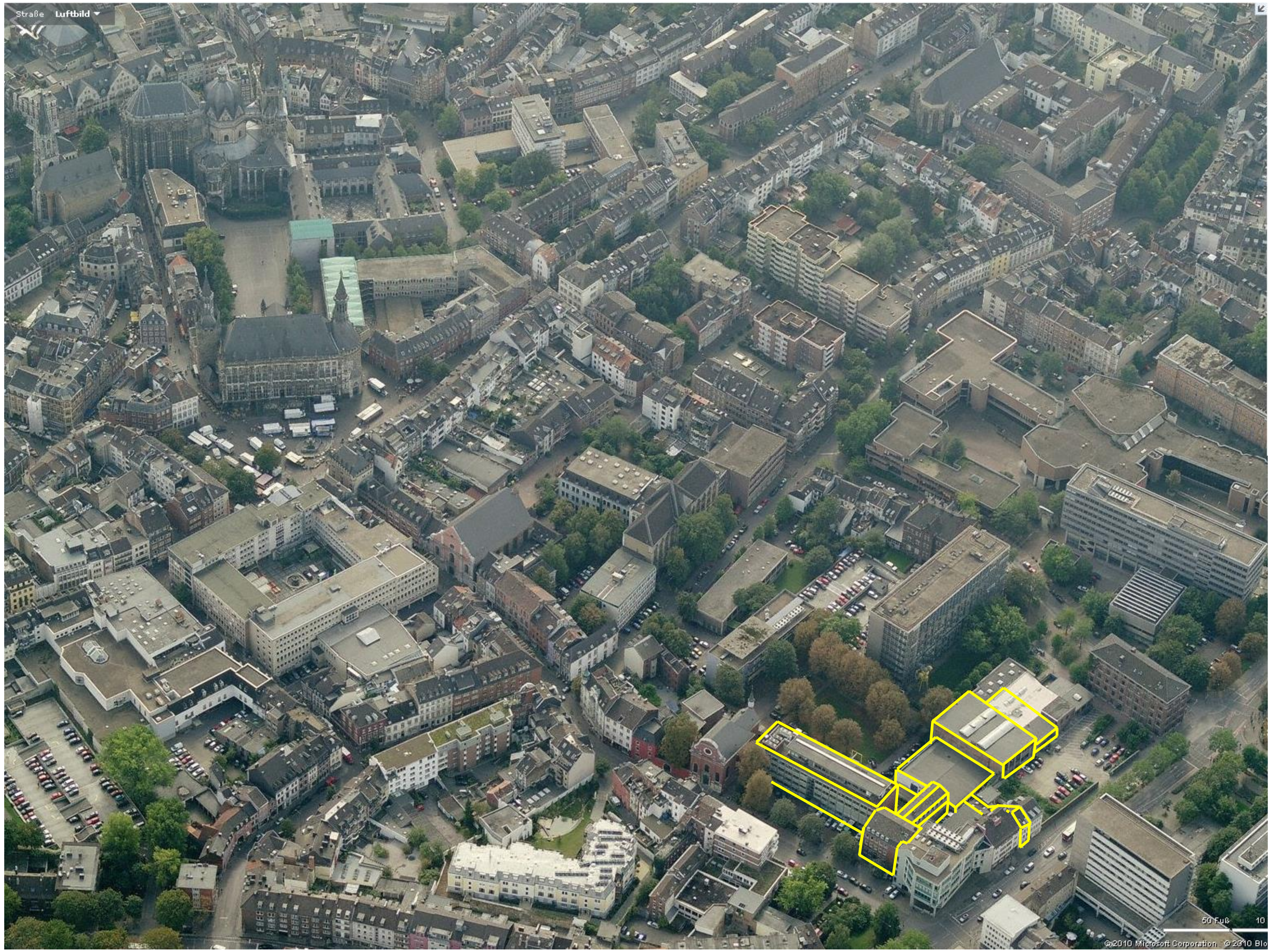
Aachen, 25.09.2014, 4. AMAP Kolloquium

Joining challenges in automotive lightweight applications

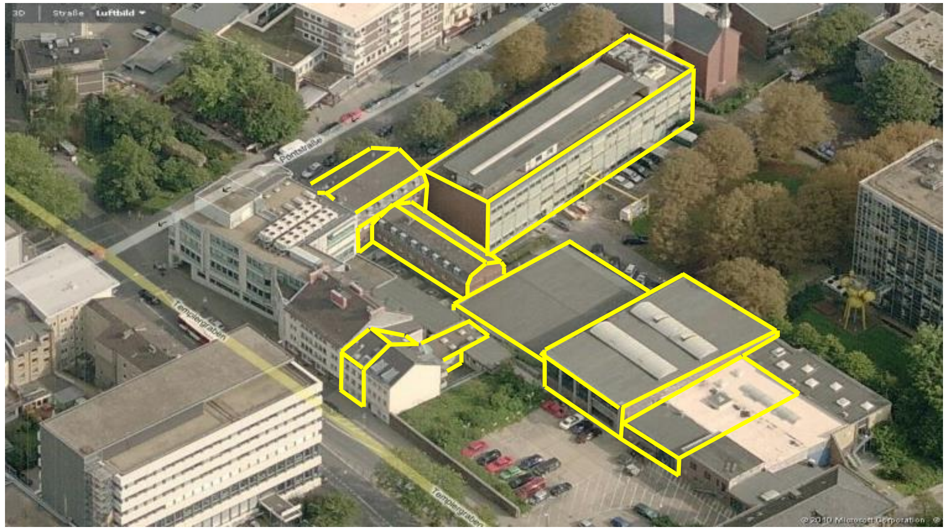
Uwe Reisgen
Christoph Geffers

- Introduction
- Motivation
- Lightweight design and multi-material mix
- Challenges to joining technology
- Composite design and multi-material mix in production
- Summary

- Introduction
- Motivation
- Lightweight design and multi-material mix
- Challenges to joining technology
- Composite design and multi-material mix in production
- Summary



Located in the center of Aachen



Univ.-Prof. Dr.-Ing. U. Reisgen

- Head of Institute -

Employees:

- 30 scientific staff
- 25 non-scientific staff
- 5 trainees
- 40 student assistants

Budget:

- ca. 4.5 million €
  (80 % third party funds)

Space for tests and laboratory :

- ca. 2700 qm

Teaching:

- Welding and Joining Technology for Bachelor und Master students
- International welding engineer (IWE)

ISF - Welding and Joining Institute

Univ.-Prof. Dr.-Ing. U. Reisgen
- Head of Institute -

Operations (R&D)

A: Arc Welding

Dipl.-Ing. K. Willms
- Head of Department -

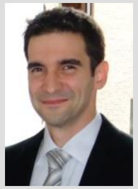
B: Beam Welding

Dr.-Ing. S. Olschok
- Head of Department -

C: Cold Technologies

Dipl.-Ing. A. Schiebahn
- Head of Department -

Operations (Industry)



FEF GmbH

Dipl.-Ing. C. Geffers
- Industrial Solutions & Services -

Administration & Finance

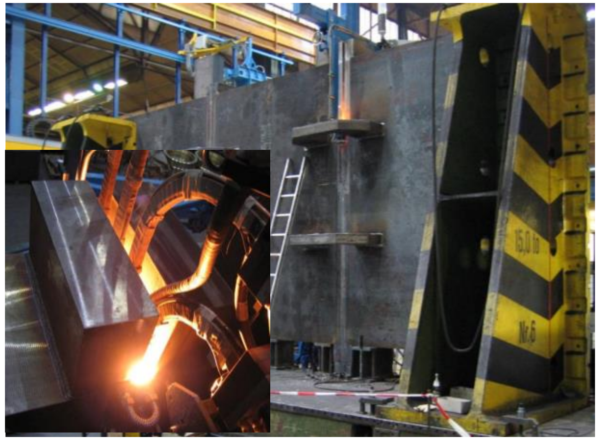
Dipl.-Kfm. (FH) R. Löhr

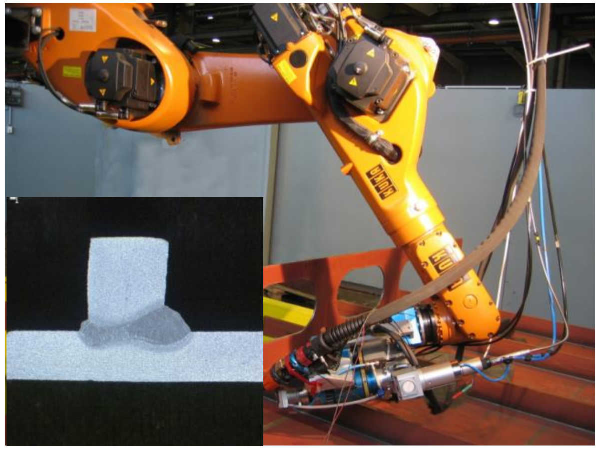
WELDING AND JOINING INSTITUTE RWTH AACHEN UNIVERSITY

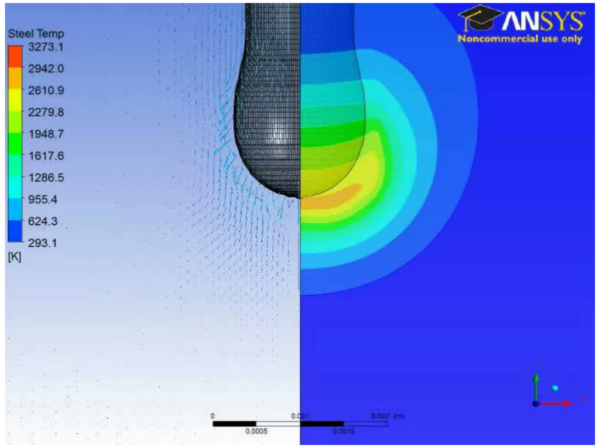
Organisational Chart

Forschungs- und Entwicklungsgesellschaft Fügetechnik GmbH

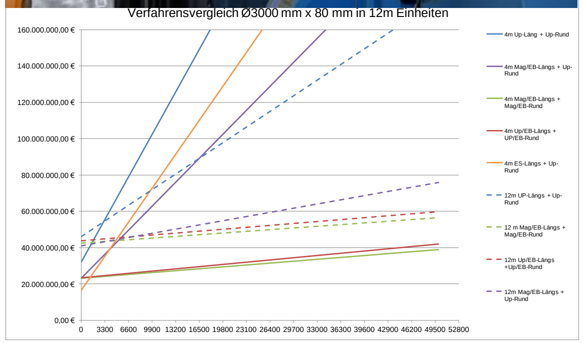
- **Arc Welding**
  - Gas Metal Arc Welding
  - TIG-, Plasma-, SA-Welding
  - Surfacing
  - Robotic/Sensoric
- **Beam Welding**
  - Laser Beam Welding
  - Electron Beam Welding
  - Health and Work Safety
- **Cold Technologies**
  - Adhesive Bonding
  - Resistance Welding
  - Friction Stir Welding
  - Ultrasonic Welding
  - Simulation and Modelling



