LIGHTWEIGHTforging

www.LIGHTWEIGHTforging.com

Phase III Hybrid Passenger Car (HEV) and Heavy-Duty Commercial Vehicle (HDV)

2017 – 2018

Stahl Steel Institute VDEh
DEUTSCHE MASSIVUMFORMUNG

Automotive Lightweight Design with Forging

LIGHTWEIGHTforging

Lightweight Forging Initiative
Forging and Steel Industry

Study of industrial lightweight design potential with 24 partners	Study of industrial lightweight design potential with 28 partners	"Lightweight Forging" Research Network	Study of industrial lightweight design potential with 39 international partners
Phase I Passenger Car	Phase II Light Commercial Vehicle		Phase III Hybrid Car/ conv. CV
2013 – 2014	2015 – 2016	2015 – 2018	2017 – 2018

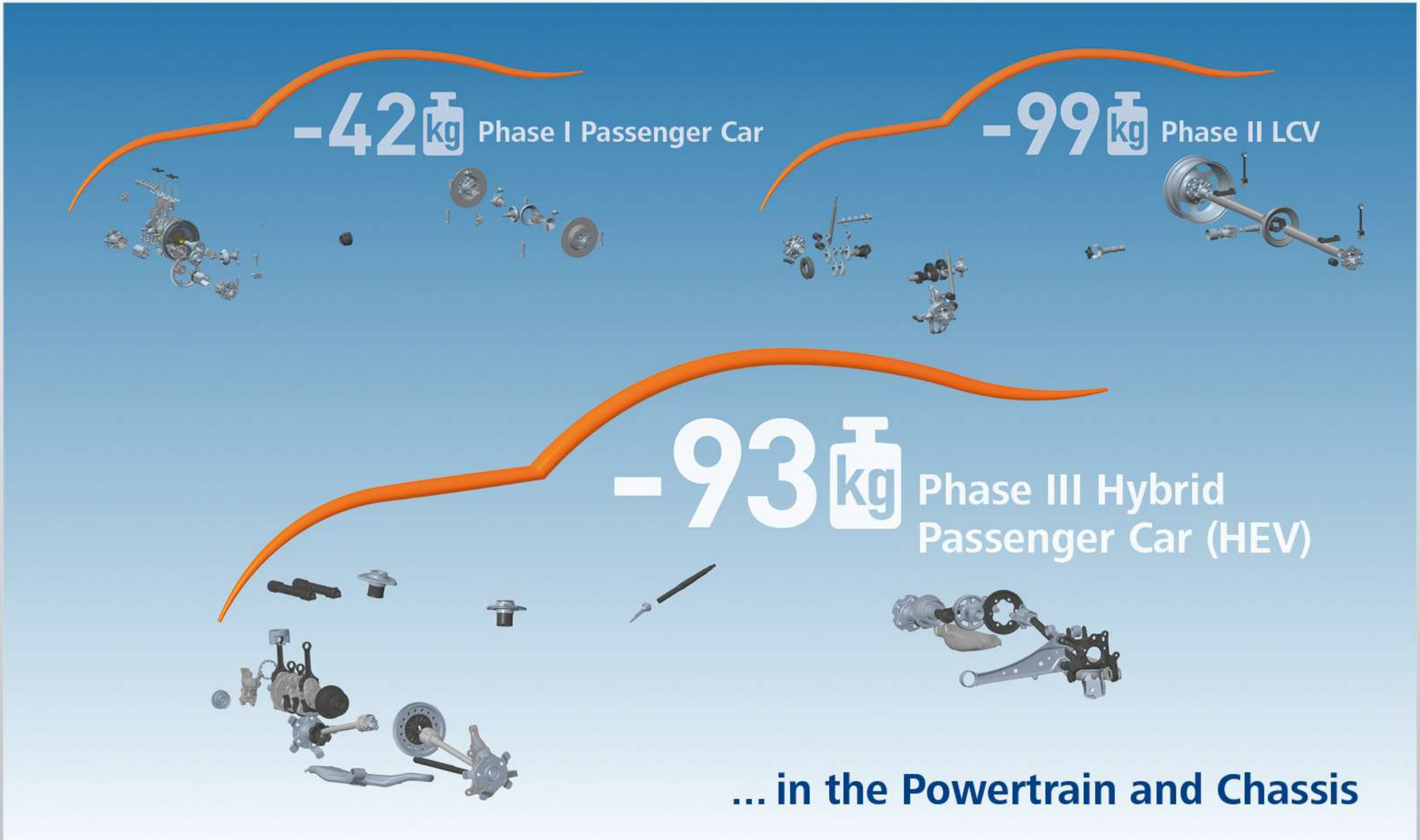
Automotive Lightweight Design with Forging

LIGHTWEIGHT**forging**

- **Phase I (2013 – 2014) – Medium-Sized Passenger Car**
  - 15 forging companies
  - 9 steel manufacturers
  - 42 kg of lightweight design potential
- **Phase II (2015 – 2016) – Light Commercial Vehicle (LCV, up to 3.5 t)**
  - 17 forging companies
  - 10 steel manufacturers
  - 1 engineering service provider
  - 99 kg of lightweight design potential
- **Phase III (2017 – 2018) – Hybrid Passenger Car and Heavy-Duty Vehicle**
  - 22 forging companies
  - 12 steel manufacturers
  - 3 machine manufacturers for forging machines
  - 2 automotive companies
  - International cooperation for the first time (Western Europe, USA, Japan)
  - 93 kg (HEV) und 124 kg (HDV) of lightweight design potential
- **The "Lightweight Forging" Research Network (2015 – 2018)**
  - 64 companies from the entire process chain, 4 research associations and 10 research institutes
  - 6 subprojects
  - Goal: to render vehicles lighter using modern steel materials as well as through part design and production methods

▶ Significant reduction in energy consumption and CO_2 emissions through NEW lightweight solutions based on design and material concepts for forged components

Lightweight Forging…



Lightweight Forging…

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… in the Transmission, Propeller Shaft and Rear Axle

The Cooperation Partners of the Initiative

LIGHTWEIGHTforging

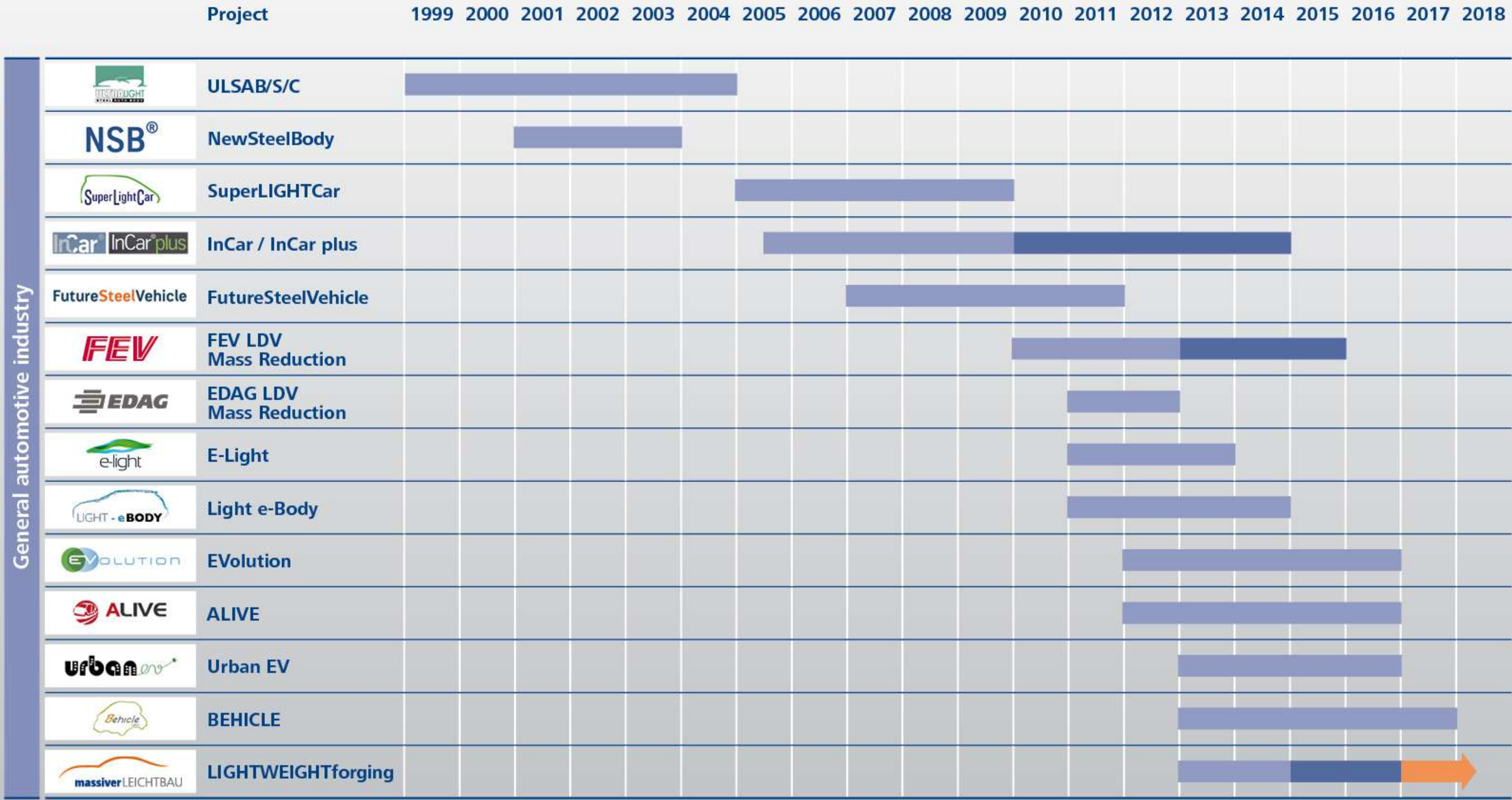
- METAL FORMING
- TEKFOR
- ArcelorMittal
- BENTELER makes it happen
- BGH
- BHARAT FORGE KALYANI
- Buderus Edelstahl
- Cotarko
- DAIDO STEEL
- DEUTSCHE EDELSTAHLWERKE
- Enomoto Technology SCREW PRESS www.enomt.co.jp
- FELSS SHORTCUT TECHNOLOGIES
- Georgsmarienhütte GMH GRUPPE
- Hammerwerk Fridingen
- HATEBUR
- HAY|GROUP member of MUSASHI
- Hirschvogel Automotive Group
- JFE
- KAMAX
- Lasco
- LEIBER GROUP
- LINAMAR SEISSENSCHMIDT FORGING
- MUSASHI Power to Value
- NEUMAYER
- NIPPON STEEL & SUMITOMO METAL CORPORATION
- NISSAN
- SCHMIEDETECHNIK PLETTENBERG
- saarstahl
- SAN GRATO
- SCHONDELMAIER PRESSWERK
- SCHULER Member of the ANDRITZ GROUP
- Setforge
- sidenor
- SMS group
- TIMKENSTEEL
- TRUMPF
- voestalpine ONE STEP AHEAD.
- YAGI POLAND
- Yamanaka Eng

In collaboration with:

- fka
- IPEK Institut für Produktentwicklung am KIT • o. Prof. Dr.-Ing. Dr. h.c. A. Albers

Project Overview

Lightweight Research Projects – Public R&D and Metastudies



Project Motivation: Hybrid Electric Vehicle

Main Drivers

Emissions Legislation

- Reduction of CO_2 emissions to achieve the fleet targets
  → target of the EU by 2020: 95 g CO_2/km
- In order to fulfill global **CO_2 legislation,** a significant **increase in efficiency** is required
- Regulation of **noise emission** and time-dependent **noise protection**

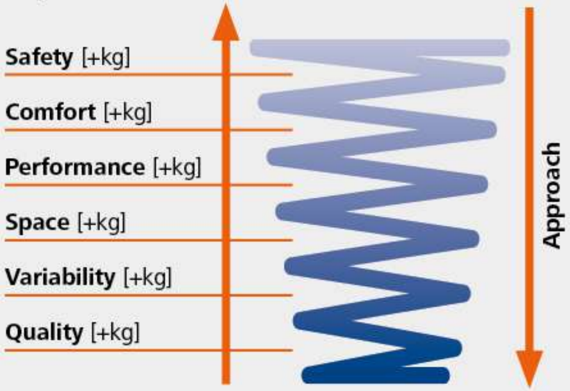
Entry Restrictions

- Expansion of environmental zones
- Tightening of entry restrictions in cities

Motivation for LW Design

Weight Spiral

Increasing requirements:



- Increasing demands led to increasing vehicle mass
- Reversal of the weight spiral through lightweight design
- Suppliers can contribute manufacturing know-how (bottom-up approach)

Megatrends

Electromobility

- Potential for global CO_2 reduction
- Local emissions and noise reduction

Autonomous Driving

- Potential for improved fuel economy
- Potential for fewer accidents
- Reduction of time expenditure

Lightweight Design

- Reduction of fuel consumption
- Environmental protection and contribution to sustainability
- Reduction of resources
- Improved driving experience and increased safety
- Compensation of additional weight due to the electrical powertrain and of the effort involved in vehicle safety
- Payload increase

Project Motivation: Heavy-Duty Vehicle

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Main Drivers

Emissions Legislation

- In order to fulfill the global **CO_2 legislation,** a significant **increase in efficiency** is required
- Emissions standards demand new technologies
- Regulation of **noise emission** and time-dependent **noise protection**

Cost Reduction

- In the commercial vehicle sector, **TCO** is the most important factor
- Innovation to reduce **costs of acquisition** and/or **operating costs**
- Lightweight design can increase transport capacity (payload)
- Autonomously driven vehicles could reduce personnel by up to 90 %

Secondary Drivers

Entry Restrictions

- **Inner city delivery traffic** with commercial vehicles is particularly restricted
- In future, a significant **expansion of environmental zones** and an **increase in entry restrictions** are to be expected

