel engine,
double-clutch transmission, all-wheel drive,
total mass: 1740 kg



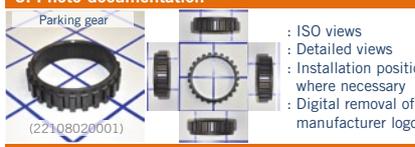
5. Weight of assemblies and systems



2. Disassembling the entire vehicle



6. Photo documentation



3. Listing and naming all individual parts

7. Database implementation with proposals for lightweight design potential



4. Analysis of individual parts

Materialcode	Bezeichnung	Gewicht [kg]	#	#	#	#	Materialbank status
222020401	Chassisrohr aufsteig. 1/ Gebauer Dimensional	0,070	16	16	16	16	Stahl
222020402	Chassisrohr aufsteig. 2/ Gebauer Dimensional	0,142	16	16	16	16	Stahl
222020403	Chassisrohr aufsteig. 3/ Gebauer Dimensional	0,214	16	16	16	16	Stahl
222020404	Chassisrohr aufsteig. 4/ Gebauer Dimensional	0,286	16	16	16	16	Stahl
222020405	Chassisrohr aufsteig. 5/ Gebauer Dimensional	0,358	16	16	16	16	Stahl
222020406	Chassisrohr aufsteig. 6/ Gebauer Dimensional	0,430	16	16	16	16	Stahl
222020407	Chassisrohr aufsteig. 7/ Gebauer Dimensional	0,502	16	16	16	16	Stahl
222020408	Chassisrohr aufsteig. 8/ Gebauer Dimensional	0,574	16	16	16	16	Stahl
222020409	Chassisrohr aufsteig. 9/ Gebauer Dimensional	0,646	16	16	16	16	Stahl
222020410	Chassisrohr aufsteig. 10/ Gebauer Dimensional	0,718	16	16	16	16	Stahl
222020411	Chassisrohr aufsteig. 11/ Gebauer Dimensional	0,790	16	16	16	16	Stahl
222020412	Chassisrohr aufsteig. 12/ Gebauer Dimensional	0,862	16	16	16	16	Stahl
222020413	Chassisrohr aufsteig. 13/ Gebauer Dimensional	0,934	16	16	16	16	Stahl
222020414	Chassisrohr aufsteig. 14/ Gebauer Dimensional	1,006	16	16	16	16	Stahl
222020415	Chassisrohr aufsteig. 15/ Gebauer Dimensional	1,078	16	16	16	16	Stahl
222020416	Chassisrohr aufsteig. 16/ Gebauer Dimensional	1,150	16	16	16	16	Stahl
222020417	Chassisrohr aufsteig. 17/ Gebauer Dimensional	1,222	16	16	16	16	Stahl
222020418	Chassisrohr aufsteig. 18/ Gebauer Dimensional	1,294	16	16	16	16	Stahl
222020419	Chassisrohr aufsteig. 19/ Gebauer Dimensional	1,366	16	16	16	16	Stahl
222020420	Chassisrohr aufsteig. 20/ Gebauer Dimensional	1,438	16	16	16	16	Stahl
222020421	Chassisrohr aufsteig. 21/ Gebauer Dimensional	1,510	16	16	16	16	Stahl
222020422	Chassisrohr aufsteig. 22/ Gebauer Dimensional	1,582	16	16	16	16	Stahl