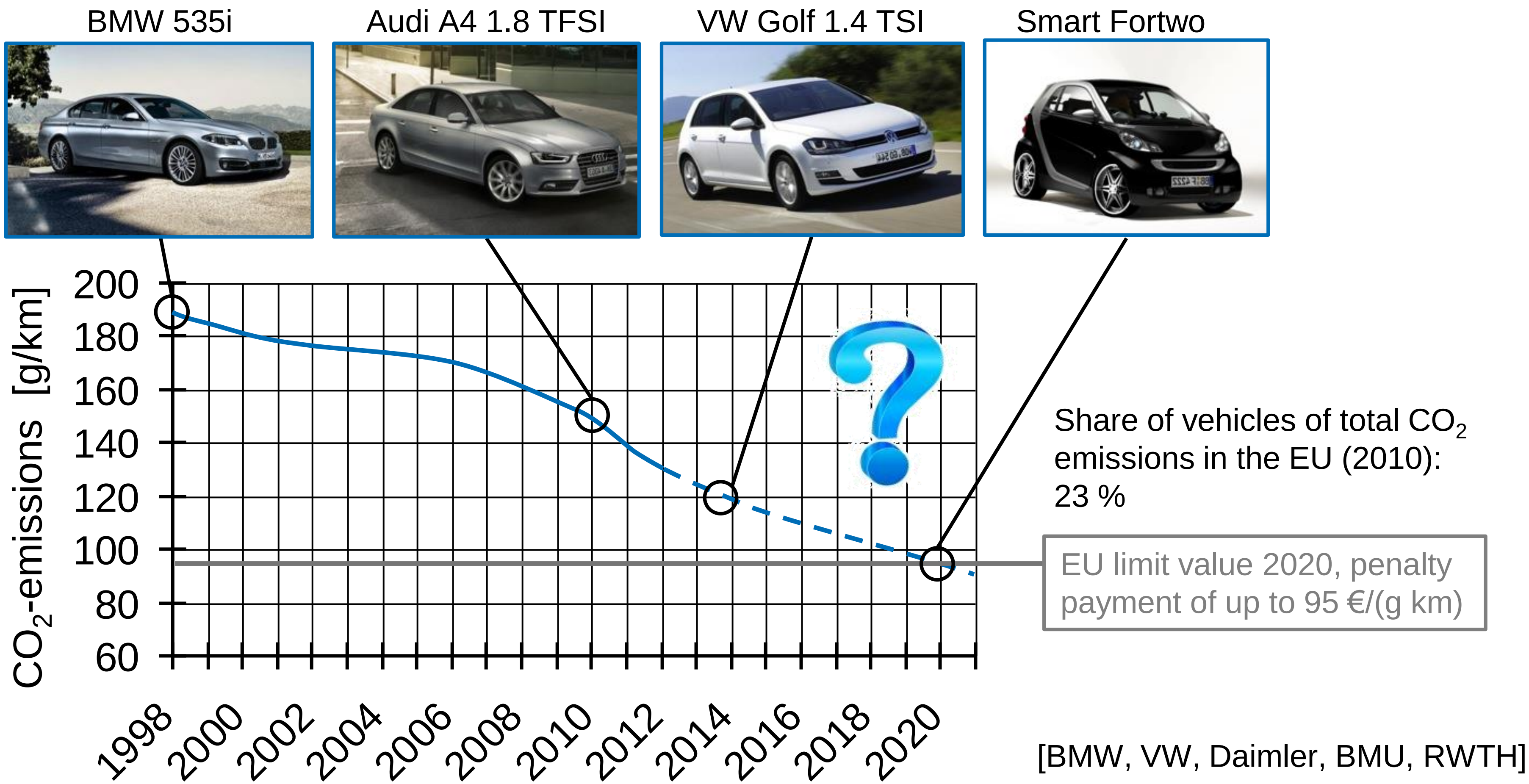




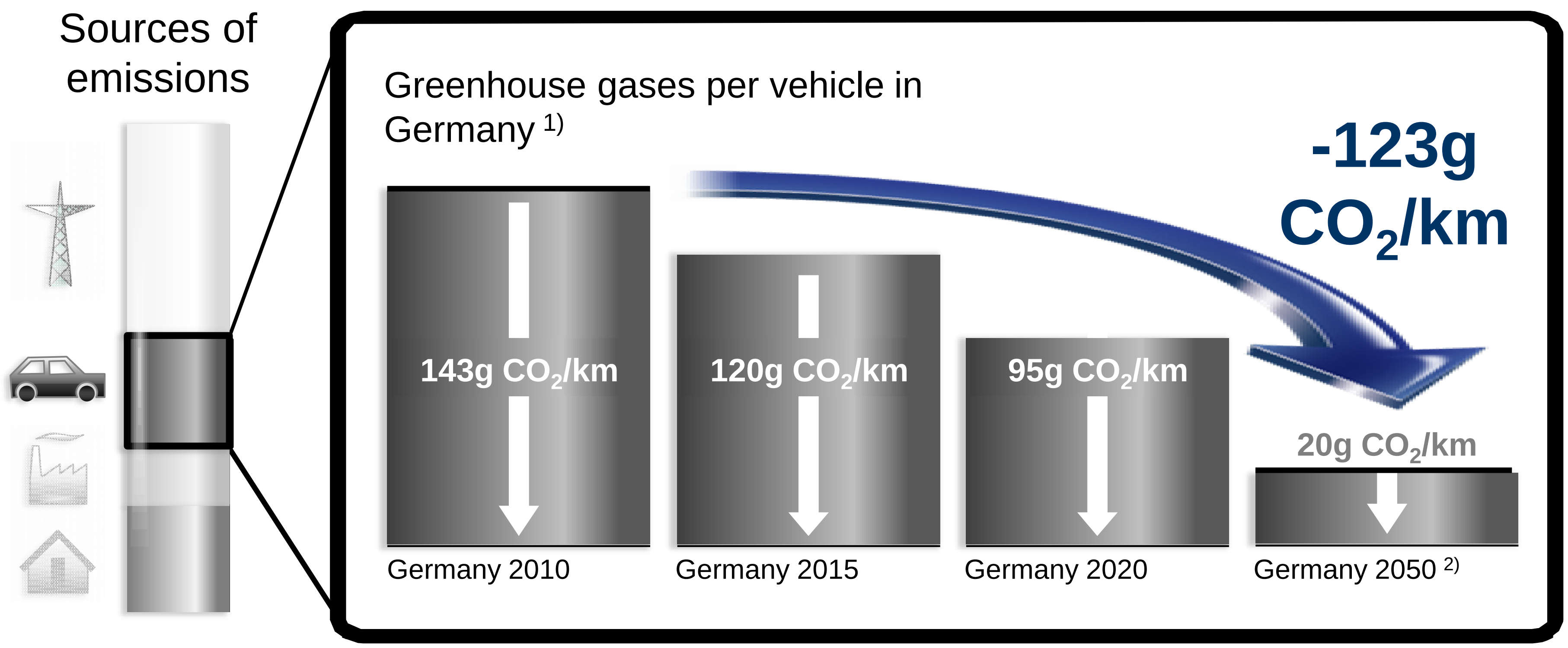
- Analysis of welding processes and optimization
- Development of cost-efficient welding processes and implementation
  - Consulting by our specialists
  - Consideration of requirements and needs of the client
  - The total manufacturing chain is considered
  - Only what the client needs ….
- Support for automation tasks
- Technology support on-site
  - During commissioning
  - During production
  - “Emergency services“
- Work-Shops
- Prototypes and pre-series
- Support in the search for competent system suppliers



- Introduction
- **Motivation**
- Lightweight design and multi-material mix
- Challenges to joining technology
- Composite design and multi-material mix in production
- Summary



Average fleet emissions and assignment of CO2 emissions of different vehicle classes