New Requirements

- Framework conditions such as the increase in **e-commerce** are demanding global solutions from OEMs and suppliers
- Diverse customer requirements are rendering it necessary to offer an increasing number of **vehicle types**

Megatrends

Electromobility

- Potential for global CO_2 reduction
- Local emissions and noise reduction

Autonomous Driving

- Reduction of personnel costs
- Potential for improved fuel economy
- Potential for fewer accidents

Lightweight Design

- Reduction of fuel consumption and/or increase in payload
- Increase in vehicle efficiency
- Reduction of resources
- Environmental protection and contribution to sustainability
- Reduction of load on roads
- Reduction of noise pollution

Project Procedure: HEV – 1

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Method:

Context Analysis

- Trends and drivers of the HEV industry
- Analysis of the developments in the powertrain
- Overview of public research

Benchmarking

- Systematic disassembly and documentation of a reference vehicle
- Generation of an online documentation tool for documentation and evaluation

Workshops

- Holding facilitated workshops on the powertrain and chassis with experts from the Initiative

and in addition…

1. Determining the Overall Vehicle Weight

Reference Vehicle: Compact SUV
Hybrid drive system, System power: 145 kW (197 PS)
Battery: 1.6 kWh
Max. speed: 180 km/h
Gross vehicle mass: 2,205 kg

2. Disassembly of the Entire Vehicle


ICE


Transmission


HV Battery

3. Listing and Naming all Individual Components

4. Component Analysis

Component Code	Naming Component	Weight [kg]	x [mm]	y [mm]	z [mm]	Material	Number	Thread Type (z.B. M12)	Thread Pitch	Thread Length [mm]	SC
42201010101	[illegible]	1.255	135	162	153	Aluminium					
42201010102	[illegible]	0.04	18	18	108	Steel	1	M8	1.25	103	n.a.
42201010103	[illegible]	0.041	8	8	117	Steel	2	M8/M8	1.25/1.25	n.a.	n.a.
42201010104	[illegible]	0.007	18	18	8	Steel	2	M8	1.25	n.a.	n.a.
42201010105	[illegible]	0.53	115	48	131	Aluminium					
42201010106	[illegible]	0.006	12	12	25	Steel	6	M6	1	19	n.a.
42201010107	[illegible]	0.009	115	1	131	Steel					
42201010108	[illegible]	0.002	65	2	77	Plastics					
42201010109	[illegible]	0.369	100	49	100	Aluminium					
42201010110	[illegible]	0.193	100	42	100	Aluminium					
42201010111	[illegible]	0.174	132	100	46	Aluminium					
42201010112	[illegible]	0.005	10	10	33	Steel	3	M5	0.8	30	n.a.
42201010113	[illegible]	0.0003	10	10	1	Steel	3				
42201010114	[illegible]	0.01	133	100	5	Steel/Plastics					
42201010115	[illegible]	0.0005	22	22	6	Plastics					

Project Procedure: HEV – 2

... Transmission Modelling

- Transmission model
- Assessment of the influencing variables with the Institute of Product Engineering Karlsruhe (IPEK)
- Development of permissible steel alternatives
- Assessment of hard and soft influencing factors on transmission design

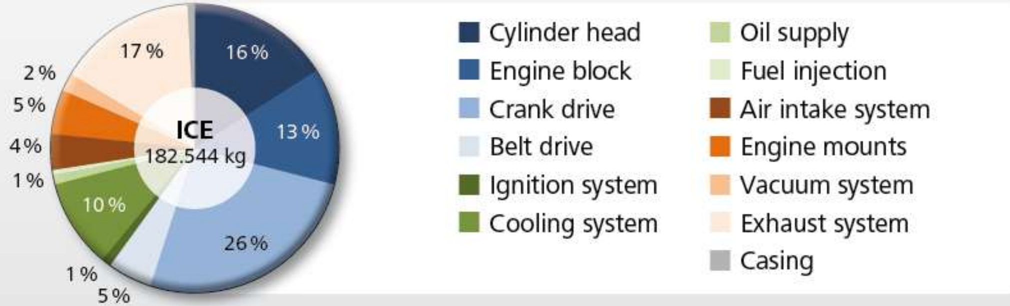
Deriving Lightweight Design Potential

- Identifying the lightweight design potential of forged components in the powertrain and chassis
- Implementation in the form of concrete lightweight design proposals

Documentation

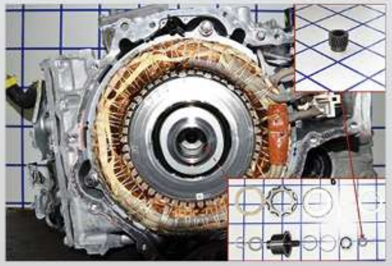
- Accompanying PowerPoint presentation
- Implementation of an online database

5. Weight Distribution of the Assembly Groups

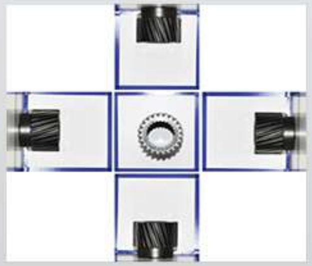


6. Photo Documentation

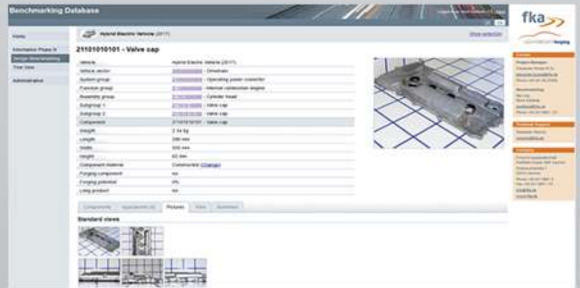
Sun gear 2



Installation position



7. Database Implementation



Project Procedure: HDV – 1

LIGHTWEIGHT**forging**

Method:

Context Analysis

- Trends and drivers of the HDV industry
- Analysis of the developments in the powertrain
- Overview of public research

Benchmarking

- Systematic disassembly and documentation
- Generation of an online documentation tool for documentation and evaluation

Workshops

- Holding facilitated workshops on the transmission and powertrain with experts from the Initiative

and in addition…

1. Reference Sub-Systems

Torque converter:
- 12-speed transmission
- 290.34 kg

Rear axle with differential and propeller shaft:
- 618.91 kg

2. Disassembly of the Sub-Systems

Torque converter

Rear axle

3. Listing and Naming all Individual Components

4. Component Analysis

Component Code	Naming Component	Weight [kg]	x [mm]	y [mm]	z [mm]	Material	Number	Thread Type	Thread Pitch	Thread Length [mm]	SC
22104070101	Planet gear 1	1.305	42	91	91	Stahl					
22104070102	Support planet gear 1	0.324	65	35	35	Stahl					
22104070103	Grub screw (type 1) support planet gear 1	0.002	6	6	14	Stahl	1	M6	1	n.a.	n.a.
22104070104	Guard plate planet gear 1	0.019	6	66	65	Stahl	2				
22104070105	[illegible]	0.004	1	44	44	Stahl	2				
22104070106	[illegible]	0.006	40	5	5	Stahl	25				
22104070107	Planet gear 2	1.305	42	91	91	Stahl					
22104070108	Support planet gear 2	0.324	65	35	35	Stahl					
22104070109	Grub screw (type 1) support planet gear 2	0.002	6	6	14	Stahl	1	M6	1	n.a.	n.a.
22104070110	Guard plate planet gear 2	0.019	6	66	65	Stahl	2				
22104070111	[illegible]	0.004	1	44	44	Stahl	2				
22104070112	[illegible]	0.006	40	5	5	Stahl	25				
22104070113	Planet gear 3	1.305	42	91	91	Stahl					
22104070114	Support planet gear 3	0.324	65	35	35	Stahl					

Project Procedure: HDV – 2

LIGHTWEIGHT**forging**

… Transmission Modelling

- Transmission model
- Assessment of the influencing variables with the Institute of Product Engineering Karlsruhe (IPEK)
- Development of alternative steel materials
- Assessment of hard and soft influencing factors on transmission design

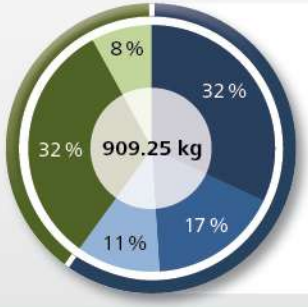
Deriving Lightweight Design Potential

- Identifying the lightweight design potential of forged components
- Implementation in the form of concrete lightweight design proposals

Documentation

- Accompanying PowerPoint presentation
- Implementation of an online database

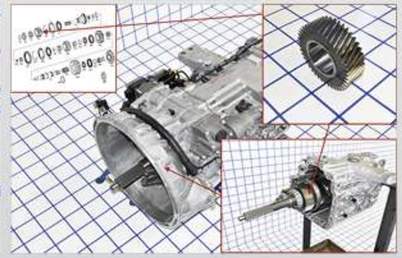
5. Weight Distribution of the Sub-Systems

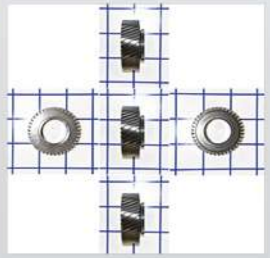


- Torque converter
- Differential and transfer transmission
- Drive shafts
- Longitudinal and lateral dynamics
- Brake system

Vacuum system

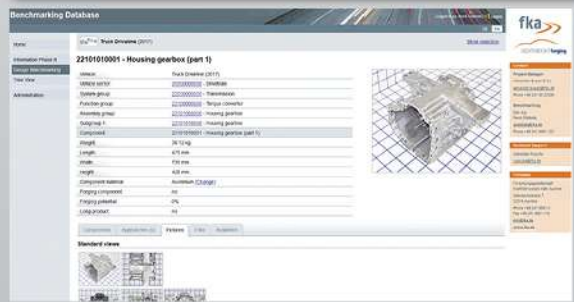
6. Photo Documentation





Gear constant drive 1
Drive shaft 1

7. Database Implementation



Weight Distribution: HEV

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Reference Vehicle: Compact SUV

- Hybrid drive system, System power: 145 kW (197 PS)
- Battery: 1.6 kWh
- Max. speed: 180 km/h
- Gross vehicle mass: 2,205 kg

Analyzed Area:

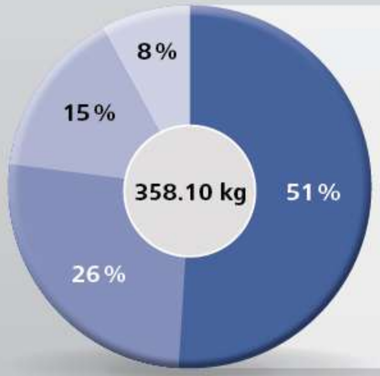
- Powertrain
- Chassis
- Electronics

plus

- Body, interior, electronics, etc.

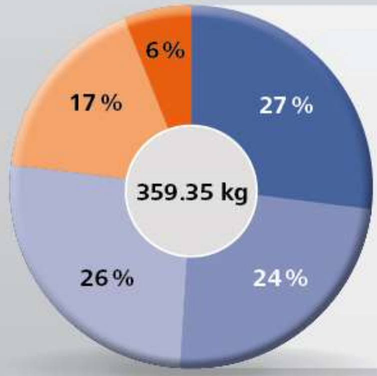
Weight Distribution in Analyzed Vehicle Areas

Powertrain



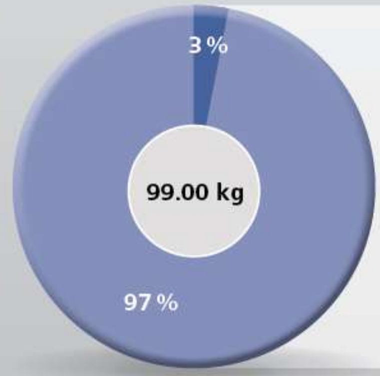
- Internal combustion engine
- Torque converter
- Differential and transfer transmission
- Drive shafts

Chassis



- Front axle
- Rear axle
- Wheels and tyres
- Brake system
- Steering system

Electronics



- Low-voltage components
- High-voltage components

Weight Distribution: HDV

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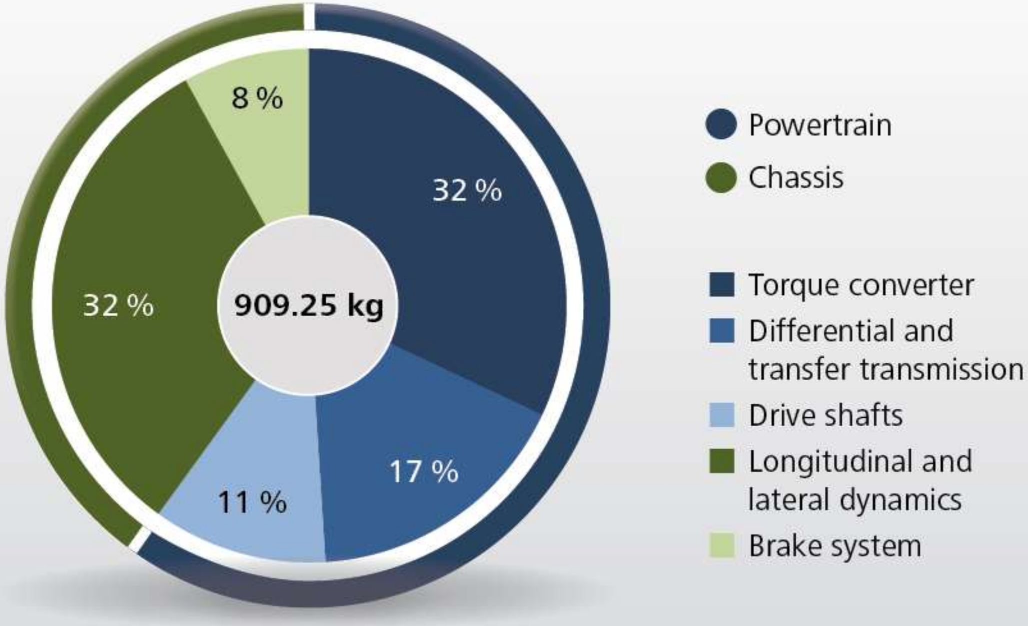
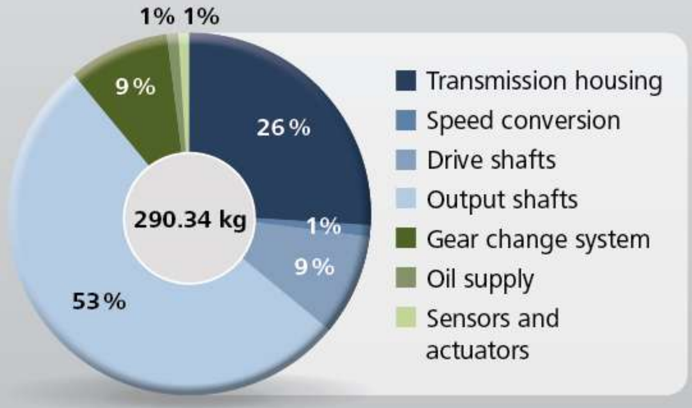
Reference Sub-Systems:

- **Torque converter**
  - 12 gears
  - 290.34 kg
- **Rear suspension (incl. propeller shaft)**
  - 618.91 kg

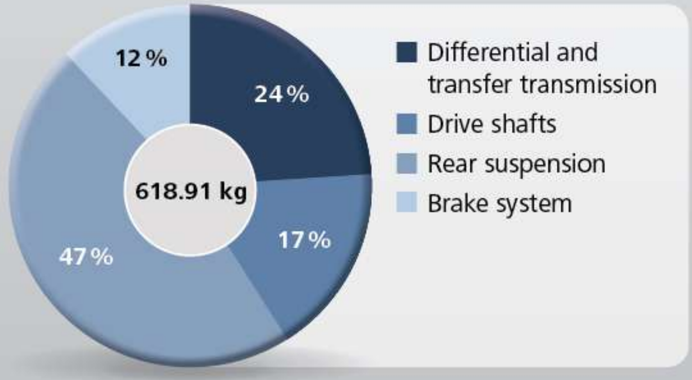


Weight Distribution of the Sub-Systems

Torque converter



Rear suspension



Workshop Overview

Workshops
with **80 experts**
from **39 companies**

Analysis
of **4,067 components**
from the entire
HEV and HDV
sub-systems

Formulation
of **983 lightweighting ideas** in total, which can
be sub-divided into various
lightweighting categories

Main documentation
in the **benchmarking database**

Impressions from the workshops






Evaluation of the Lightweighting Ideas

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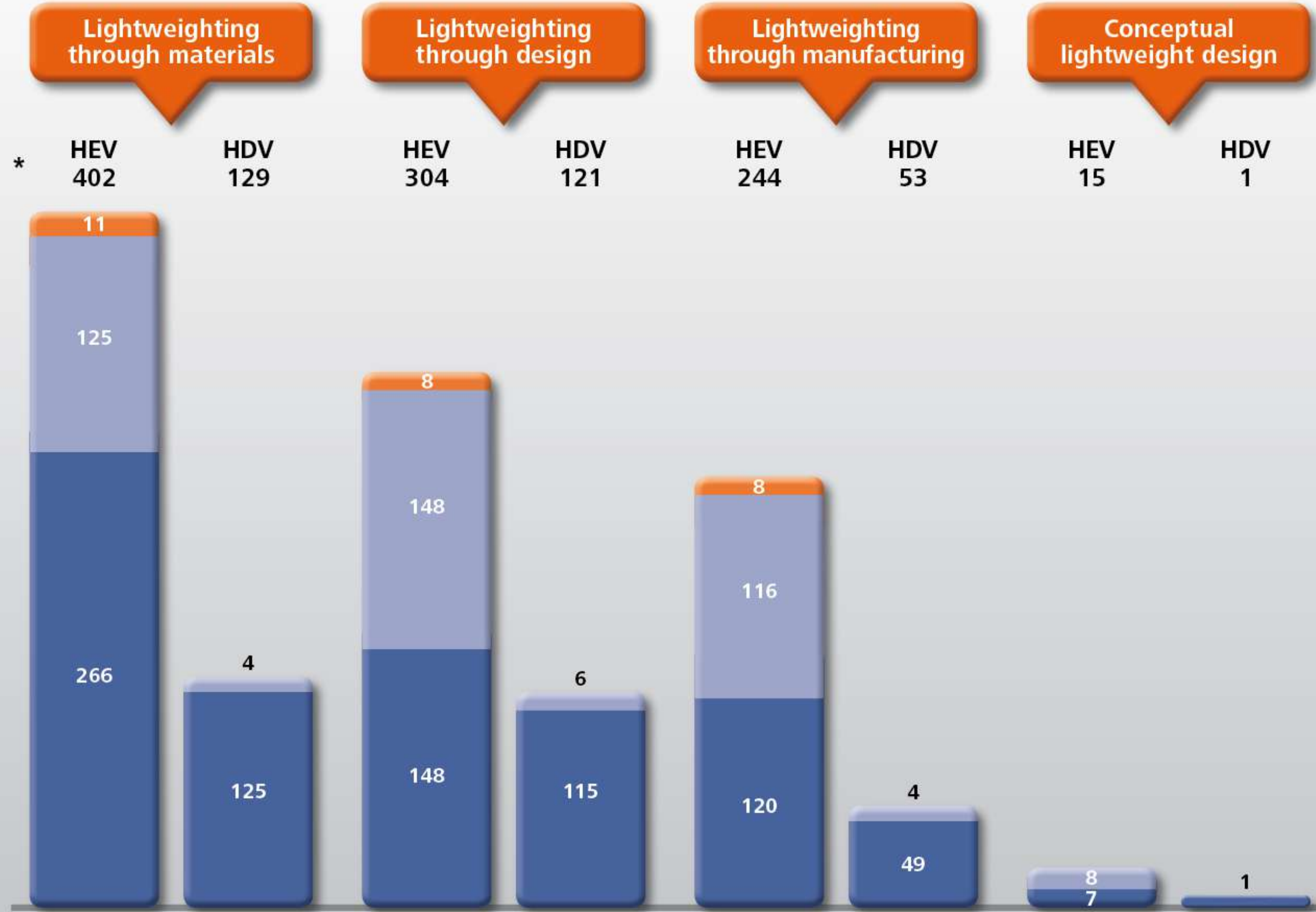

Total Lightweighting ideas = 983

HEV = 732

HDV = 251

- Electronics
- Chassis
- Powertrain

*Lightweight design ideas can often be assigned to various lightweighting categories.
The use of a new material may lead to an adapted manufacturing process, for example.

Portfolio Charts of the Lightweighting Ideas

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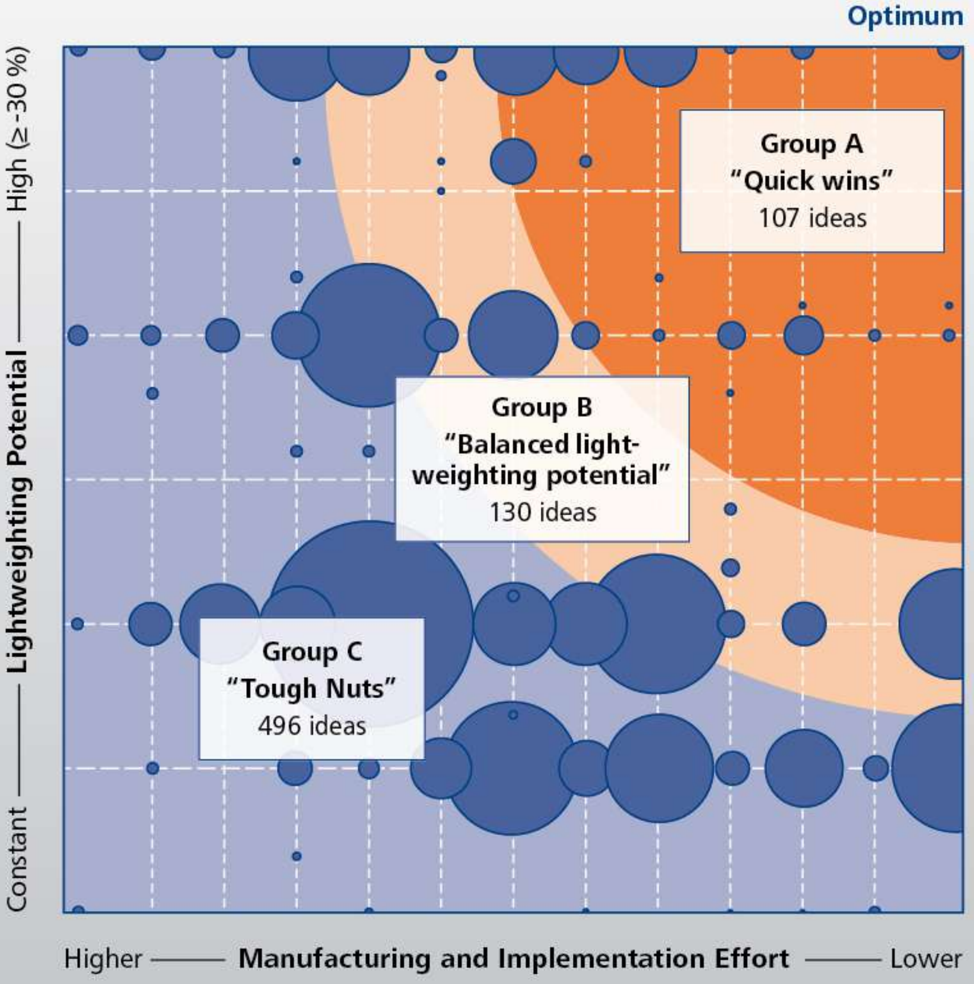
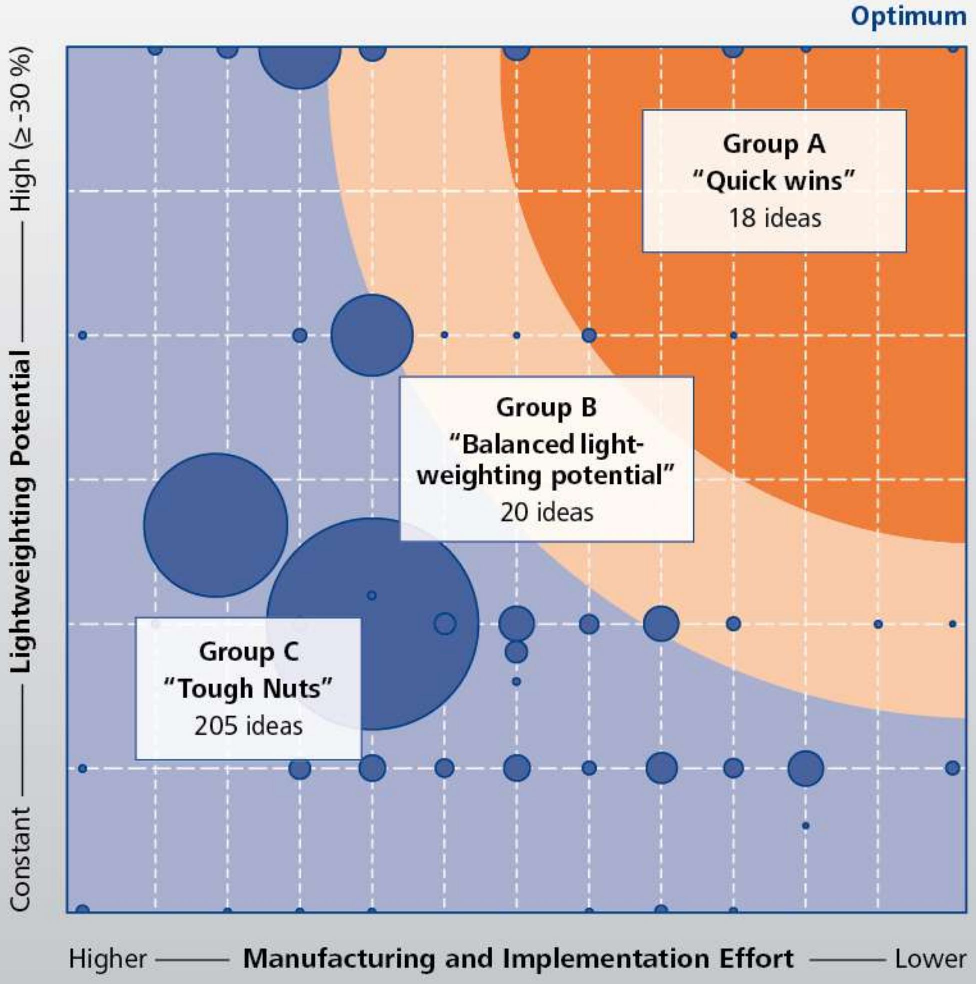
HEV