222020423	Chassisrohr aufsteig. 23/ Gebauer Dimensional	1,654	16	16	16	16	Stahl
222020424	Chassisrohr aufsteig. 24/ Gebauer Dimensional	1,726	16	16	16	16	Stahl
222020425	Chassisrohr aufsteig. 25/ Gebauer Dimensional	1,798	16	16	16	16	Stahl
222020426	Chassisrohr aufsteig. 26/ Gebauer Dimensional	1,870	16	16	16	16	Stahl
222020427	Chassisrohr aufsteig. 27/ Gebauer Dimensional	1,942	16	16	16	16	Stahl
222020428	Chassisrohr aufsteig. 28/ Gebauer Dimensional	2,014	16	16	16	16	Stahl
222020429	Chassisrohr aufsteig. 29/ Gebauer Dimensional	2,086	16	16	16	16	Stahl
222020430	Chassisrohr aufsteig. 30/ Gebauer Dimensional	2,158	16	16	16	16	Stahl
222020431	Chassisrohr aufsteig. 31/ Gebauer Dimensional	2,230	16	16	16	16	Stahl
222020432	Chassisrohr aufsteig. 32/ Gebauer Dimensional	2,302	16	16	16	16	Stahl
222020433	Chassisrohr aufsteig. 33/ Gebauer Dimensional	2,374	16	16	16	16	Stahl
222020434	Chassisrohr aufsteig. 34/ Gebauer Dimensional	2,446	16	16	16	16	Stahl
222020435	Chassisrohr aufsteig. 35/ Gebauer Dimensional	2,518	16	16	16	16	Stahl
222020436	Chassisrohr aufsteig. 36/ Gebauer Dimensional	2,590	16	16	16	16	Stahl
222020437	Chassisrohr aufsteig. 37/ Gebauer Dimensional	2,662	16	16	16	16	Stahl
222020438	Chassisrohr aufsteig. 38/ Gebauer Dimensional	2,734	16	16	16	16	Stahl
222020439	Chassisrohr aufsteig. 39/ Gebauer Dimensional	2,806	16	16	16	16	Stahl
222020440	Chassisrohr aufsteig. 40/ Gebauer Dimensional	2,878	16	16	16	16	Stahl
222020441	Chassisrohr aufsteig. 41/ Gebauer Dimensional	2,950	16	16	16	16	Stahl
222020442	Chassisrohr aufsteig. 42/ Gebauer Dimensional	3,022	16	16	16	16	Stahl
222020443	Chassisrohr aufsteig. 43/ Gebauer Dimensional	3,094	16	16	16	16	Stahl
222020444	Chassisrohr aufsteig. 44/ Gebauer Dimensional	3,166	16	16	16	16	Stahl
222020445	Chassisrohr aufsteig. 45/ Gebauer Dimensional	3,238	16	16	16	16	Stahl
222020446	Chassisrohr aufsteig. 46/ Gebauer Dimensional	3,310	16	16	16	16	Stahl
222020447	Chassisrohr aufsteig. 47/ Gebauer Dimensional	3,382	16	16	16	16	Stahl
222020448	Chassisrohr aufsteig. 48/ Gebauer Dimensional	3,454	16	16	16	16	Stahl
222020449	Chassisrohr aufsteig. 49/ Gebauer Dimensional	3,526	16	16	16	16	Stahl
222020450	Chassisrohr aufsteig. 50/ Gebauer Dimensional	3,598	16	16	16	16	Stahl