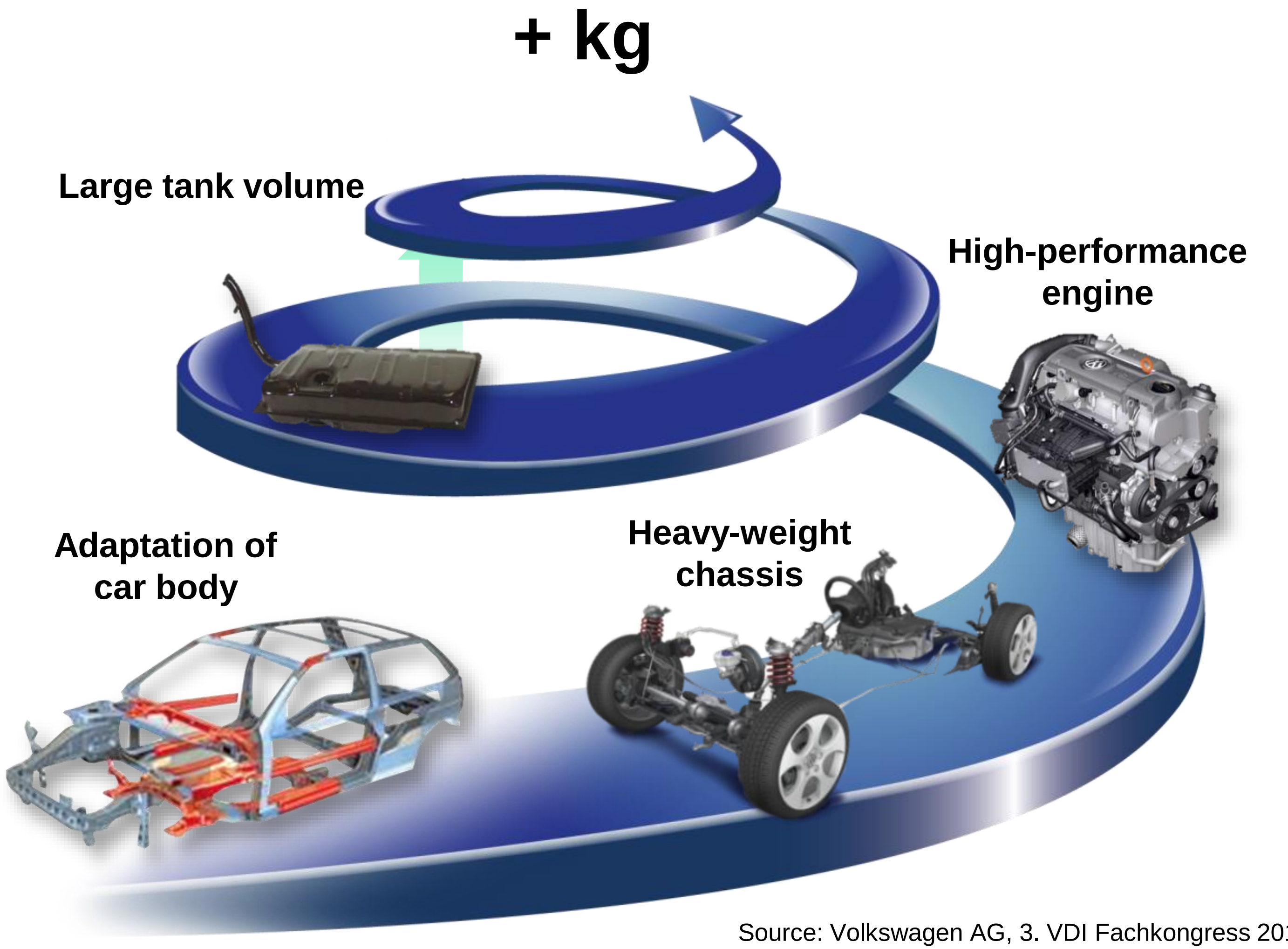


Source: Volkswagen AG, ManuLight 2014

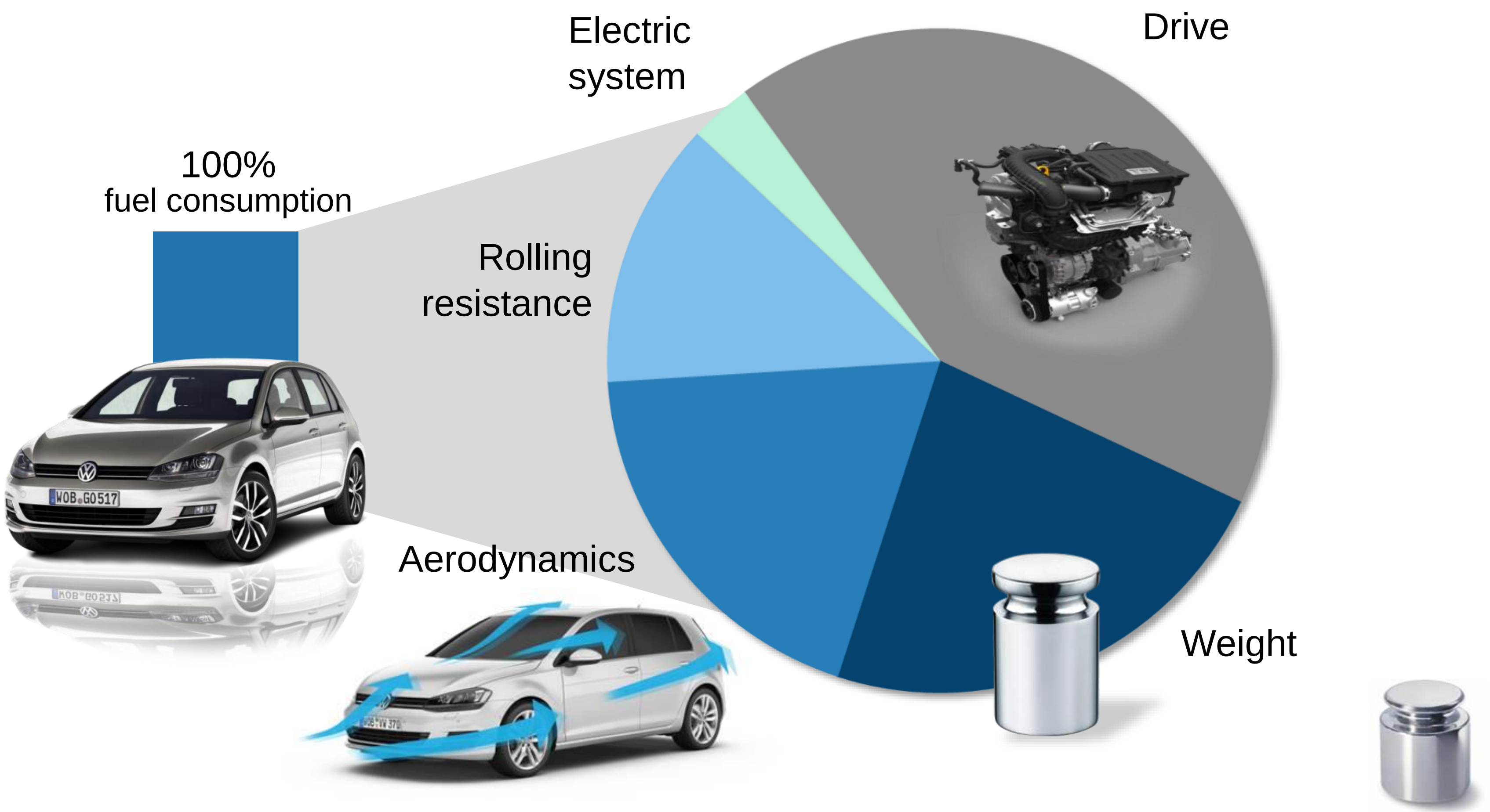
1) Source: McKinsey & Company, Ministry for the Environment
2) Memorandum of understanding, e.g. EU and G8+5 states, part of Copenhagen Accord 2009