HDV

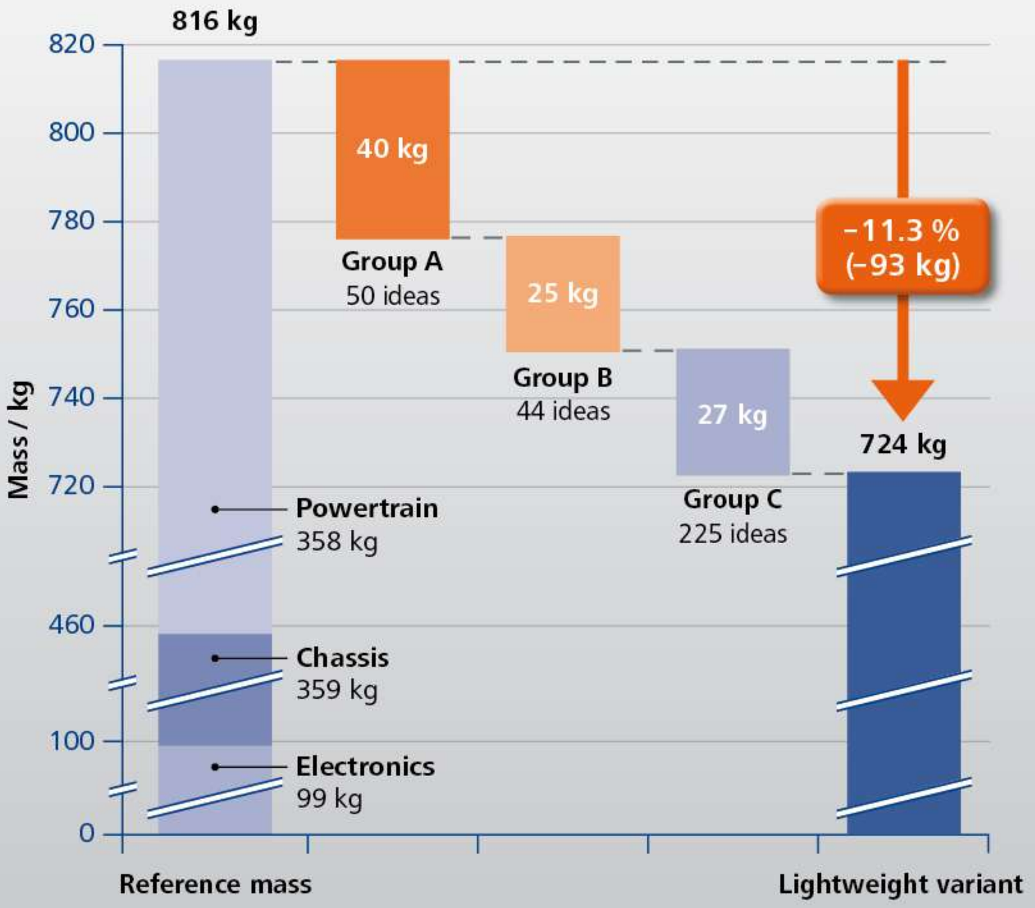


The blue circles show the number of ideas in this point.

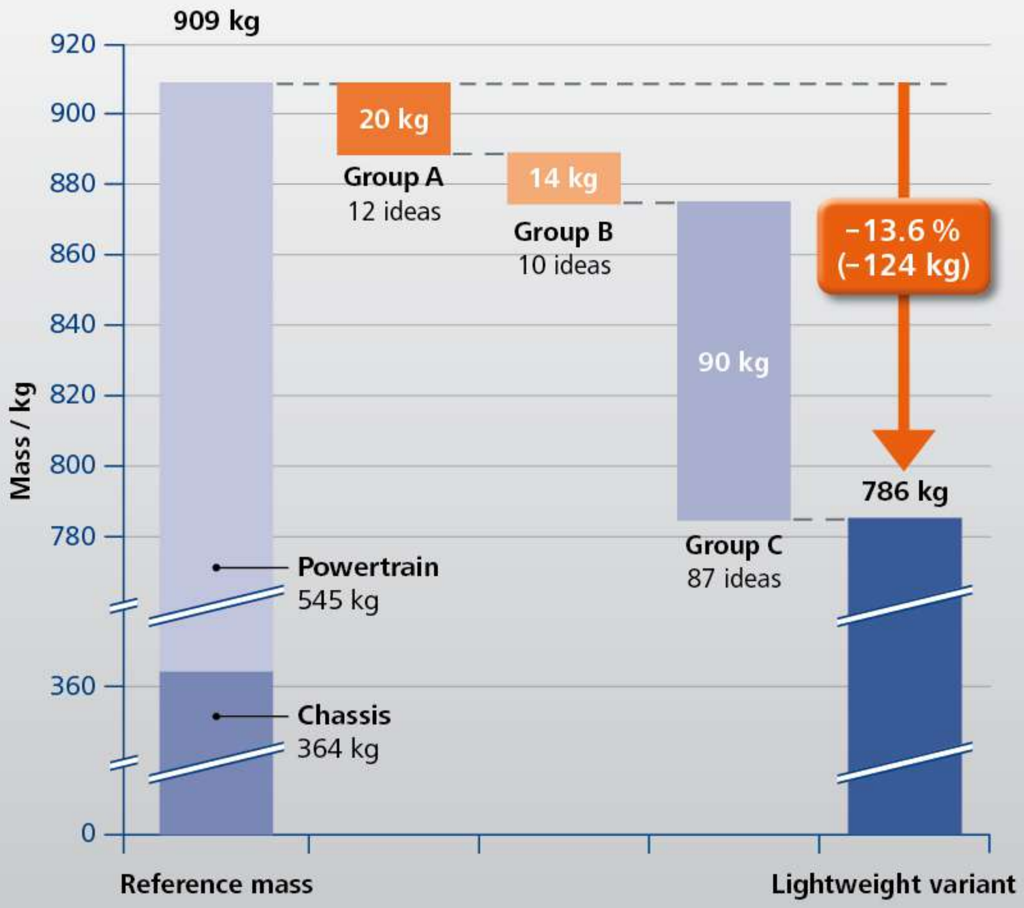
Source: fka for Phase III of The Lightweight Forging Initiative

Portfolio Evaluation

HEV



HDV



Source: fka for Phase III of The Lightweight Forging Initiative

Selected Lightweighting Proposals

Combustion Engine

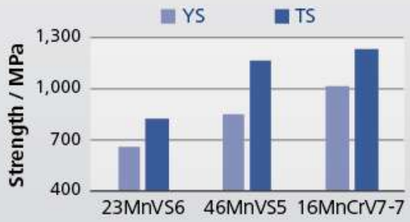
1. Conrod

Series

- 23MnVS3
- m = 572 g

Lightweighting Proposals

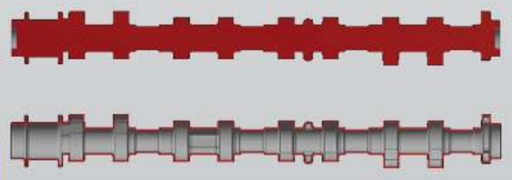
- Reduction in cross section of conrod shaft
- 46MnVS5: Δm = 51 g (10 %)
- 16MnCrV7-7: Δm = ~75 g (~15 %)



2. Camshaft

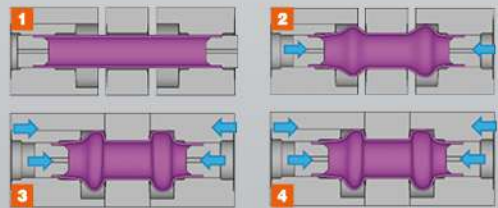
Series

- Cast solid shaft
- m = 2,400 g



Lightweighting Proposal

- Forming from steel tube with internal pressure
- Δm = 1,800 g (400 %)

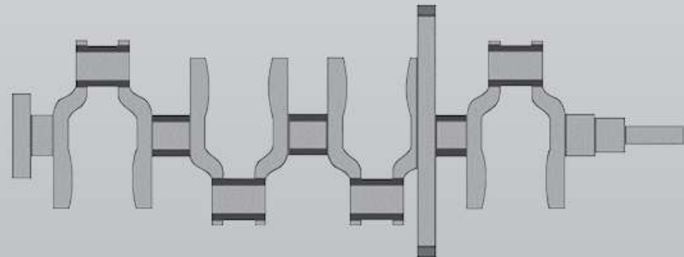


3. Crankshaft

Series

Lightweighting Proposals

- **Material proposals → estimated Δm = 1,700 g (11 %)**
  - SolamB1100
  - Higher strength 46MnVS5
  - 46MnVS6 or bainite
  - Microalloyed C50
  - Reduced sulphur content
- **Design proposal → Δm = 5,100 g (42 %)**
  - Forged single parts with pockets or cavities
  - Joined by laser welding using means of hollow bearing pins



Sources: 1 = Georgsmarienhütte, Schmiedetechnik Plettenberg; 2 = Yamanaka Engineering; 3 = ArcelorMittal, Georgsmarienhütte, Saarstahl, Sidenor, TimkenSteel, Trumpf

Selected Lightweighting Proposals

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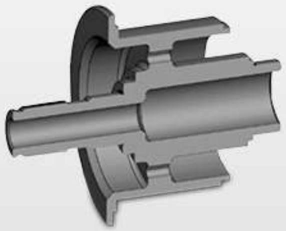
Front Electric Motor and Powertrain

4. Rotor Shaft

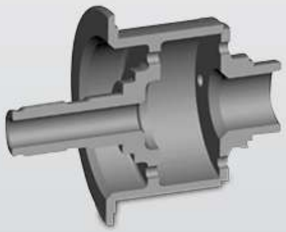
Series

- Two-part solution: with central shaft press fit into outer part
- m = 3,180 g



Lightweighting Proposal

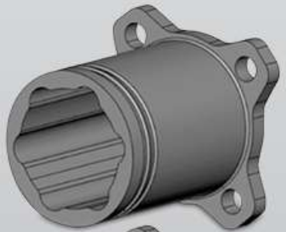
- Two-part solution
- Right bearing flange: laser welding or shrinking
- Δm = 701 g (29 %)



5. Tripods

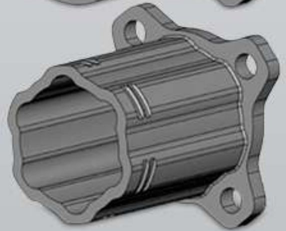
Series

- Circular on the outside
- m = 957 g



Lightweighting Proposal

- Forged contour on the outside
- 50CrMnB5-3 (H50)
- Δm = 156 g (19 %)



6. Drive Shaft

Series

- Machined from bar
- m = 2,160 g

Lightweighting Proposal

- Swaged from tube
- Spline axially forged
- Resource-efficient manufacturing
- Variable wall thicknesses can be produced without machining
- Internal undercut
- Δm = 860 g (66 %)

Sources: 4 = Hirschvogel; 5 = Georgsmarienhütte, Hirschvogel; 6 = Felss

Selected Lightweighting Proposals

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Powertrain

7. Differential

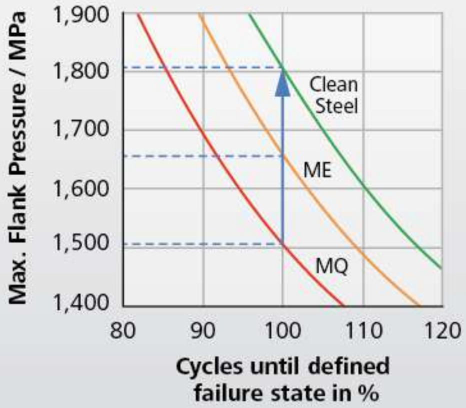
Series

- Conventional cast housing
- 4-wheel differential
- m = 6,600 g

Lightweighting Proposal

- 6-wheel differential
- More compact design
- Welded housing
- Δm = 3,630 g (122 %)

9. Material for Gears

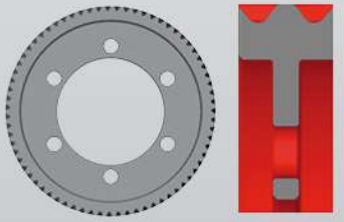


- Influence of steel cleanliness on fatigue
- Oxidic inclusions, in particular, impair performance
- Δm = 10 – 30 %, depending on load case of components and previous cleanliness level

8. Input Wheel

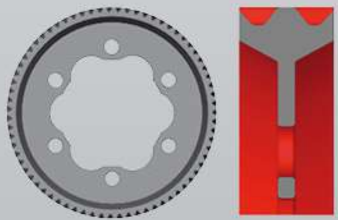
Series

- Conventional round wheel, machined on all sides
- m = 1,381 g



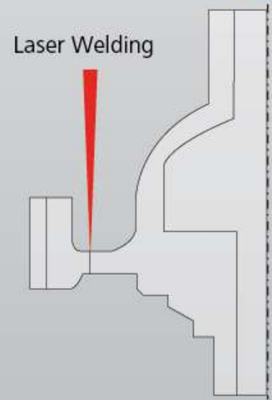
Lightweighting Proposal

- Variable wall thickness below the teeth
- Contoured piercing
- 16MnCrV7-7 (H2): Hardenability ↑ → Tooth width ↓
- Δm = 353 g (34 %)



10. Differential

Series



Lightweighting Proposal

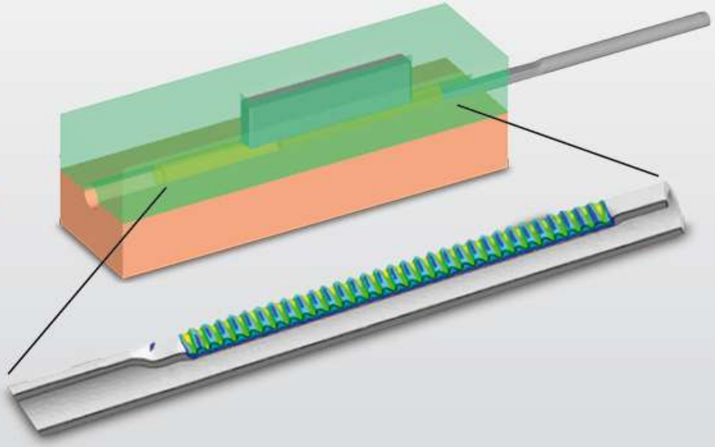
- Switch from bolts to laser welding
- Avoids double material layers
- Δm = ~1,000 g (~13 %)