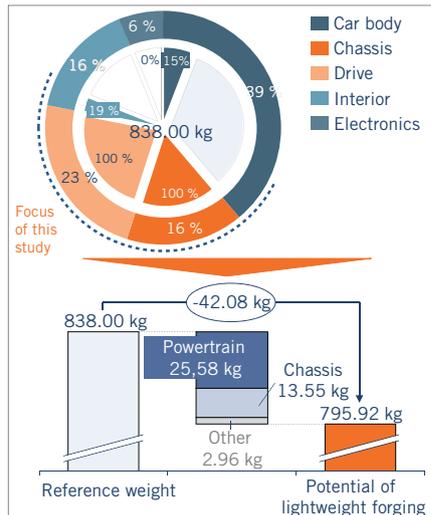
2 Procedure of the lightweight design potential study (Sources: Lightweight design potential study of The Lightweight Forging Initiative, fka, RWTH Aachen)

- : Three workshops
- : 65 experts from 30 companies and research institutes



- : Analysis of approx. 3500 parts from the powertrain, chassis and other areas
- : 399 ideas for lightweight potential in various types of lightweight design approaches
- : Documentation in the fka benchmarking database

Lightweight design potential of 42.08 kg for the areas identified



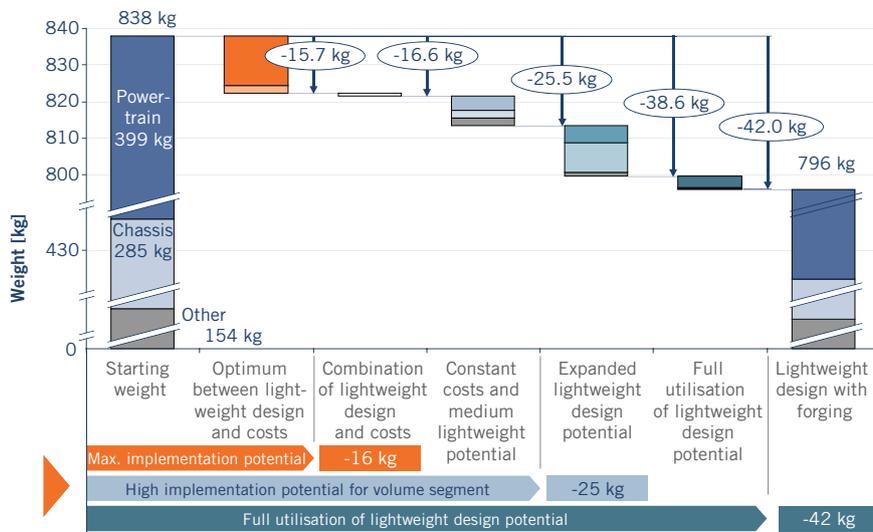
3 Results of the lightweight design potential study (Sources: Lightweight design potential study of The Lightweight Forging Initiative, fka, RWTH Aachen)

Bainitic grades, for example, are appearing on the market which can be processed just as cost efficiently as dispersion-hardening steels, this means without additional heat treatment, but which achieve mechanical values comparable to quenched and tempered steels, 5 [1, 7]. By using these steels, lightweight design potential may be leveraged in an economic way. One example is the trailer coupling which may be dimensioned with less weight using a stronger and, at the same time, tougher steel.

Compared to steel, the use of lightweight metals may lead to lightweight design solutions in some cases. 5, right, shows a chassis bearing on the rear axle.

Here, a switch was made from steel to high-strength aluminium with a larger contact surface. Furthermore, the part has a hollow design with internal undercut. Both may be implemented cost-effectively and easily by means of cold forging.

However, other developments using steel also hold considerable lightweight design potential, too. The use of fastening elements with a higher strength class could make a significant contribution to lightweight design due to the large number of such parts in vehicles. This would be possible in cases where the strength class is the principal design criterion and not, for example, the strength of the part to be fastened.



4 Classification of the lightweight design ideas (Sources: Lightweight design potential of The Lightweight Forging Initiative, fka)



5 Material lightweight design potential (Sources: GMH, EZM, Hirschvogel, A+E Keller)

LIGHTWEIGHT POTENTIAL THROUGH DESIGN

6 (upper left) shows geometrical optimisations on a crankshaft. In the area of the pin bearings, recesses may be forged into the part. A rough calculation of imbalance shows that this can lead to material savings on the counterweights, too.

Geometries which are not rotationally symmetric may be produced easily by means of forging. 6 (upper right) shows a flywheel with pockets at three sites on the circumference. A solution involving machining alone would not allow this lightweight design potential to be exploited or would only do so at higher

costs, as milling these pockets would be expensive.

6 (lower right) uses the example of a connecting rod to demonstrate the potential of increasing the strength class of a fastening element. At the same pre-stressing force, the screw can be designed smaller, leading to a reduction in the dimensions of the connecting rod. Particularly weight reductions achieved on the connecting rod result in greater secondary effects in the engine (bearings, balancer shafts).

Additional lightweight design potential may be tapped by fully exploiting the forming possibilities offered by forging. This is shown in 6 (lower left). In this case, it is important to consider materi-

als which permit considerable upsetting of the steel without causing a drop in their load-bearing capacity [8].