Expectable CO_2 limit values until 2050

- Safety
- Legislation
- Comfort
- Interior trim
- Quality



Source: Volkswagen AG, 3. VDI Fachkongress 2013

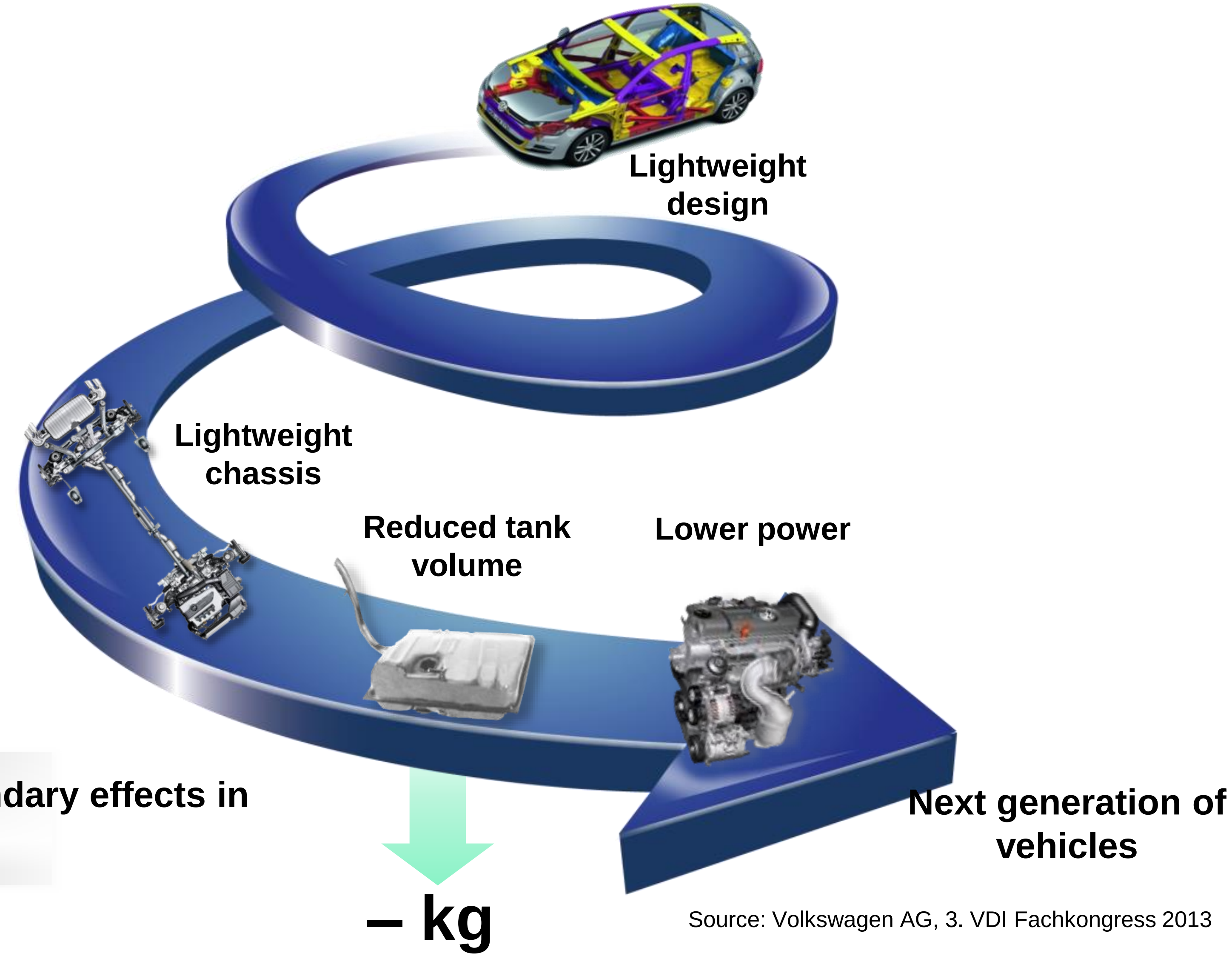


weight
100kg ~ 8.4g CO_2/km

Source: Volkswagen AG, Automotive Lightweighting & Manufacturing 2014

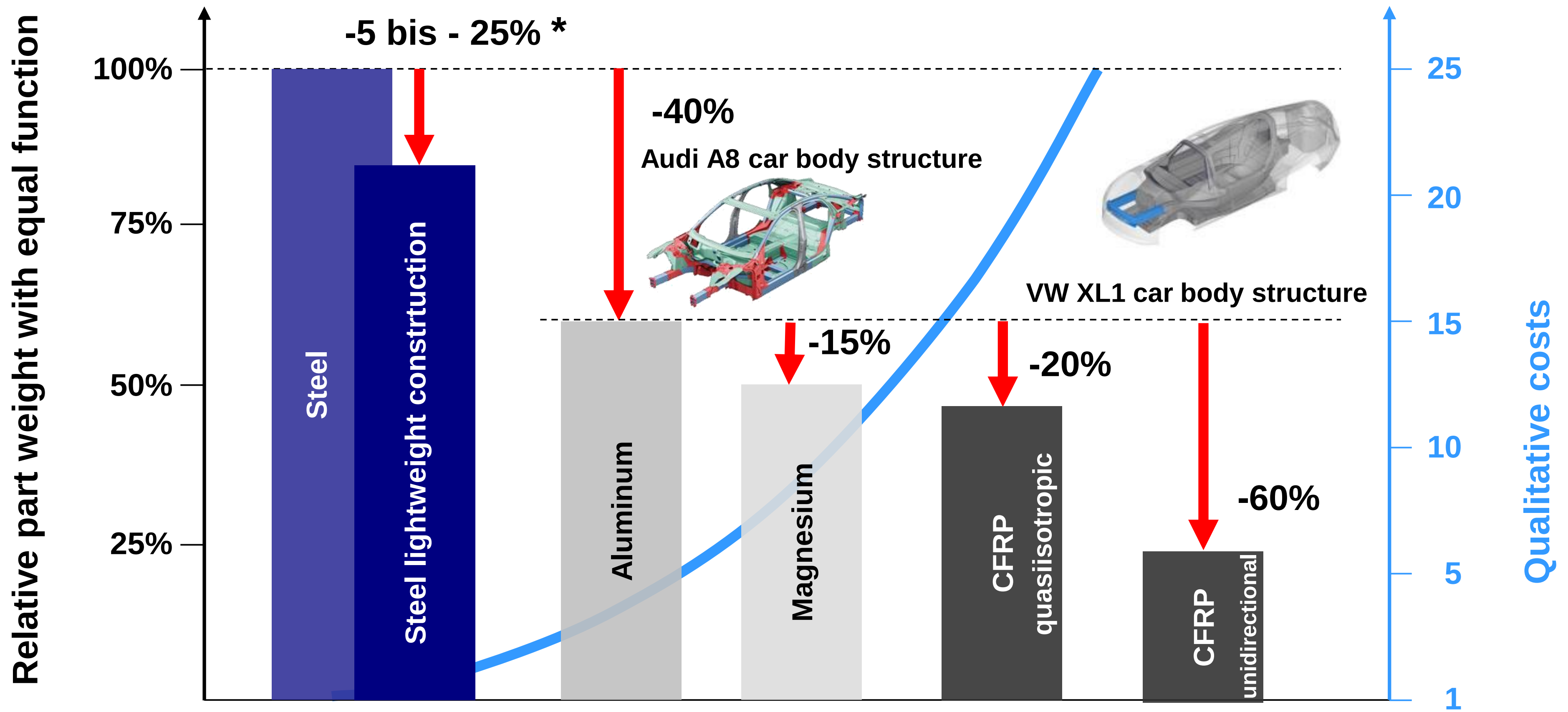
Almost ¼ of consumption are a direct consequence of the weight

- Part- and function integration
- New materials and processes
- Cost - /weight optimization



» Starting with the car body allows secondary effects in the entire vehicle

Source: Volkswagen AG, 3. VDI Fachkongress 2013

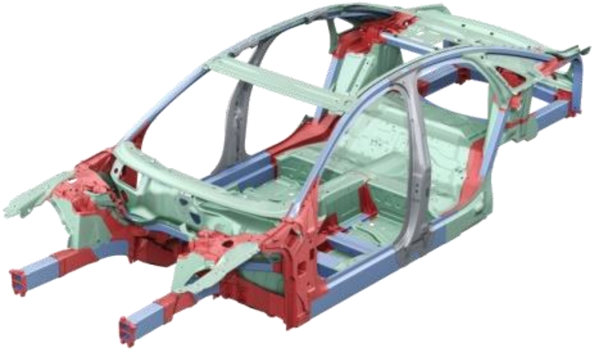


* High values for spec. parts

Source: Volkswagen AG, Werkstoffsymposium 2012
„Prozess- und Werkstoffinnovationen in der Pulvermetallurgie“

Sheet monocoque design (steel)

Audi-Space-Frame (ASF) design

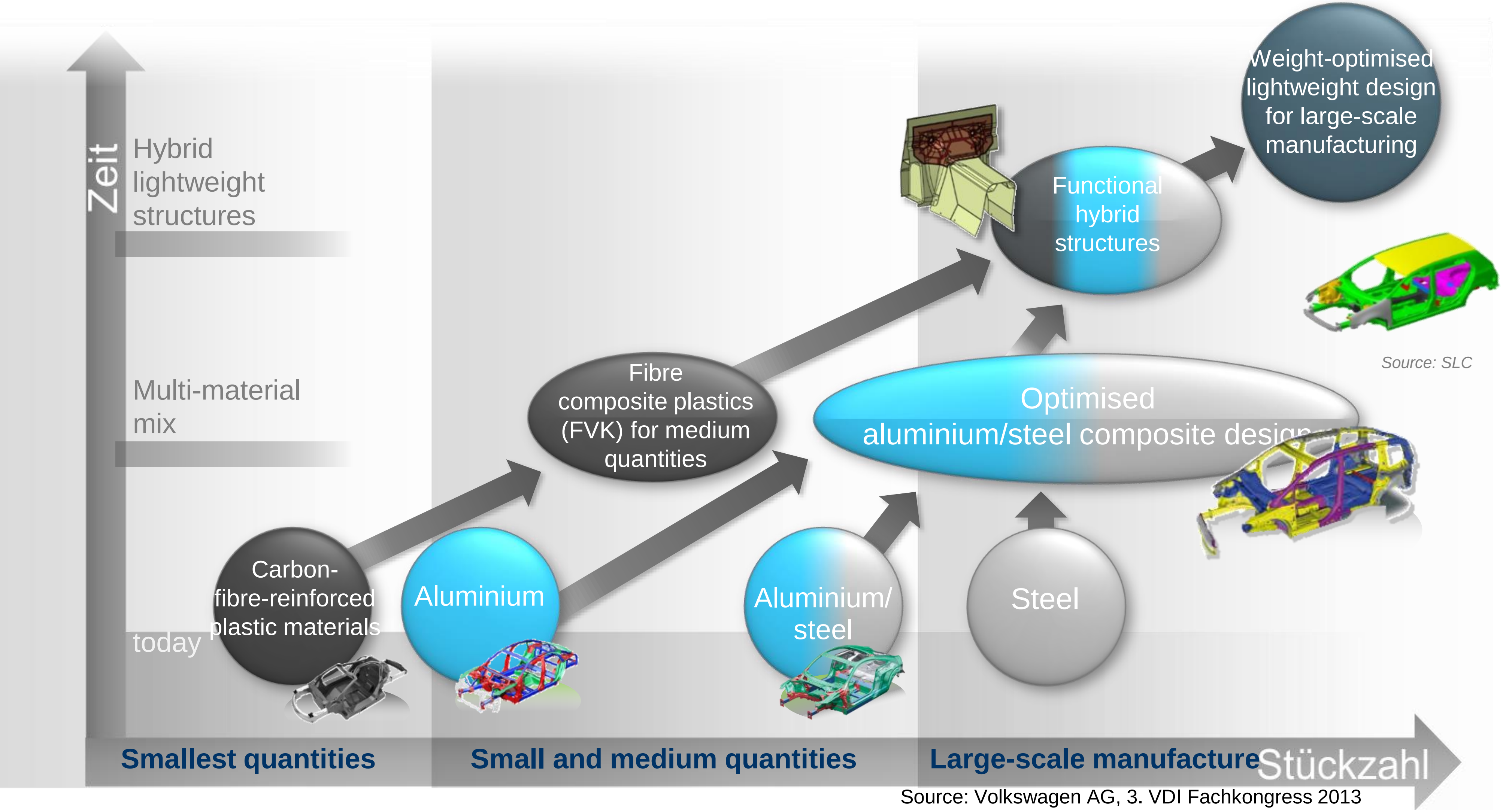


Composite design

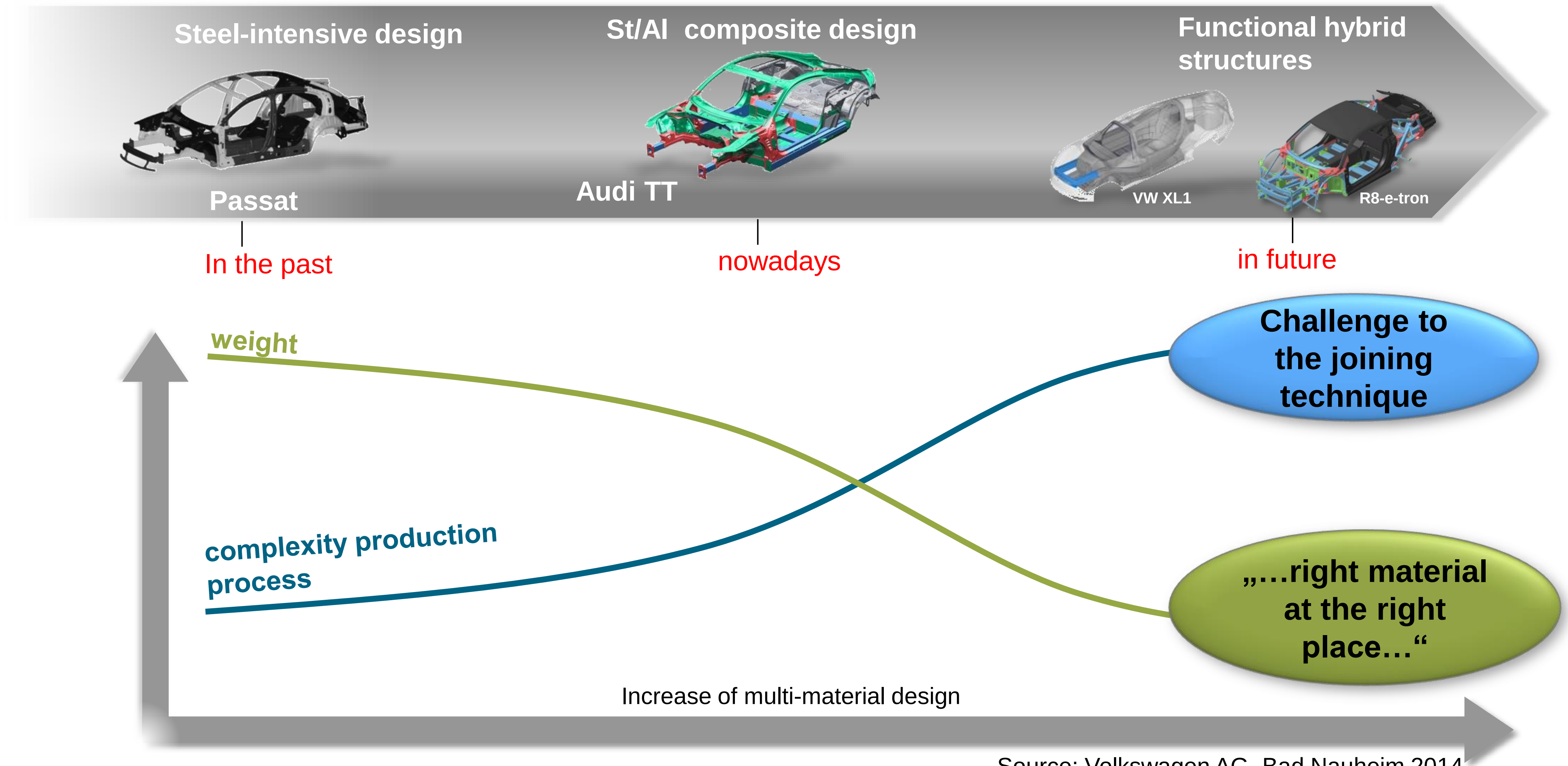
(e.g. ASF® car body with steel rear part)