Sources: 7 = AAM Metal Forming; 8 = Hirschvogel, Georgsmarienhütte; 9 = TimkenSteel; 10 = Trumpf

Selected Lightweighting Proposals

Chassis – 1

11. Steering Rack



Series

- Solid bar
- Teeth produced by machining and induction hardening
- m = 2,611 g

Lightweighting Proposal

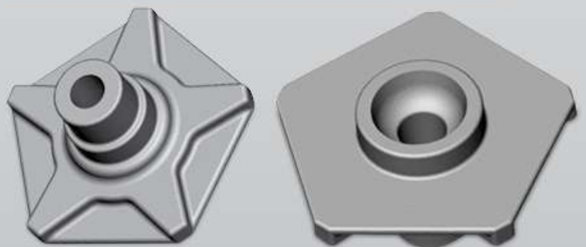
- Production from tube
- Forging of teeth with toothed punch and mandrel
- Δm = 1,338 g (95 %)

12. Wheel Hub

Series

- Induction hardened steel
- m = 1,637 g

Lightweighting Proposal A



- Contoured shape, not round
- Stiffness-increasing structures
- Δm = 436 g (36 %)

Lightweighting Proposal B

- Direct connection of brake disc to wheel hub
- No hat shape on brake disc
- Δm = ~ 400 g (+ lighter brake disc)

Sources: 11 = Yamanaka Engineering; 12 = Linamar Seissenschmidt Forging (A), Hirschvogel (B)

Selected Lightweighting Proposals

LIGHTWEIGHT**forging**

Chassis – 2

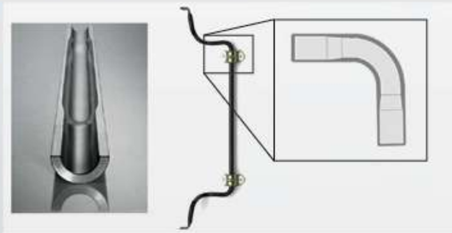
13. Stabilizer

Series

- Tube with constant wall thickness
- m = 3,880 g

Lightweighting Proposal

- Tube with variable wall thickness
- Increased thickness in corners
- Δm = 1,550 g (66.5 %)



14. Steering Knuckle

Series

- Cast iron
- m = 5,060 g

Lightweighting Proposal

- Forged aluminium
- YS = 350 MPa,
  TS = 390 MPa
- Δm = 3,320 g (191 %)

15. Damper Strut Bearing

Series

- Part comprising several steel sheets, joined with rubber bearing
- m = 960 g

Lightweighting Proposal

- Aluminium forging
- Crimped rubber bearing
- Δm = ~200 g (~25 %)

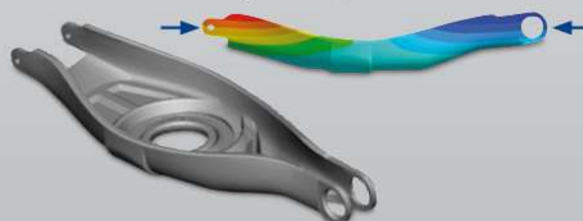
16. Rear Transverse Strut

Series

- Welded design from deep-drawn sheet metal and stamped-bent parts
- m = 3,080 g

Lightweighting Proposal

- Aluminium forging (here still in simplified form)
- Stiffness in longitudinal direction +4 %
- Δm = 310 g (11 %)



Sources: 13 = BENTELER; 14 = Hirschvogel, Lasco, Leiber, Nissan, Schuler, Setforge; 15 = Leiber, Schuler, Hirschvogel (image); 16 = Hirschvogel

Selected Lightweighting Proposals

Lightweight Potential in the Heavy-Duty Vehicle

17. Brake Carrier: Rear Axle

Series

- Forging
- m = 10,320 g

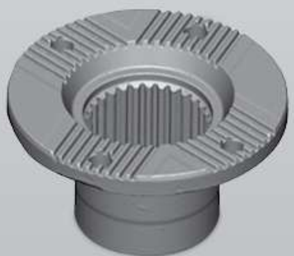
Lightweighting Proposal

- Forging with filigree structures and piercings
- Δm = 2,320 g (29 %)

18. Connecting Flange: Propeller Shaft

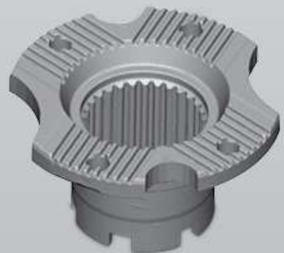
Series

- Series mass m = 4,000 g



Lightweighting Proposal

- Remove material in areas subjected to less load
- Δm = 420 g (11.7 %)



19. Countershaft Transmission

Series

- Solid shaft
- m = 23,990 g

Lightweighting Proposal

- Swaged hollow shaft starting from tube
- Δm = 6,540 g (37.5 %)

20. Fasteners

Series

M12

Lightweighting Proposal

- Downsizing by strength class 15.9U
- Lightweight head
- Δm_{HEV} = 5,600 g
- Δm_{HDV} = 1,600 g

M10

Sources: 17 = Hammerwerk Fridingen; 18 = Buderus Edelstahl; 19 = Linamar Seissenschmidt Forging; 20 = Kamax

Wide Spectrum of Quality and Special Steels –

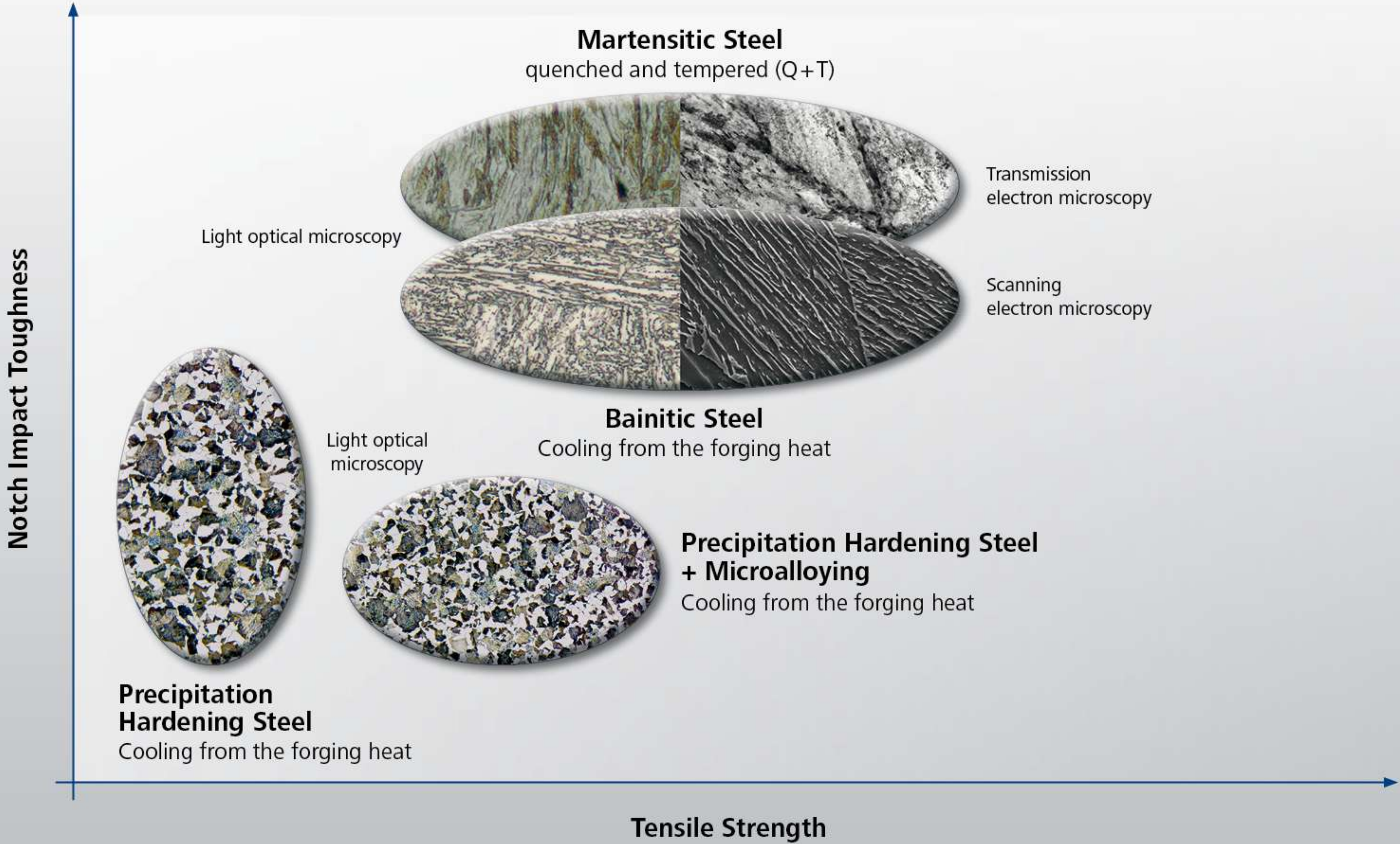
Steels with High-Strength and High Toughness

- Steel variety leads to application-oriented part design
- Combination of high strength and high toughness leads to lightweighting through materials
- Material family trees enable targeted product-based material selection