Other geometrical possibilities allow more effective dimensioning and thus lead to parts which are smaller and can bear greater load. One example of this is shown in 7. Here, the gears of the differential pinions are continually optimised with respect to load-bearing capacity. But also the possibility of connecting forged gear teeth to a flange, which is not possible with milled gears, increases the load-bearing capacity of these parts, allowing smaller and thus lighter dimensioning.

The same is true of the speed gear in 7 (upper right). Here, too, the starting point was a classic, pure rotationally symmetric geometry in the connection between the gear rim and hub. On the one hand, stiffening radial arms were produced. On the other, material was removed between these arms by means of punching to achieve maximum weight savings.

Additional potential on speed gears is shown in 7 (lower right). Here, the possibility of reducing the wall thickness below the tooth ends is identified. In the case of crowned teeth which bear the load in the centre, the main bending load of the teeth lies in the centre of the tooth. It should thus be possible to use less material at the tooth ends to support the bending load of the tooth.

Gearwheels are attracting particular attention due to the high total number thereof in transmissions. Accordingly, 7 (lower left) shows additional optimisation achieved through a non-rotationally symmetric design of the gear rim connection with reduced wall thicknesses.

Depending on the forging facilities available (press forces, number of stages, possibility of single or multiple piercing), different forging companies will arrive at different solution approaches with respect to lightweight design in order to reduce the rotating masses in particular. These will need to be given greater attention, as their impact on fuel consumption is especially high.

8 (left) shows the input shaft in the transfer gearbox. Here, the lightweight design potential is identified below the hypoid gears. It is thus possible to forge a recess which does not need to be machined, depending on imbalance requirements. Furthermore, a hole can be introduced into the shaft centre. While

the latter does generate a small additional effort in soft machining, as the hole cannot be produced by means of forging, it should nevertheless prove cost-efficient when calculating “€ per kg”.

⑧ (right) shows an output flange. The lightweight design proposal encompasses the following points: The external geometry deviates from the rotational symmetry. Pockets are forged into the part and the internal geometry is drawn deeper without increasing the stresses in the external undercut. The proposal with respect to the journal certainly needs to still be assessed in more detail. It is assumed that the inner race of the bearing does not necessarily need to lie flush with the flange, but that individual contact surfaces are sufficient. These may be produced easily by means of forging.

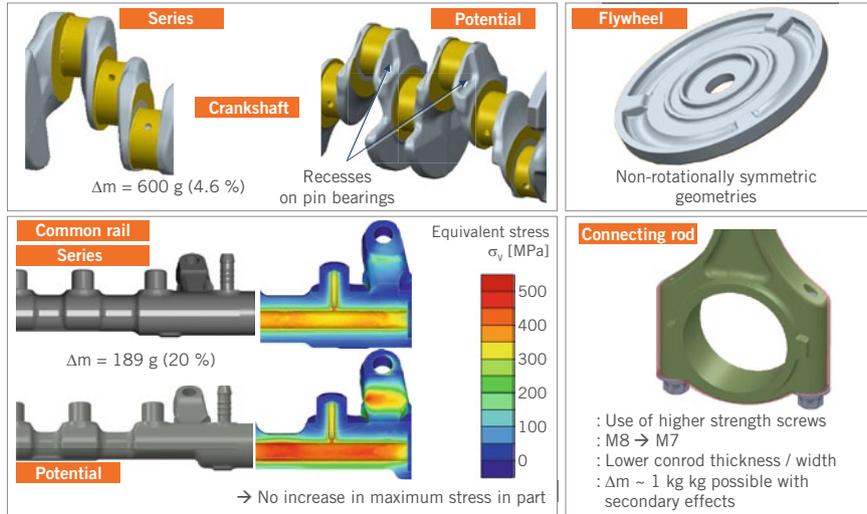
An important chassis part is the wheel hub. Depending on the wheel bearing generation, the functional integration of the anti-friction bearings directly on the wheel hub have already led to weight savings; this was the case in the reference vehicle analysed. The lightweight design proposal shown in ⑨ (left) represents a large weight reduction. However, due to its bold design, it also falls under the category of suggestions involving significantly higher implementation efforts.