CFRP design

Source: Volkswagen AG, Werkstoffsymposium 2012
„Prozess- und Werkstoffinnovationen in der Pulvermetallurgie“



Source: Volkswagen AG, 3. VDI Fachkongress 2013

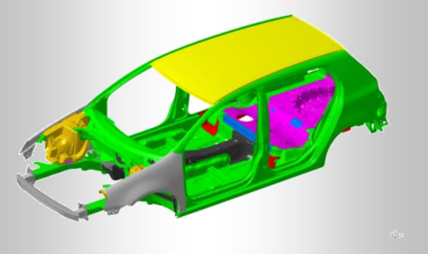


Source: Volkswagen AG, Bad Nauheim 2014

Lightweight Design increases Application of Multi-Material Design

- Introduction
- Motivation
- Lightweight design and multi-material mix
- Challenges to joining technology
- Composite design and multi-material mix in production
- Summary

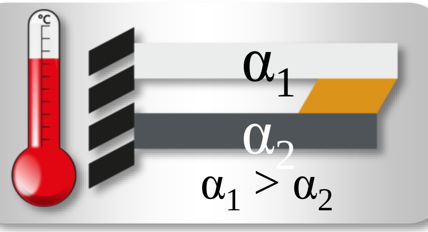
Application



Future car body design concepts with composite design

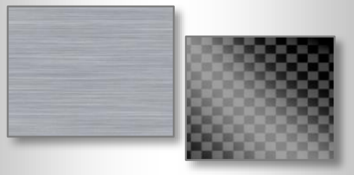
- Thermal load in paintwork drying processes
- Material combination of highest-strength steels/ aluminium / magnesium/fibre-reinforced plastic materials
- Structural crash-proof joints

Challenges



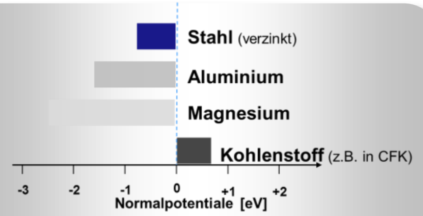
Different heat expansion coefficients

Intermetallic phases in fusion welding processes



New surfacing combinations

(coatings, lubricants, release agents)

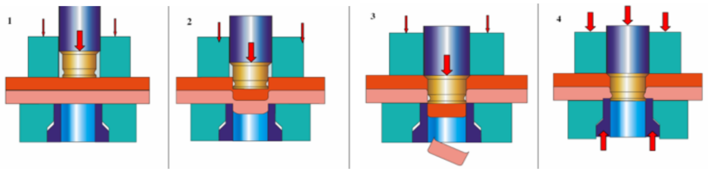


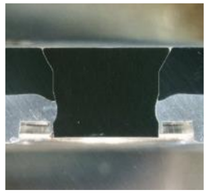
Increased risk of contact corrosion

(potential difference aluminium / steel and also aluminium / magnesium fibre-reinforced plastic materials)

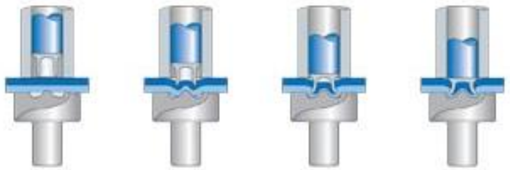
Quelle: Volkswagen AG

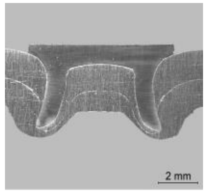
Rivetting with solid rivet





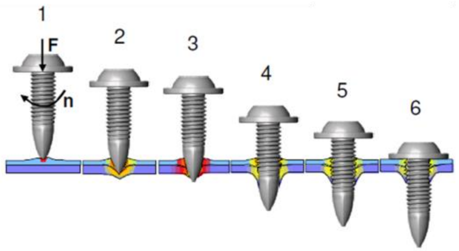
Self pierce rivetting (with semi-tubular rivet)





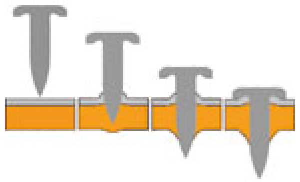
Source: Böllhoff

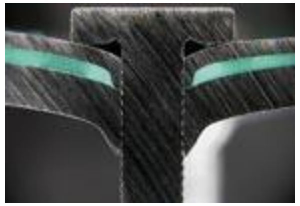
Flow drill screw (FDS), with/without predrilled hole



Source:LWF

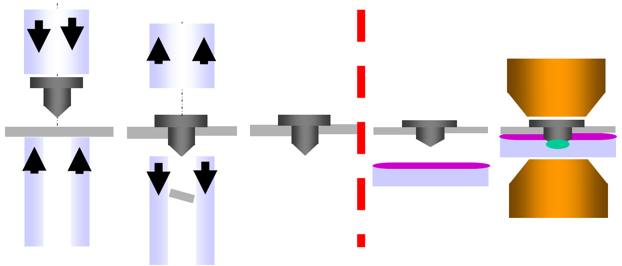
High-speed stud-setting

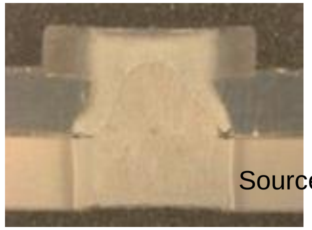




Source:Böllhoff

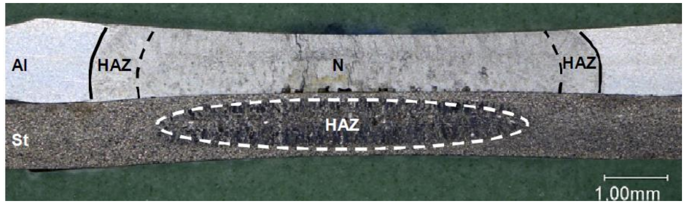
Resistance element welding



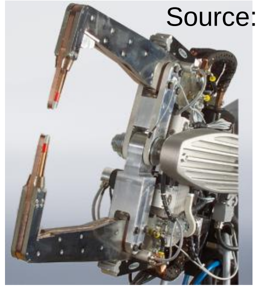


Source: VW

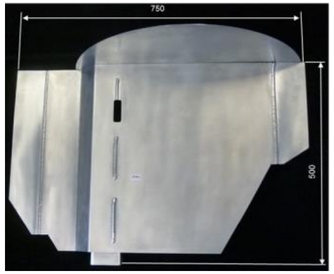
Resistance spot welding via process tapes (DeltaSpot)



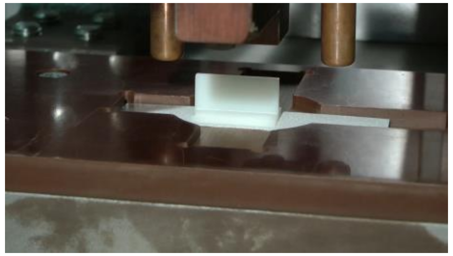
Source: Fronius



CMT braze welding



Thermal direct joining



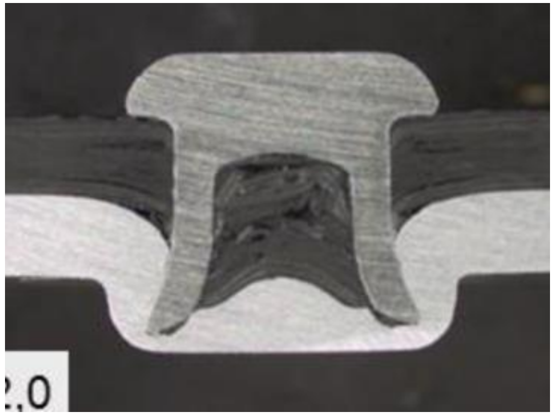
General Limits of Rivetting:

- The quasi-static loads are below the achievable strength values of RP welding
- Two-sided accessibility
- Complementary element required
- A punching develops
- High joining forces (up to 100 kN)- heavy C-guns – large space required

Limits of semi-tubular self piercing rivetting compared to solid rivetting:

- Sheet strength values only up to max. 1000 MPa instead of 1600 MPa
- Maximally three instead of possibly four sheet layers
- High mechanical load on rivets
- Thicker sheet required on side of die
- It is impossible to join brittle cast materials
- Joining forces of up to 60 kN

Source: Avdel



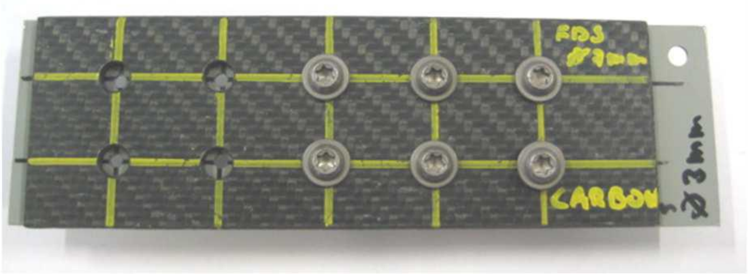
Semi-tubular self piercing rivet: Damage of the fibre-reinforced material by squeeze force and process fluctuations
Source: Magna

Limits of FDS:

- Local heat flow
- Complementary element required
- Preferably from the thinner into the thicker material
- Preferably to be screwed from the softer into the harder material

Limits of Stud-Setting:

- Joint is undetachable
- Complementary element required
- Loud impulse noises during setting of studs
- Rear sheet layer must offer necessary support
- The material on the side of the setting has a max. strength of approx. 1000 MPa, the rear material can have a strength of approx.1600 MPa
- Minimum material strength for the rear sheet of 1,5 mm in the case of steel and of 2,5 mm in the case of aluminium
- Material combination: preferably thin into thick and soft into hard