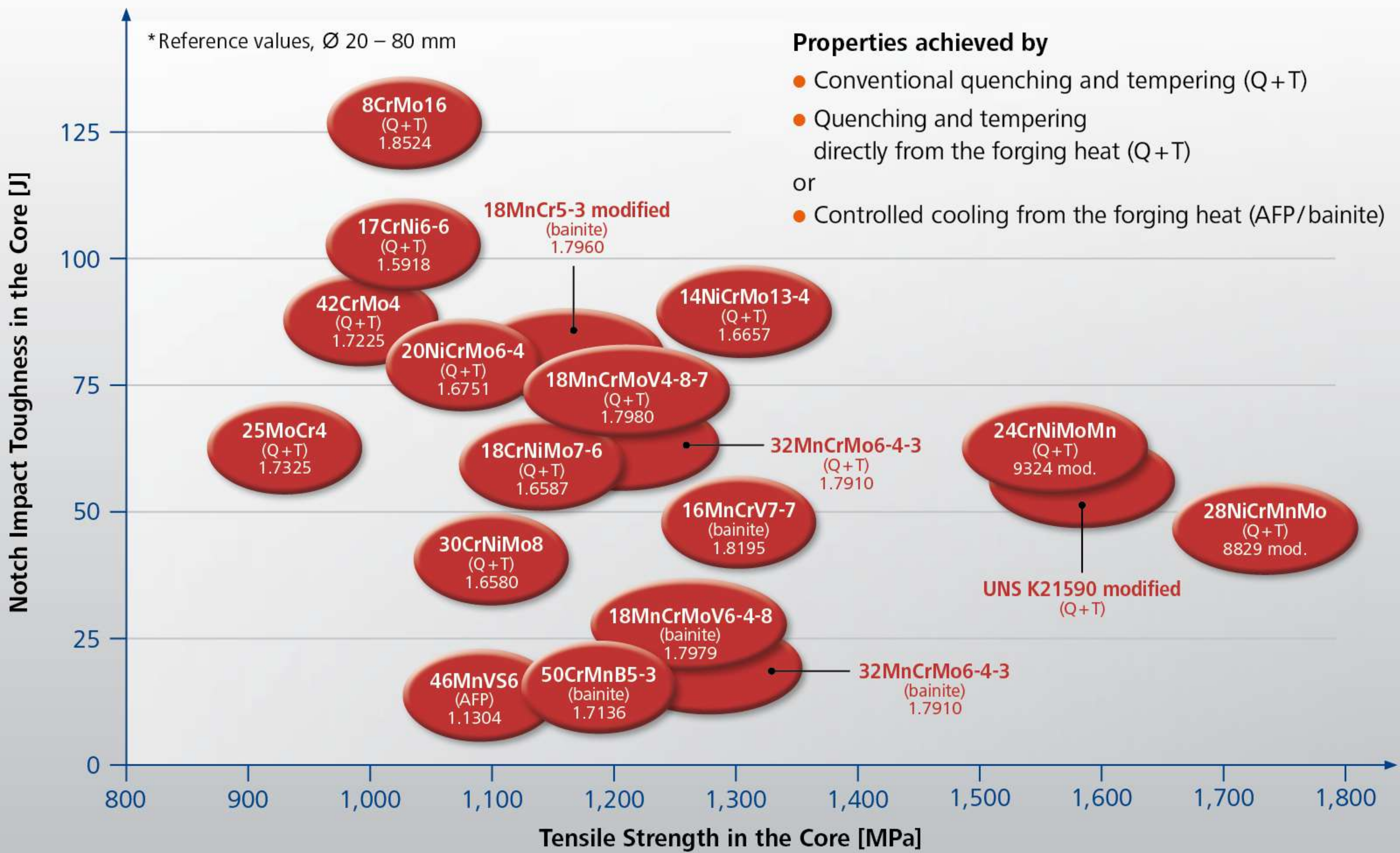
Properties of Steel Bar

LIGHTWEIGHTforging

Microstructure-dependent strength and toughness of steel bar



Material Family Tree "High-Strength Special Steels"*



Material Family Tree "Case-Hardening Steels"*

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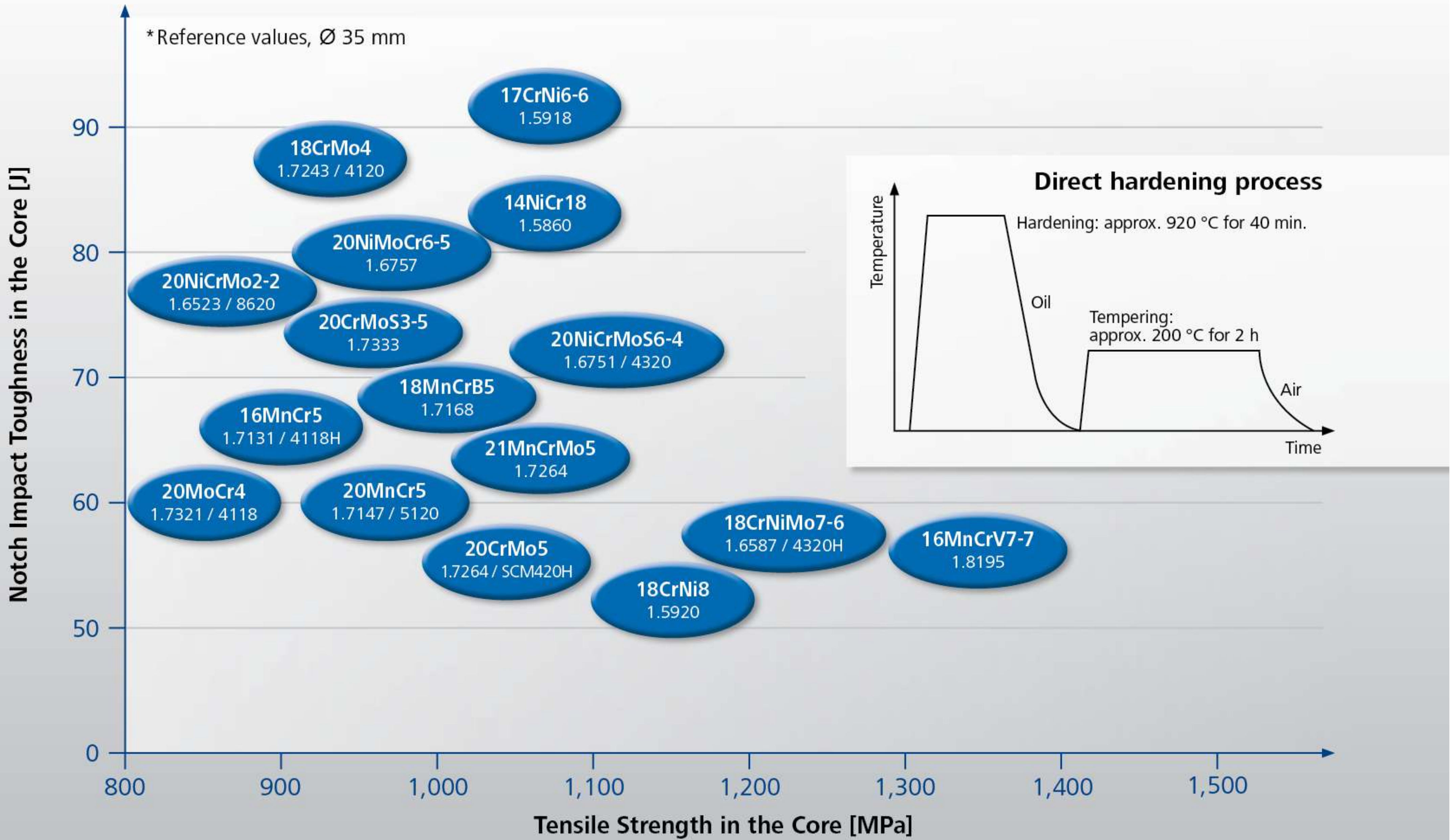
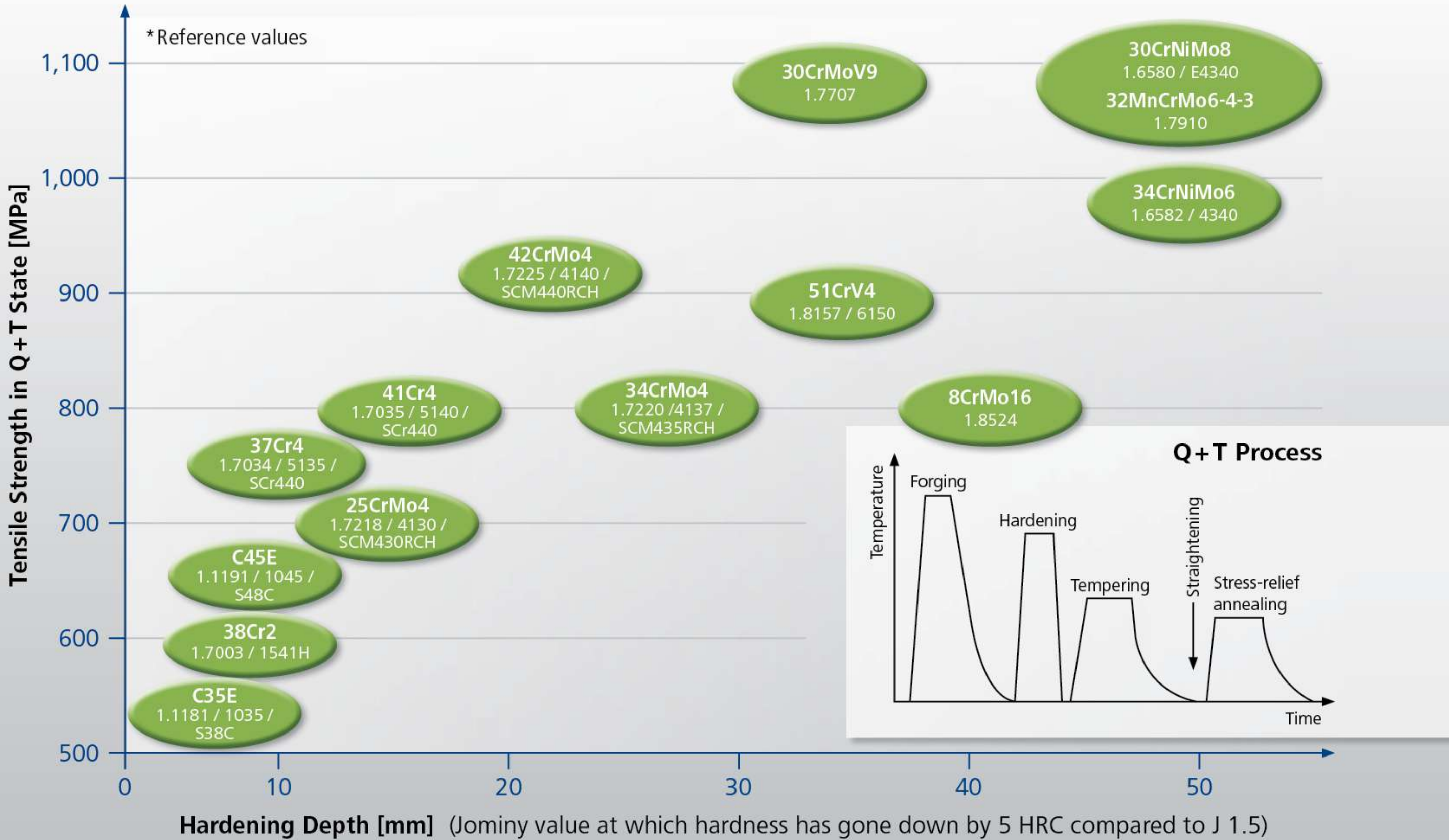


Material Family Tree "Quenched and Tempered Steels"*

LIGHTWEIGHTforging



Lightweighting with High-Strength Steels

1. Drive Shaft Differential

Series

- Case-hardening steel SCr420H
- m = 1,182 g

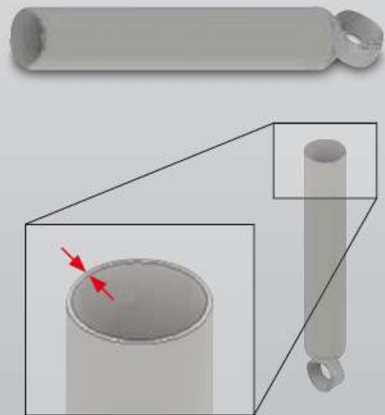
Potential

- High-strength case-hardening steel 16MnCrV7-7 (H2) and improved manufacturing enable reduction in cross section
- m = 875 g
- Δm = 307 g (35 %)

2. Shock Absorber

Series

- Steel tube e.g. E235 (1.0308)
- Wall thickness 2.8 mm
- m = 1,054 g



Potential

- High-strength tube FB590
- Wall thickness 2.0 mm
- m = 804 g
- Δm = 250 g (31 %)

3. Wheel Carrier: Front Left

Series

- Cast iron (TS = 400 – 600 MPa)
- m = 5,060 g

Potential

- Steel forging made of ferritic-pearlitic or bainitic steel
- TS = 1,100 MPa
- m ≈ 4,100 g
- Δm ≈ 960 g (23 %)

4. Conrod

Series

- 23MnVS3
- m = 572 g

Potential

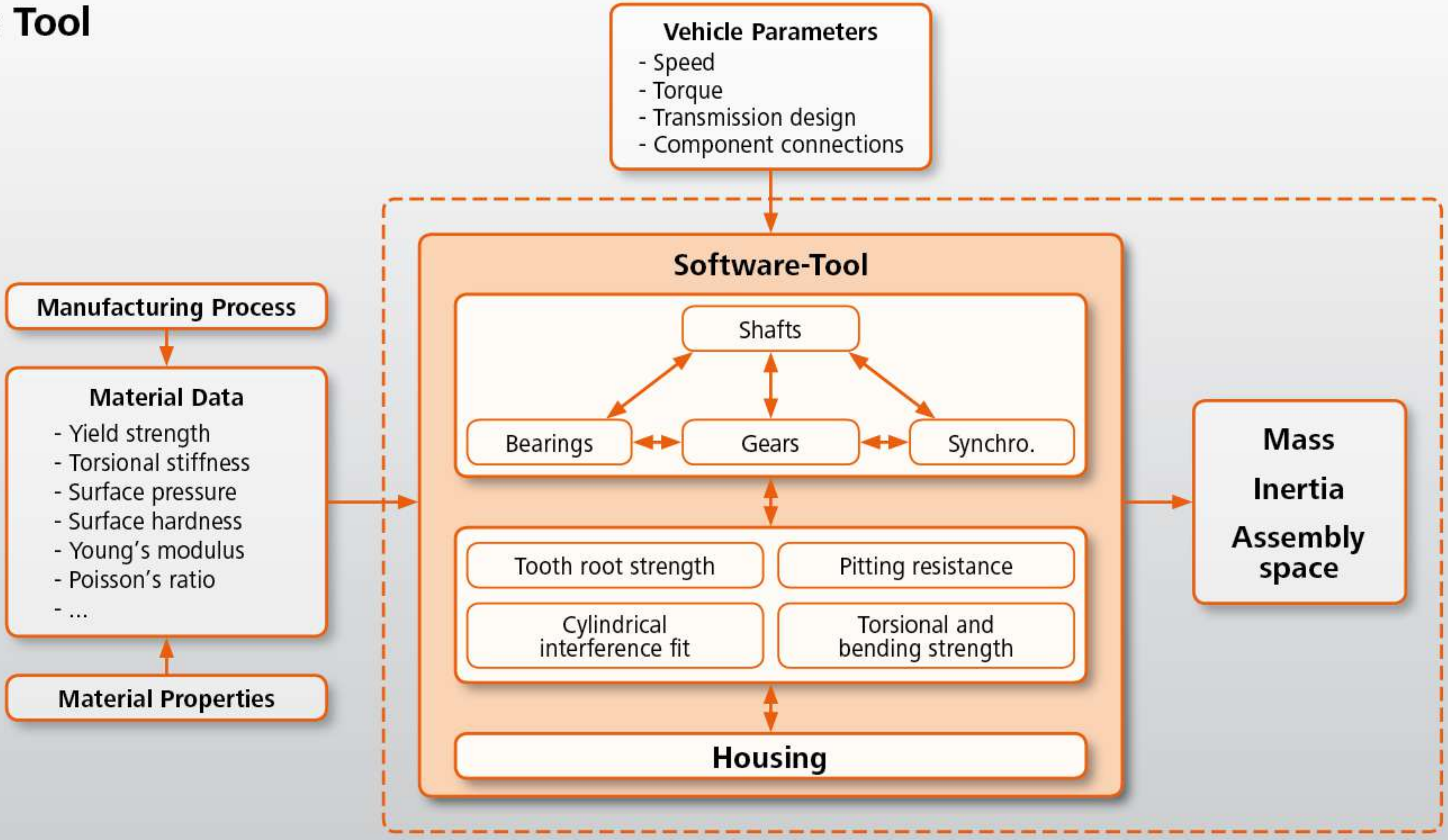
- High-strength steel 36/46MnVS6Mod → Δm ≈ 35 %
- Other high-strength steels: 27/30/38 MnVS6 or similar; 16MnCrV7-7, S40C + P

Sources: 1 = Hirschvogel, Georgsmarienhütte; 2 = BENTELER; 3 = ArcelorMittal;
4 = TimkenSteel, Nissan Motor, Deutsche Edelstahlwerke, Nippon Steel & Sumitomo Metal, Schmiedetechnik Plettenberg, Georgsmarienhütte, Saarstahl, ArcelorMittal

Lightweighting Potential of High-Performance Steels

LIGHTWEIGHTforging

Software Tool



- Dimensioning of the shafts according to DIN 743
- Dimensioning of the gears according to DIN 3990
- Dimensioning of the planetary gear according to VDI 2157
- Dimensioning of cylindrical interference fit according to DIN 7190

Source: Institute of Product Engineering Karlsruhe (IPEK)