Furthermore, ⑨ (right) shows an almost revolutionary lightweight design idea. The hexagon on nuts and bolts is a highly classic, almost iconic design element. It may be deviated from by exploiting the design possibilities of cold forging. Although, per part, only a few grams are saved, the high number of such fastening elements means that the lightweight design advantage multiplies to a corresponding degree in the vehicle. Weight savings of up to 20 %, depending on the size of the nuts, are stated for this solution [9].

CONCEPTUAL LIGHTWEIGHT DESIGN POTENTIAL

Lightweight design generated by means of concept changes is highly effective, as it is of a disruptive rather than incremental character. However, this can also magnify the implementation obstacles.

⑩ shows a lightweight design proposal whose implementation hurdles still need to be tested out. The lightweight design proposal foresees that torque transfer is achieved via Hirth gears, which may be produced ready-for-assembly by means



⑥ Lightweight design potential on engine parts (Sources: cdp Bharat Forge, Hammerwerk Fridingen, Kamax, Hirschvogel)



⑦ Lightweight design potential on transmission parts (Sources: Metaldyne, metallumform, Seissenschmidt, Sona BLW Präzisionsschmiede)

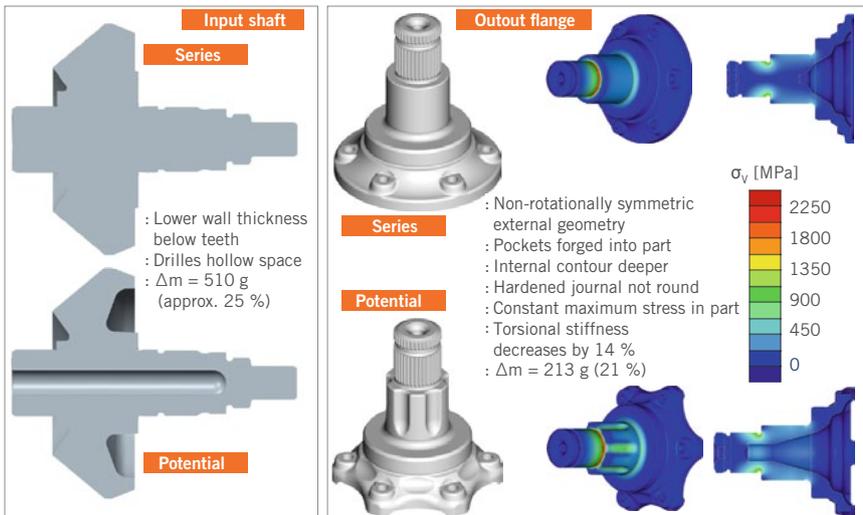
of forging both on the output shaft as well as on the tripod. The proposal thus not only leads to a reduction in weight of 33.5 % but also to the omission of the welding process and to a reduction of effort in vehicle assembly.

SUMMARY AND OUTLOOK

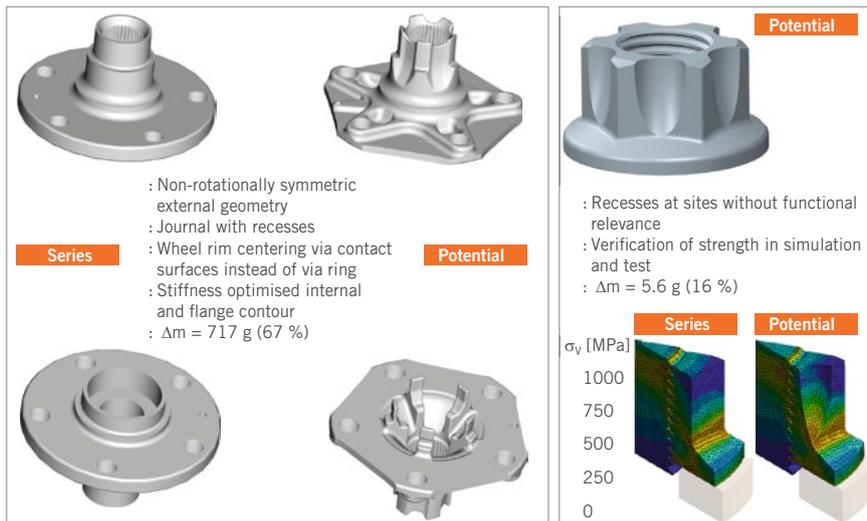
The results outlined above highlight the innovation of the steel and forging industry. Assessing material, design and forging innovations demonstrates that a significant weight reduction of 42 kg appears possible on the vehicle analysed. Secondary lightweight design potential [10] has