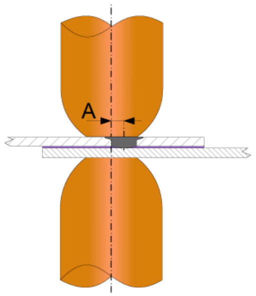
Source: Magna

Quelle: Magna

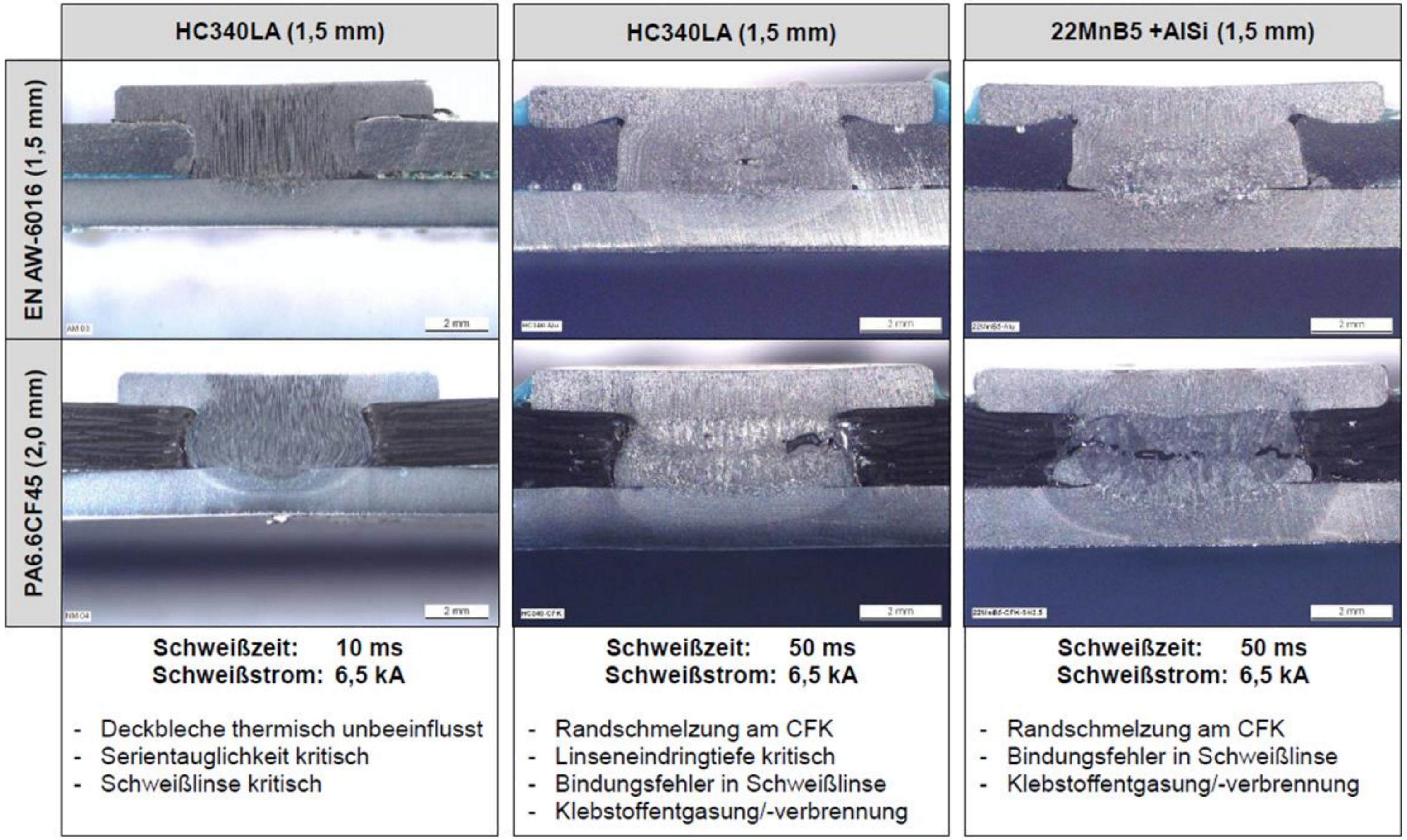
Rivtac: Fracture of the fibre-reinforced structure. Fibre-reinforced material takes in kinetic energy and causes thus the base material to deform too slowly, the consequence is risk of fracture

Limits of resistance element welding (WES):

- Two-sided accessibility
- Complementary element required
- A punching develops
- Handling safety required



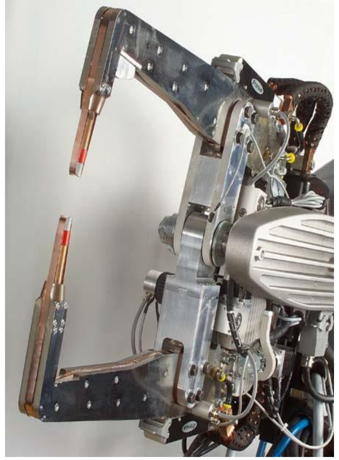
Disturbing influence: Shifting of the electrodes



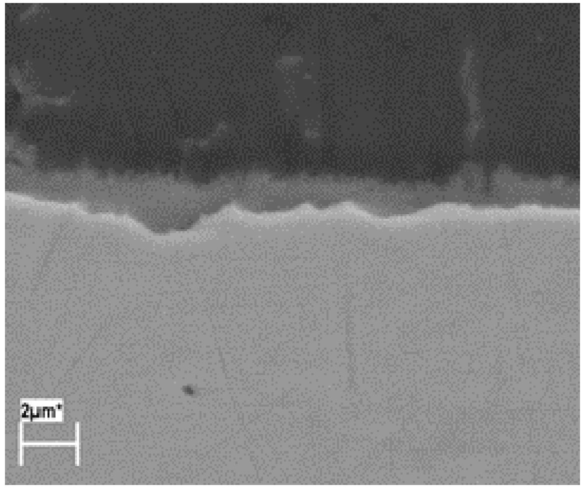
Source: LWF, Paderborn

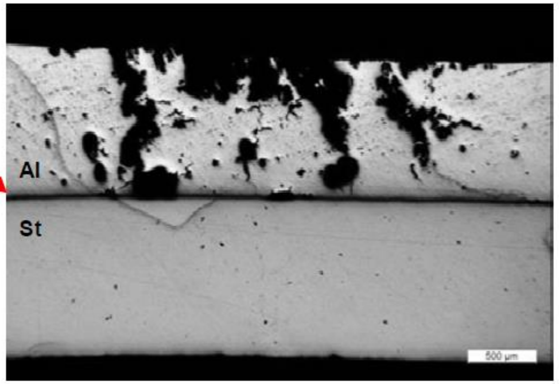
Limits of DeltaSpot:

- Process tapes required
- Additional expenditure/costs, change of the process tapes
- Restrictions accessibility / flange width by the process tapes
- Process control with aluminium/steel joints in combination with adhesives is still a challenge




Source: Fronius

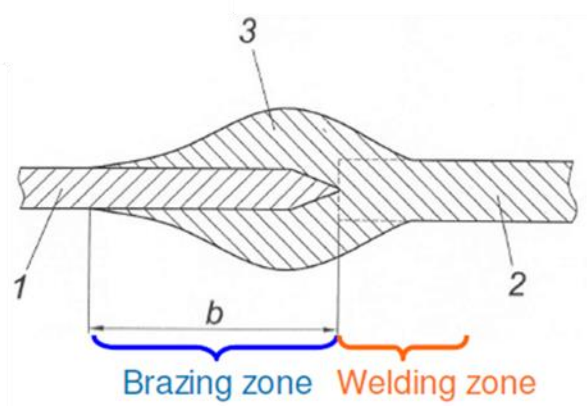




Source: Audi, Bad Nauheim 2012

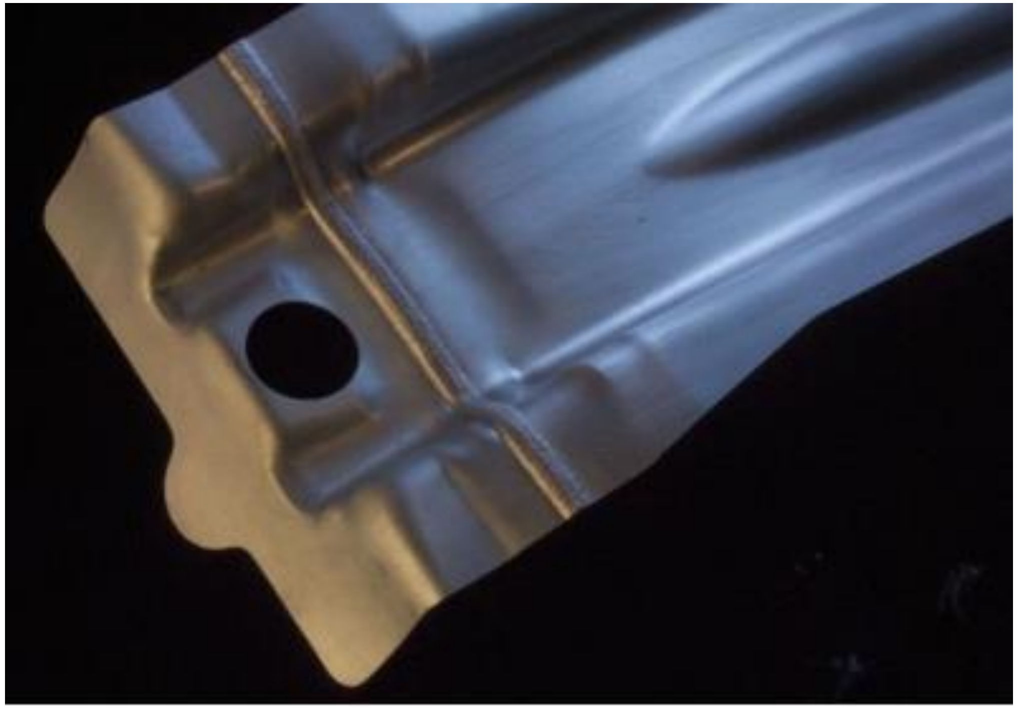
Limits : CMT braze welding of hybrid board by Fronius and Voestalpine

- Only for production of blanks
- Steel sheet side must be galvanized
- Special edge preparation on the steel side
- Weld reinforcement
- Restricted forming property caused by weld reinforcement



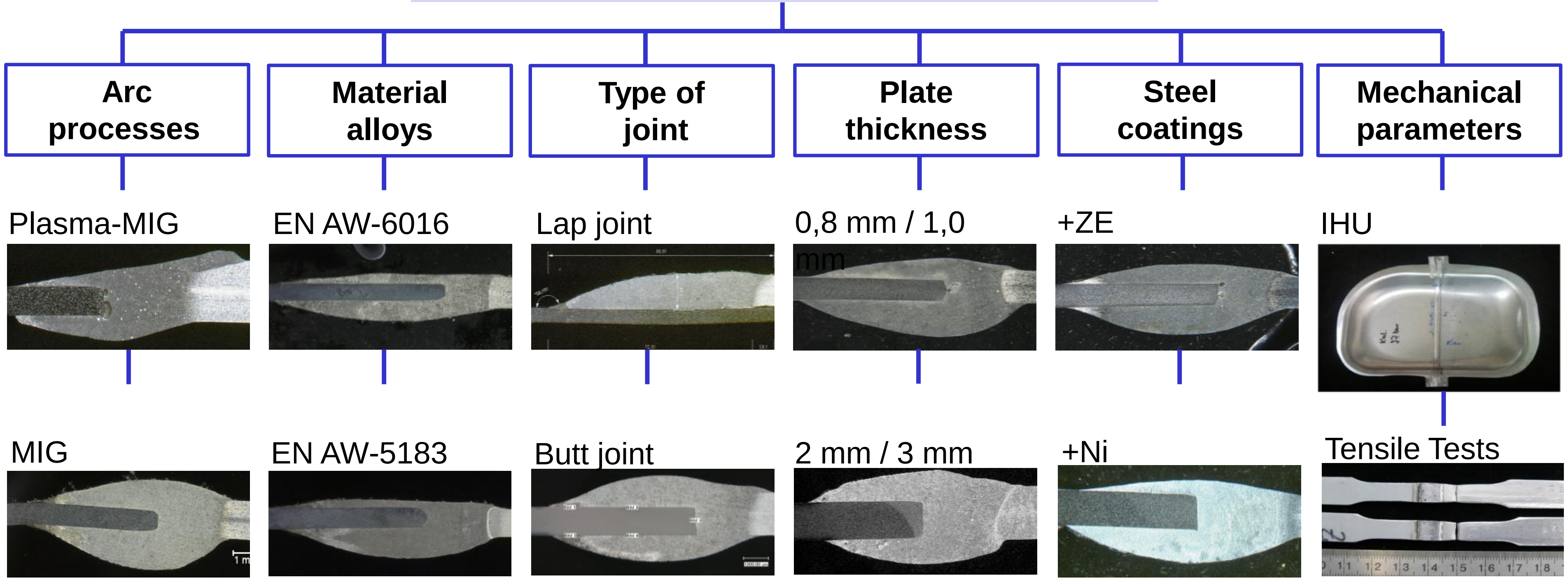
1. Steel sheet, galvanised
2. Aluminium sheet
3. Filler material