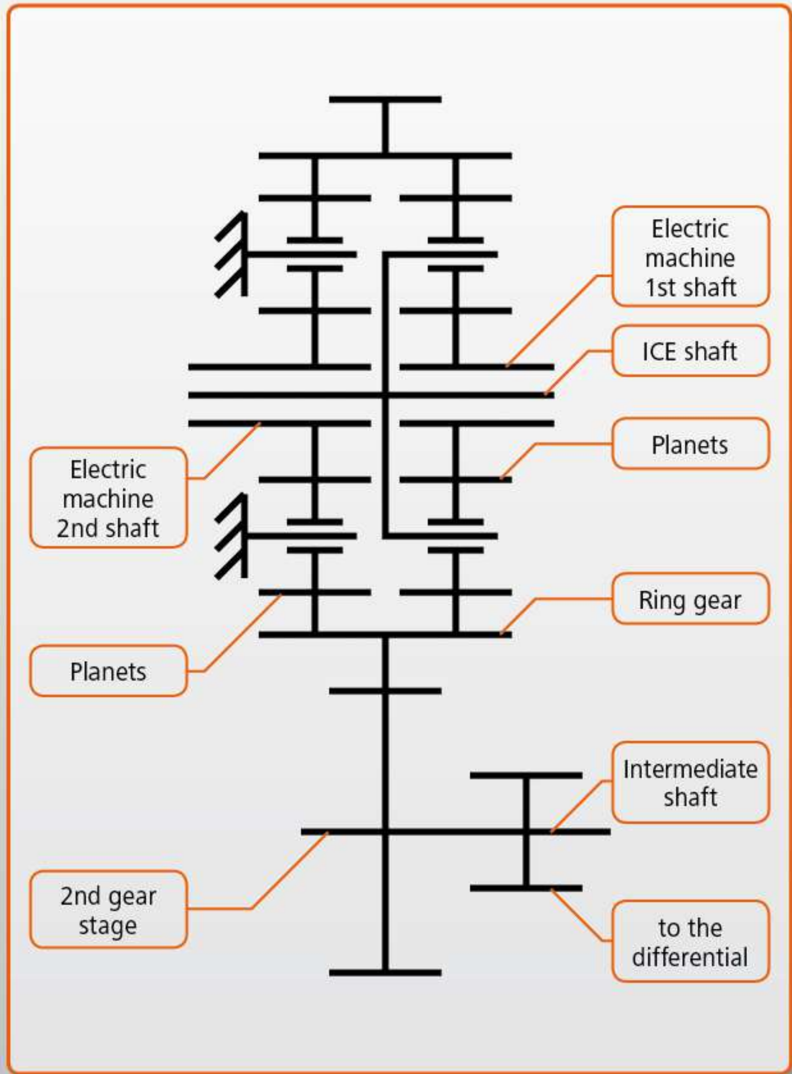
Lightweighting Potential of High-Performance Steels

LIGHTWEIGHTforging

Software Tool

- Development of a model for rough design / calculation of transmission design and mass
- Model created and verified for:
  - e-hybrid CVT, SCr420H, SCM420H (similar to 25CrMo4)
  - 12-speed truck transmission, 25MoCrS4, 30MnSiV6, 20MoCrS4
- Evaluation of the influencing variables of the material characteristics for transmission dimensioning
- Examination of the real influences of high-strength steels
- Evaluation of the "soft influencing factors" from the transmission standard ISO 6336, Part 5

Functional layout of the e-hybrid CVT



Source: Institute of Product Engineering Karlsruhe (IPEK)

Lightweighting Potential of High-Performance Steels

LIGHTWEIGHTforging

Software Tool: e-hybrid CVT

Software Tool planetary gearbox

IPEK
Institut für Produktentwicklung
am Karlsruher Institut für Technologie

Input variables

Dimension gear wheels

σ_{HP}	Permitted pitting resistance	1500	1500	N/mm^2
σ_F	Permitted tooth strenght	1000	1000	N/mm^2
E	E-Modul gear wheels	206000	206000	N/mm^2

Dimension gear shafts

τ_{tw}	Permitted swelling torsional tension	270	270	N/mm^2
τ_{bw}	Permitted bending fatigue strength	450	450	N/mm^2

Engine parameters

Power combustion engine	114	kW
Power electric engine	105	kW
Power generator	50	kW
Input torque: petrol engine	206	Nm
Input torque: electric engine	270	Nm
Input torque: generator	139	Nm
Input speed at maximum power of the combustion engine	4500	1/min

Total weight of the gear box

Weight of the reference gear box	104,1	kg
Weight of the optimized gear box	104,1	kg
Weight saving in kg	0,000	kg
Weight savin in %	0,000	%

Inertia of the shafts and gear wheels

Inertia of the reference gear box	0,0019	$kg*m^2$
Inertia of the optimized gear box	0,0019	$kg*m^2$
Inertia saving in $kg*m^2$	0,000	$kg*m^2$
Inertia saving in %	0,000	%

Shaft length

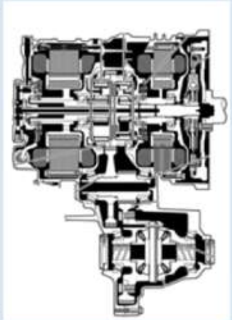
	reference	optimized	saving	
VKM-shaft	173,5	173,50	0,00	mm
MG1-shaft	89	89,00	0,00	mm
MG2-shaft Inside	170	170,00	0,00	mm
MG2-shaft Outside	76	76,00	0,00	mm
Hollow wheel shaft	81	81,00	0,00	mm
Intermediate shaft	143	143,00	0,00	mm

GT: pitting resistance (flank pressure)
ZT: tooth strenght (tooth root tension)

Housing modification

0,00 mm

0,00 mm



Width: const.

Total weight change
0,000 kg

Housing weight

	reference	optimized	saving	
Width	550	550,00	0,00	mm
Length	435,00	435,00	0,00	mm
Height	405,00	405,00	0,00	mm
Weight	26,833	26,833	0,000	kg

shaft weight

	reference	optimized	saving	
VKM-shaft	0,674	0,674	0,000	kg
MG1-shaft	1,298	1,298	0,000	kg
MG2-shaft Inside	0,966	0,966	0,000	kg
MG2-shaft Outside	1,160	1,160	0,000	kg
Hollow wheel shaft	3,209	3,209	0,000	kg
Intermediate shaft	1,151	1,151	0,000	kg

Gear wheel width

	sun gear_1	planetary gear	ring gear_1	sun gear_2	planetary gear	ring gear_2	GS1_Z1	GS1_Z2	GS2_Z1	GS2_Z2	
Reference gear box	30,00	28,50	29,50	21,00	17,20	23,00	25,00	25,00	38,70	33,00	mm
Optimized gear box	30,00	28,50	29,50	21,00	17,20	23,00	25,00	25,00	38,70	33,00	mm
Width savings	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	mm
Dimension after	GT	GT	ZT	GT	GT	ZT	ZT	ZT	ZT	ZT	

Gear wheel mass

	sun gear_1	planetary gear	ring gear_1	sun gear_2	planetary gear	ring gear_2	GS1_Z1	GS1_Z2	GS2_Z1	GS2_Z2	
Reference gear box	0,262	0,785	0,222	0,209	0,267	0,131	0,585	2,300	1,504	3,560	kg
Optimizied gear box	0,262	0,785	0,222	0,209	0,267	0,131	0,585	2,300	1,504	3,560	kg
Mass savings	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	kg

Input Values:
- pitting resistance
- tooth root stress
- E module
- torsional tension, pulsating
- bending fatigue strength
- power
- torque
- rotational speed

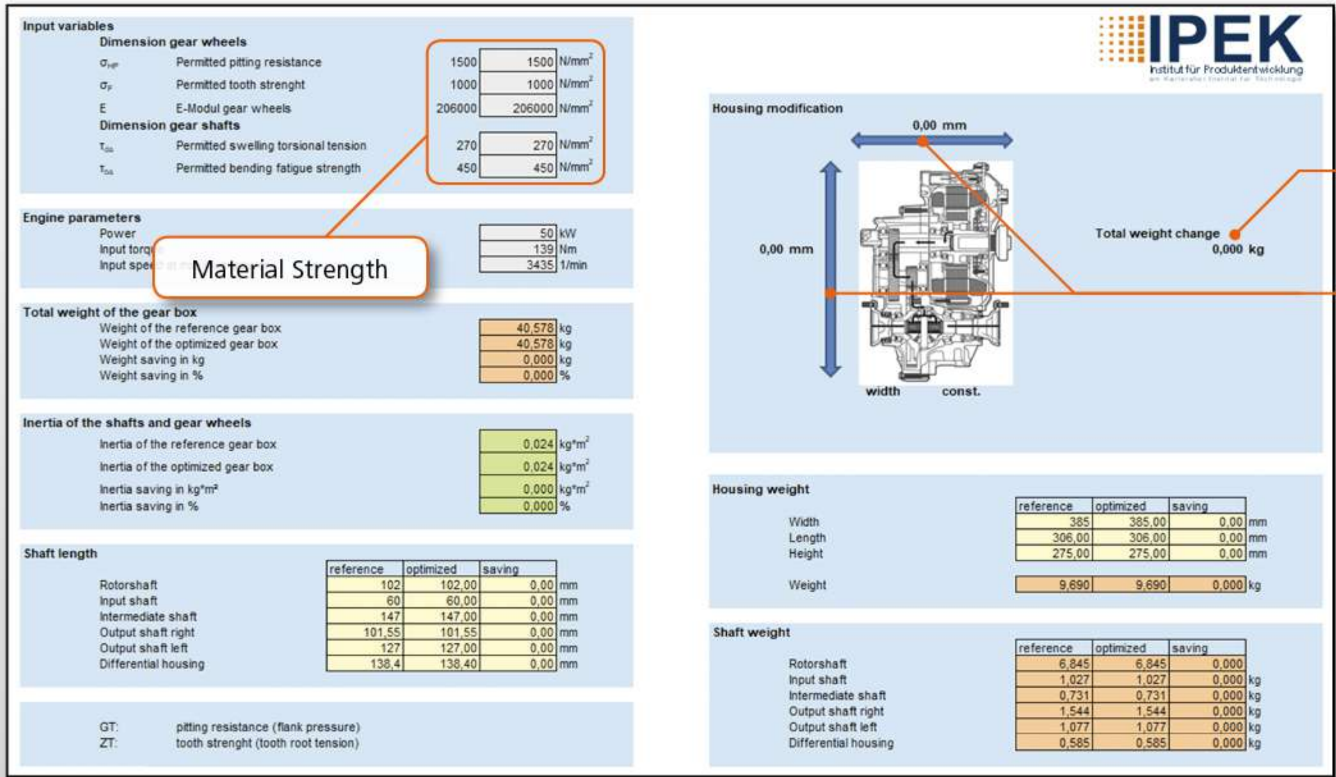
Output Values:
- Transmission weight
- Reduction in transmission weight

Output Values:
- Transmission width
- Transmission height
- Transmission length
- Reduction in transmission geometry

Output Values:
- inertia
- Reduction in transmission inertia

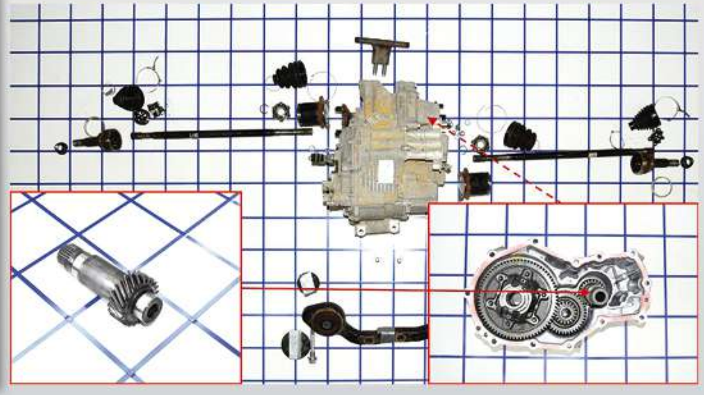
Source: Institute of Product Engineering Karlsruhe (IPEK)