not yet been taken into account. With respect to the lightweight design potential, the areas of powertrain and chassis are of equal importance as the car body. Steel materials and forging technology may be used to achieve lightweight design, with the cost per kilogram lightweight design lying below that incurred for many new types of manufacturing technologies. Some lightweight design potential even promises cost neutrality. This lightweight design thus has a broad impact and can contribute significantly to reducing the total CO₂ emissions.

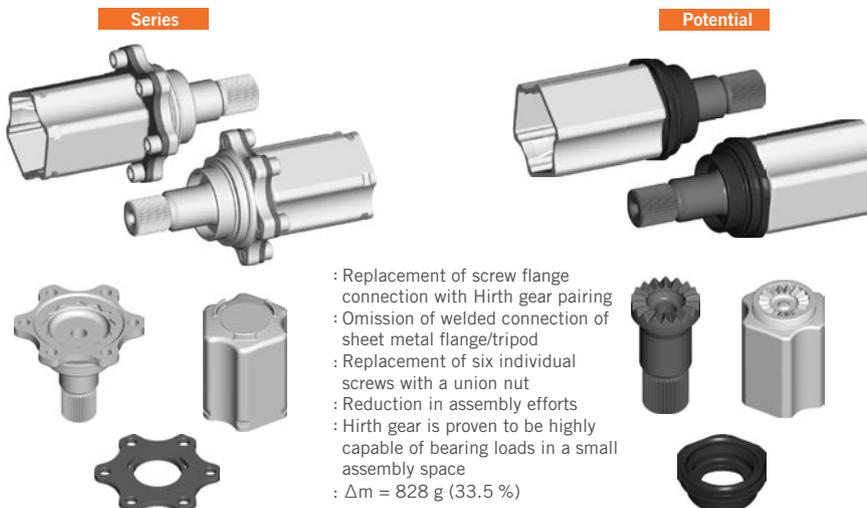
To utilise these lightweight design ideas, it is necessary to include material and forg-



8 Lightweight design potential in the remaining power train (Sources: Seissenschmidt, Hirschvogel)



9 Lightweight design potential in the chassis (Sources: Hirschvogel, HEWI)



10 One example of conceptual lightweight design potential (Source: Hirschvogel)

ing potential in the early phases of system and part development. Here, there are tried-and-tested simultaneous engineering processes. However, these need to be used for considerably more components than is currently the case. The purchasing process should begin during earlier phases of development, namely when the lightweight design proposals of the supplier can still flow from material or production engineering into part design.

In this study, The Lightweight Forging Initiative has determined that not only is there potential to be tapped, but also that there is a need for research. For example, the correlation between the cleanliness of the steel and the fatigue strength needs to be better quantified even for applications beyond anti-friction bearings in order to transfer new steel manufacturing technologies into lightweight design potential. To address these and other issues, a lead technology project is being applied for at the AiF (an alliance of research associations). Currently (January 2014), this project is in the assessment phase.

Future activities of The Lightweight Forging Initiative will include communication of the results within the industry, partly by means of a conference event at the end of 2014. Furthermore, discussions will be held on continuing the successful and cooperative collaboration on an electric vehicle, for example, or on raising collaboration to a global level.

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