Source: Fronius

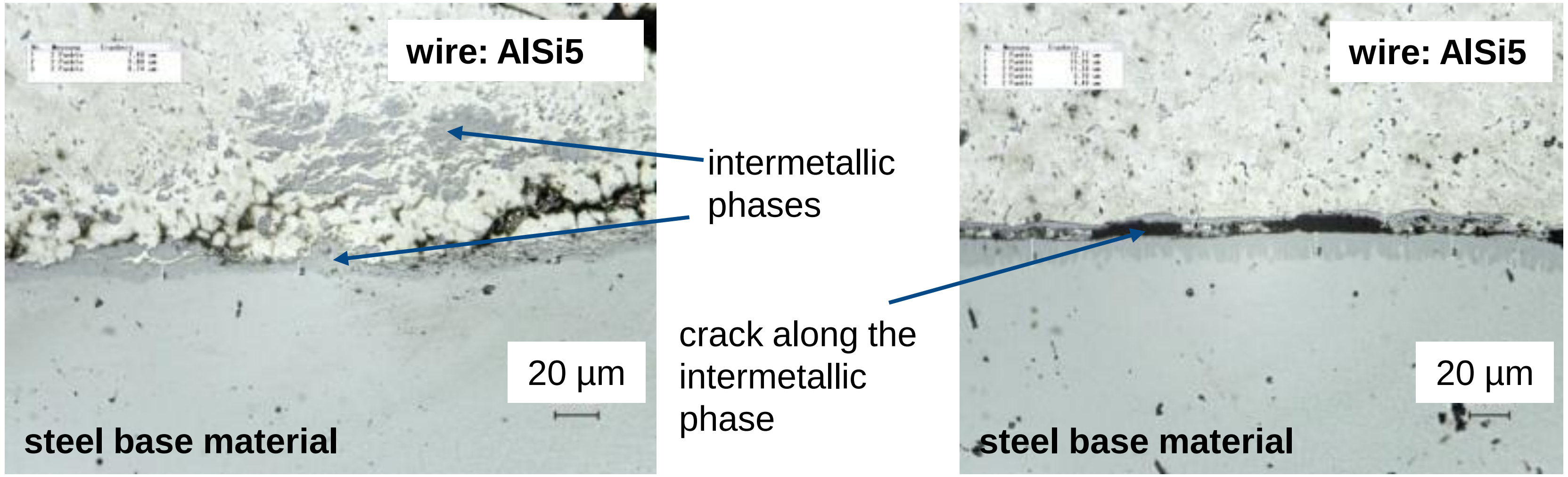


Steel-aluminium hybrid blank Source: Voest-Alpine

Steel-Aluminum Dissimilar Material Joints



- During the last few years, several projects with the topic of joining steel with aluminum have been carried out.
- The focus of the research work has been put on the suitability of different aluminum filler materials (AlSi5, AlMg4,5Mn) for the joining of steel-aluminum dissimilar material joints.



- Formation of brittle intermetallic phases due to the non-existing solubility of steel and aluminum at room temperature. The phases must not exceed 10 µm.
- Physical problems due to different melting points, expansion coefficients and thermal conductivity

➡
- Complex integration of the joining process into automobile production (application of flux, complex clamping devices due to distortion, …..)
- Compared with other thermal joining processes only small range of facility
- Determination of the formation of the intermetallic phases is, so far, only possible by using destructive testing

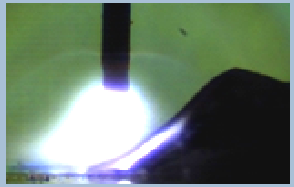
Aims

Joining of materials which are relevant in vehicle construction under practice-related boundary conditions

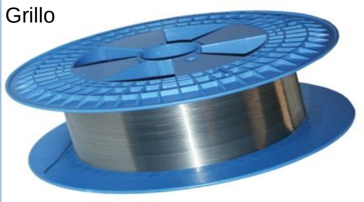
Reduction of the influence of the metallurgical incompatibility in thermal joining of steel and aluminum

Approach

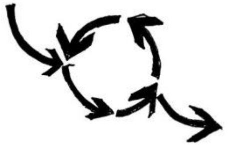
Testing of applications in vehicle construction by carrying out an assessment of demand



Lower energy input by the application of controlled short-arc processes (CMT, coldArc)

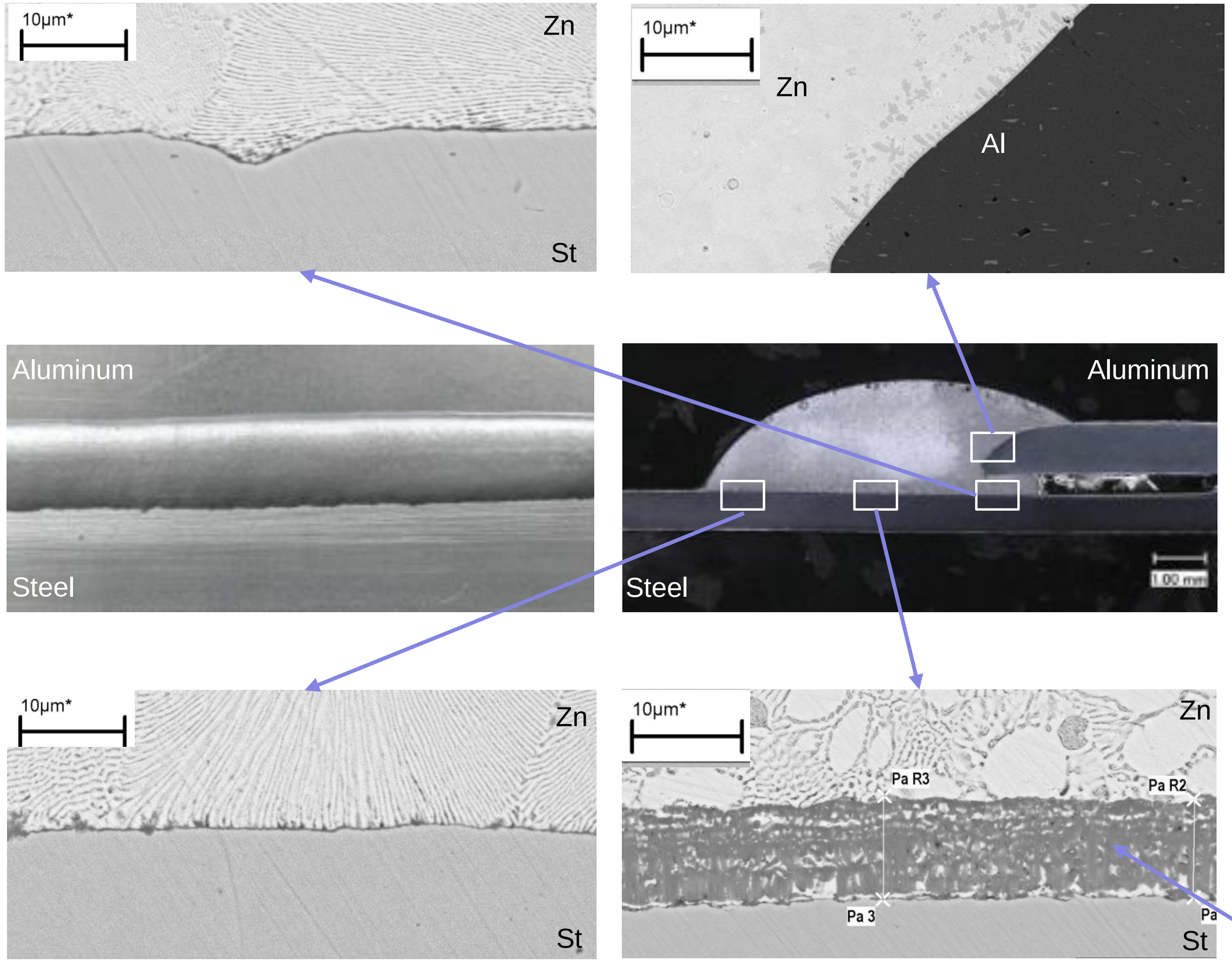


Further development of low melting zinc based brazing materials for application cases (alloying elements, diameter, surface condition, coating, etc…)



This development is carried out within the scope of iterative processes from the fields of users of vehicle construction (application know-how), welding institute (process know-how) and wire manufacturers (material know-how).