IPEK Transmission Study – Rear Axle Transmission



Change in weight depending on material properties

Change in dimension depending on material properties

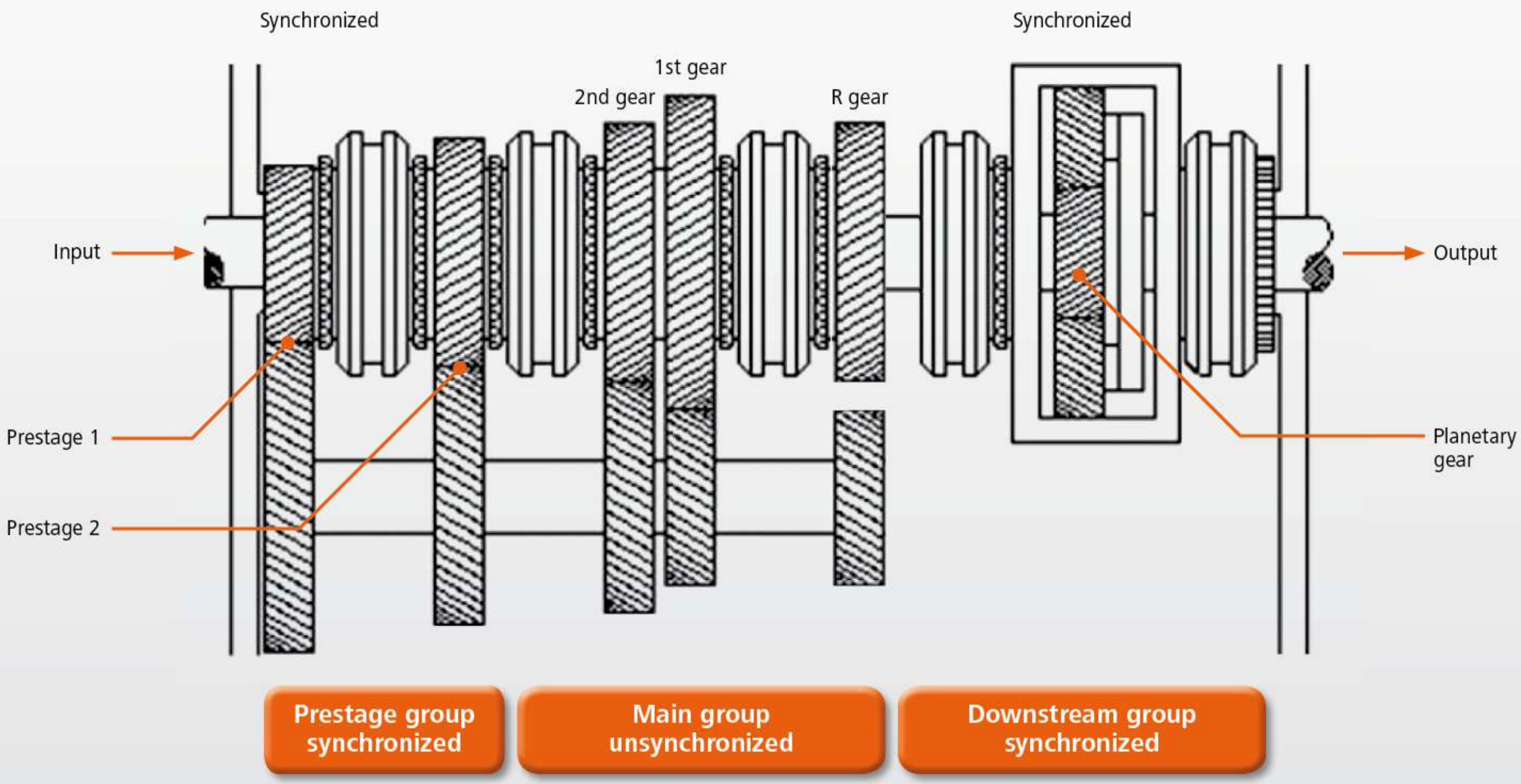


Tooth flank strength/MPa	Tooth root strength/MPa	Pulsating torsional strength/MPa	Bending fatigue strength/MPa	Δ Weight/g
1,500 → 1,800	1,000	270	450	129
1,500 → 1,800	1,000 → 1,200	270	450	-1,216
1,500 → 1,800	1,000 → 1,200	270 → 324	450	-1,722
1,500 → 1,800	1,000 → 1,200	270 → 324	450 → 450	-1,875

Source: Institute of Product Engineering Karlsruhe (IPEK)

LIGHTWEIGHTforging

Functional Layout of the HDV Transmission



Source: Institute of Product Engineering Karlsruhe (IPEK)

Lightweighting Potential of High-Performance Steels

LIGHTWEIGHT**forging**

Software Tool: HDV Transmission

Software Tool commercial vehicle

IPEK
Institute of Product Engineering
at Karlsruhe Institute of Technology

Input variables

Dimension gear wheels

σ_{HP}	Permitted pitting resistance	1500	1500	N/mm²
σ_F	Permitted tooth strenght	1000	1000	N/mm²
E	E-Modul gear wheels	206000	206000	N/mm²

Dimension gear shafts

τ_{Sch}	Permitted swelling torsional tension	430	430	N/mm²
τ_{bW}	Permitted bending fatigue strength	450	450	N/mm²

Engine parameters

Input torque	3300	Nm
Input speed at maximum power	2000	1/min

Total weight of the gear box

Weight of the reference gear box	283,3	kg
Weight of the optimized gear box	283,3	kg
Weight saving in kg	0,0	kg
Weight savin in %	0,0	%

Inertia of the shafts and gear wheels

Inertia of the reference gear box	0,143	kg*m²
Inertia of the optimized gear box	0,143	kg*m²
Inertia saving in kg*m²	0,000	kg*m²
Inertia saving in %	0,0	%

Shaft length

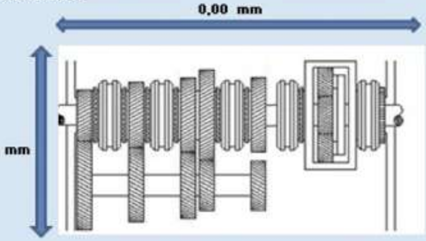
	reference	optimized	saving	
Input shaft	446,50	446,50	0,00	mm
Forward shaft	544,00	544,00	0,00	mm
Forward 1+2	165,00	165,00	0,00	mm
Forward 3	128,00	128,00	0,00	mm
Intermediate shaft	517,00	517,00	0,00	mm
Planetary shaft	64,50	64,50	0,00	mm
Reversal of rotation	118,50	118,50	0,00	mm
Output shaft	288,00	288,00	0,00	mm

GT: pitting resistance (flank pressure)
ZT: tooth strenght (tooth root tension)

Housing modification

0,00 mm

0,00 mm



width: 0,00 mm

Total weight change
0,000 kg

Housing weight

	reference	optimized	saving	
Width	556	556,00	0,00	mm
Length	917,00	917,00	0,00	mm
Height	550,00	550,00	0,00	mm
Weight	72,120	72,120	0,000	kg

Shaft weight

	reference	optimized	saving	
Input shaft	9,51	9,51	0,00	kg
Forward shaft	16,42	16,42	0,00	kg
Forward 1+2	3,18	3,18	0,00	
Forward 3	3,49	3,49	0,00	
Intermediate shaft	14,81	14,81	0,00	
Planetary shaft	0,33	0,33	0,00	kg
Reversal of rotation	0,47	0,47	0,00	kg
Output shaft	21,30	21,30	0,00	kg

Gear wheel width

	Vor1 Z1	Vor1 Z2	Vor2 Z1	Vor2 Z2	G3 Z1	G3 Z2	G4 Z1	G4 Z2	R1	R2	R3	sun gear	planetary ge	ring gear	
Reference gear box	56,50	56,00	54,50	54,00	61,50	61,50	80,00	77,00	53,00	49,00	48,00	44,00	42,00	50,00	mm
Optimized gear box	56,50	56,00	54,50	54,00	61,50	61,50	80,00	77,00	53,00	49,00	48,00	44,00	42,00	50,00	mm
Width savings	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	mm
Dimension after	GT	GT	GT	GT	GT	ZT	GT	ZT	GT	GT	ZT	GT	GT	ZT	

Gear wheel mass

	Vor1 Z1	Vor1 Z2	Vor2 Z1	Vor2 Z2	G3 Z1	G3 Z2	G4 Z1	G4 Z2	R1	R2	R3	sun gear	planetary ge	ring gear	
Reference gear box	8,06	3,42	5,76	5,10	1,53	7,78	1,21	12,58	0,46	3,10	6,34	0,76	1,31	4,60	kg
Optimizied gear box	8,06	3,41	5,76	5,10	1,53	7,78	1,21	12,58	0,46	3,10	6,34	0,76	1,30	4,60	kg
Mass savings	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	kg

Input Values:
- pitting resistance
- tooth root stress
- E module
- torsional tension, pulsating
- bending fatigue strength
- torque
- rotational speed

Output Values:
- Transmission weight
- Reduction in transmission weight

Output Values:
- Transmission width
- Transmission height
- Transmission length
- Reduction in transmission geometry

Output Values:
- inertia
- Reduction in transmission inertia reduced of 1st gear

Source: Institute of Product Engineering Karlsruhe (IPEK)

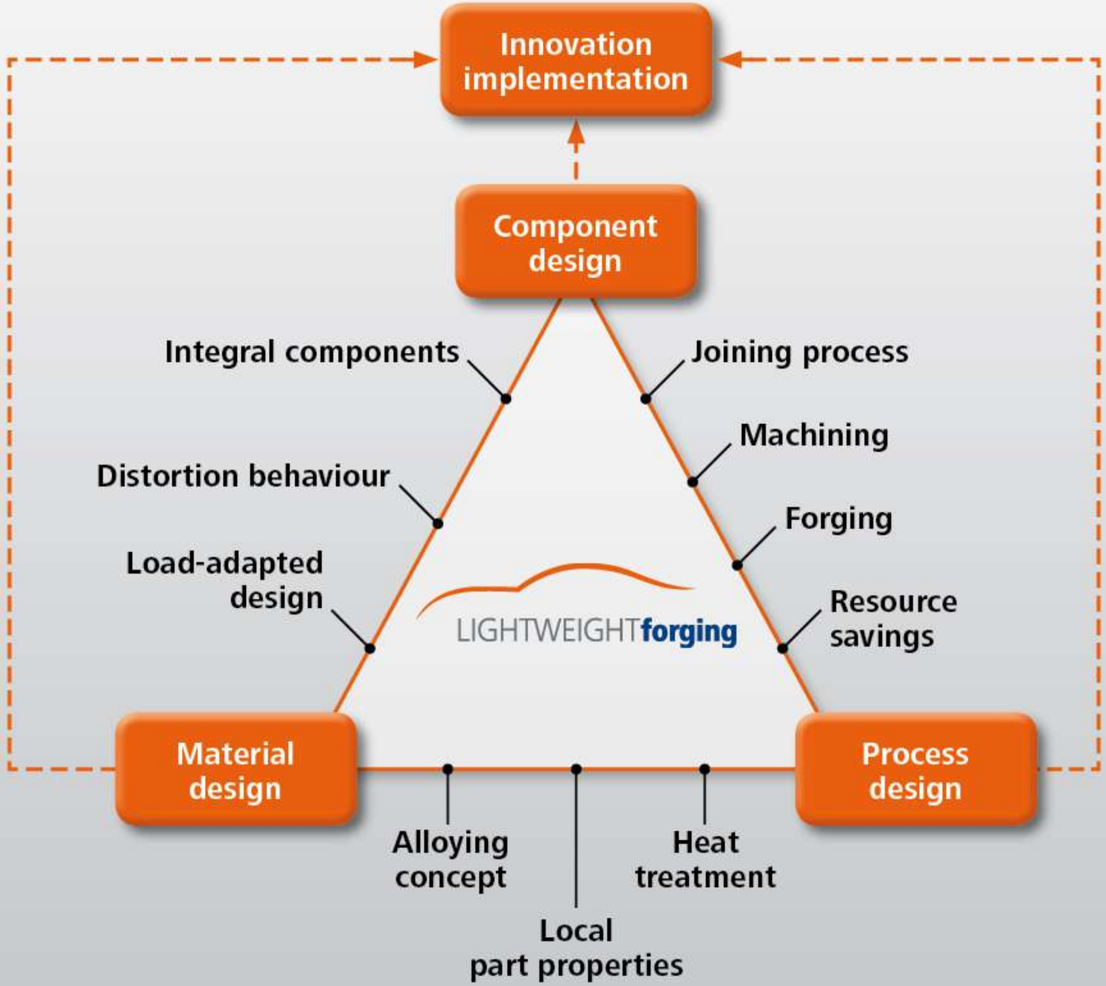
Lightweighting Potential of High-Performance Steels

Results

- Through optimization of the material properties by 10 %, the lightweight potential could be:
  - up to approx. 3.5 kg for the e-hybrid CVT
  - up to approx. 17 kg for the 12-speed truck transmission
- The model also shows that:
  a further increase in the material strength
  of the gear wheels and shafts
  may lead to additional weight savings

Research – Today and Tomorrow

The "Lightweight Forging" Research Network



The Research Network entitled "Lightweight Forging – Innovation Network for Technological Progress in Part, Process and Material Design for Forged Parts in Automotive Technology" was generated from the idea competition "Leading Technologies for SMEs" held by the Industrial Collective Research program (IGF) of the Federal Ministry for Economic Affairs and Energy (BMWi) via the German Federation of Industrial Research Associations (AiF).

▶ **Goal: To use new steel materials, part designs and production methods to also make the car powertrain – from the engine to the transmission and wheel bearings – even lighter, while still fulfilling the stringent requirements with regard to service life.**

Research – Today and Tomorrow

Multi-Component Gearwheels

Material	18CrNiMo7-6	18CrNiMo7-6	18CrNiMo7-6
Geometry	Fully machined solid body	4 x boreholes	Circumferential groove
Production process	Turned	Turned/milled	Turned/milled
			
Weight reduction	0 %	-25 %	-25 %
Torque (static)	794 Nm* / 889 Nm**	192 Nm*	333 Nm*

Material	DC04 (sheet metal)	Dual-phase steel	C15
Geometry	Lightweight structure	Lightweight structure	Lightweight structure
Production process	Deep-drawn	Blanked sheet/stacked	Joined by forging
			
Weight reduction	-44.5 %	-30.5 %	-30 %
Torque (static)	433 Nm**	627 Nm* / 776 Nm**	1,200 Nm

* Joined during quenching / ** Joined during tempering

Research – Today and Tomorrow

The Research Associations

The Research Network has been financed since 01.05.2015 and will continue to be financed until 31.10.2019...

FOSTA	AWT Arbeitsgemeinschaft Wärmebehandlung + Werkstofftechnik e.V.	FVA Forschungsvereinigung Antriebstechnik e.V.	Forschungsgesellschaft Stahlverformung e. V. FSV AiF Mitglied
Research Association for Steel Application (Forschungsvereinigung Stahlanwendung e. V. – FOSTA), which serves as the lead institution	Heat Treatment and Material Engineering Association (Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V. – AWT), Bremen	Research Association for Drive Technology (Forschungsvereinigung Antriebstechnik e. V. – FVA), Frankfurt	Research Association of Steel Forming (Forschungsgesellschaft Stahlverformung e. V. – FSV), Hagen

... from funds of the Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie – BMWi) via the German Federation of Industrial Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e. V. – AiF).

Building on the results from Phase I and II, further lightweighting potential is expected in approx. two years. Additional results can only be ensured by scientifically verifying the dynamic load of the new materials from the five research projects that commenced in May 2015. The Lightweight Forging Initiative expects that new weight optimization possibilities shall emerge from the Research Network.

Transfer of Findings

- Current information at **www.LIGHTWEIGHTforging.com**
- Publications
- Presentation events and exhibitions
- “Lightweight Forging” TechDays at automotive companies and system suppliers
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