GRILLO



Application Case

- Process-reliable joining of steel-aluminum dissimilar material joints without flux
- Development of weld geometries with mechano-technological favourable properties
- In the zone of the arc attachment point, a phase of steel, aluminum and zinc is developed which, compared with joining using an aluminum-based brazing material, is less brittle

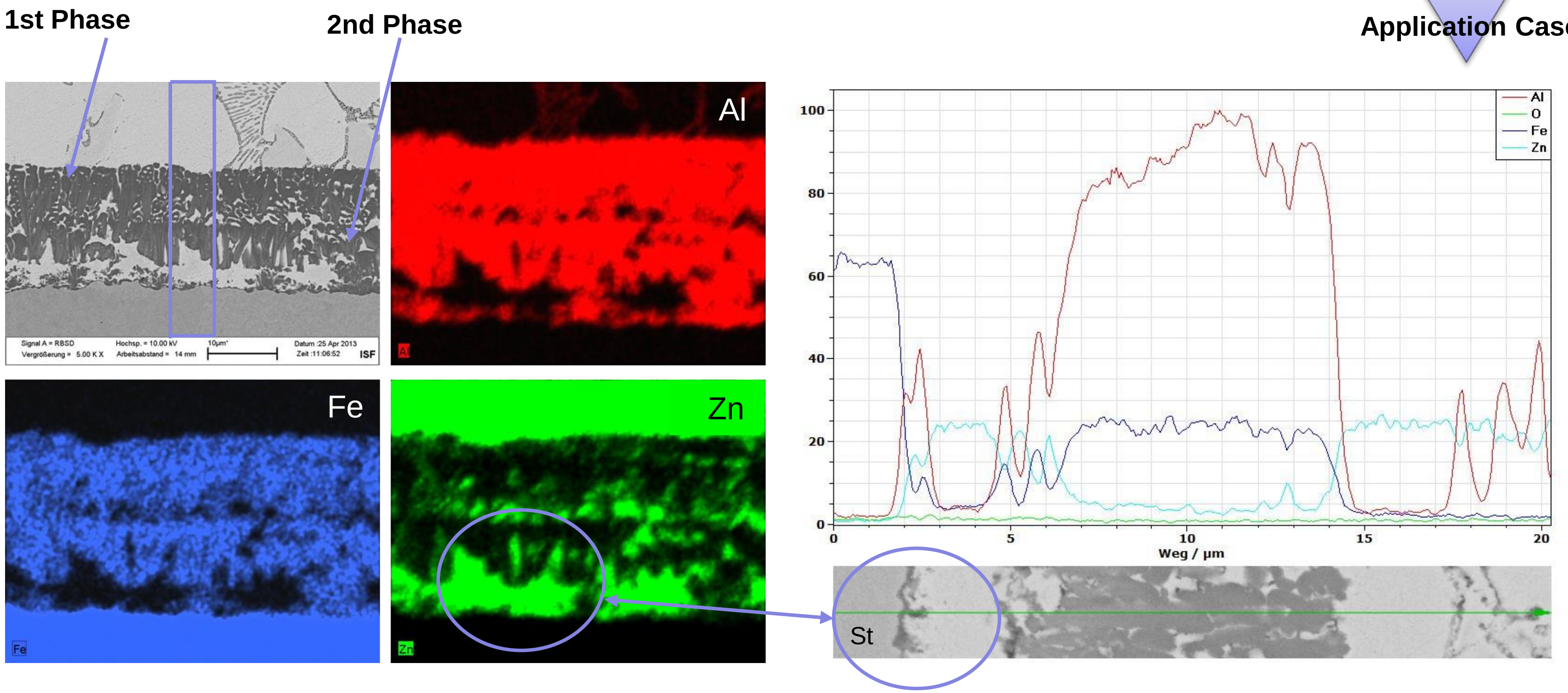
Intermetallic phase which has been saturated with zinc (St/Al/Zn)

WELDING AND JOINING INSTITUTE
RWTH AACHEN UNIVERSITY

Exemplary
Joining Results DX56D / EN AW-6016

Forschungs- und Entwicklungs-gesellschaft Fügetechnik GmbH

Application Case

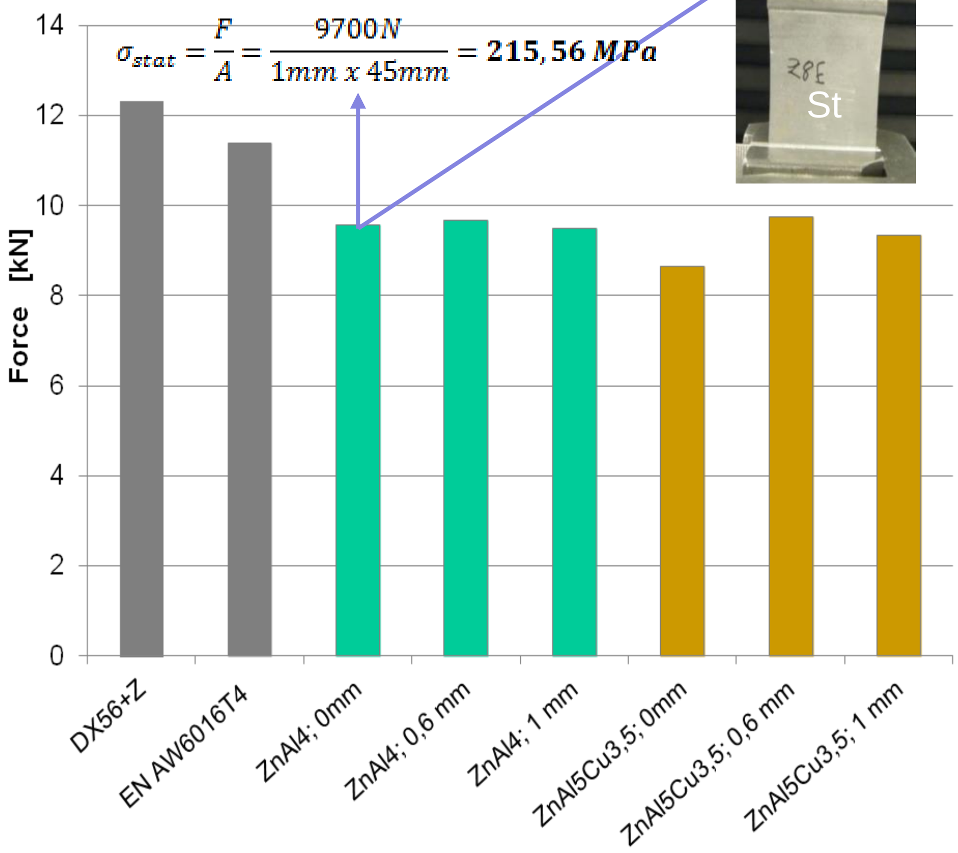


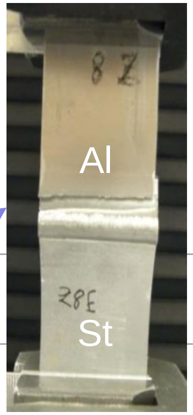
- During the joining process, intermetallic phases are developed which detach as from a thickness of max. 5 µm and which are saturated by phases which are rich in zinc.
- A ductile phase which is rich in zinc is adjoining the steel base material.

Application Case

Static Strength

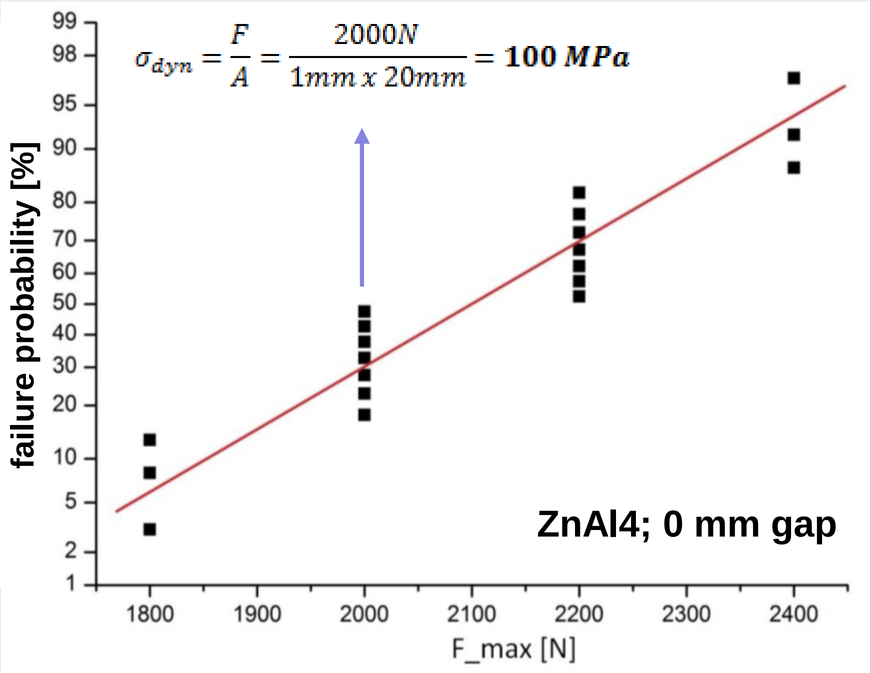
$$\sigma_{stat} = \frac{F}{A} = \frac{9700N}{1mm \; x \; 45mm} = \mathbf{215{,}56 \; MPa}$$





Cyclic Strength

$$\sigma_{dyn} = \frac{F}{A} = \frac{2000N}{1mm \; x \; 20mm} = \mathbf{100 \; MPa}$$



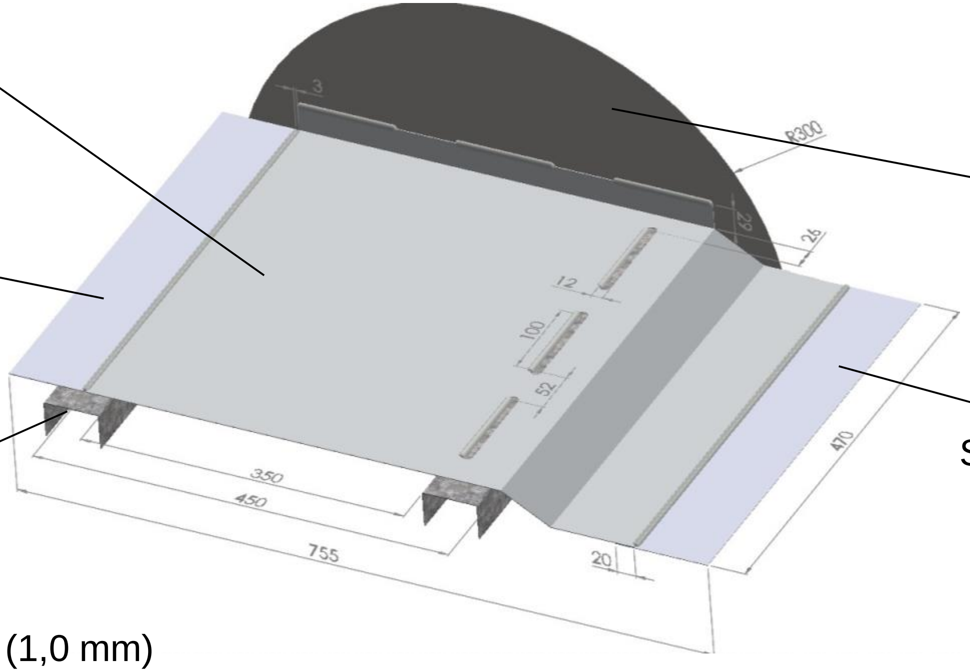
- $R = \frac{\sigma_u}{\sigma_o} = 0$ (tensile force)

Static and Cyclic Strength Values of DX56D / EN AW-6016

Demonstrator

Aluminum plate (1,15 mm)

Steel plate (0,8 mm)



Steel plate (1,0 mm)

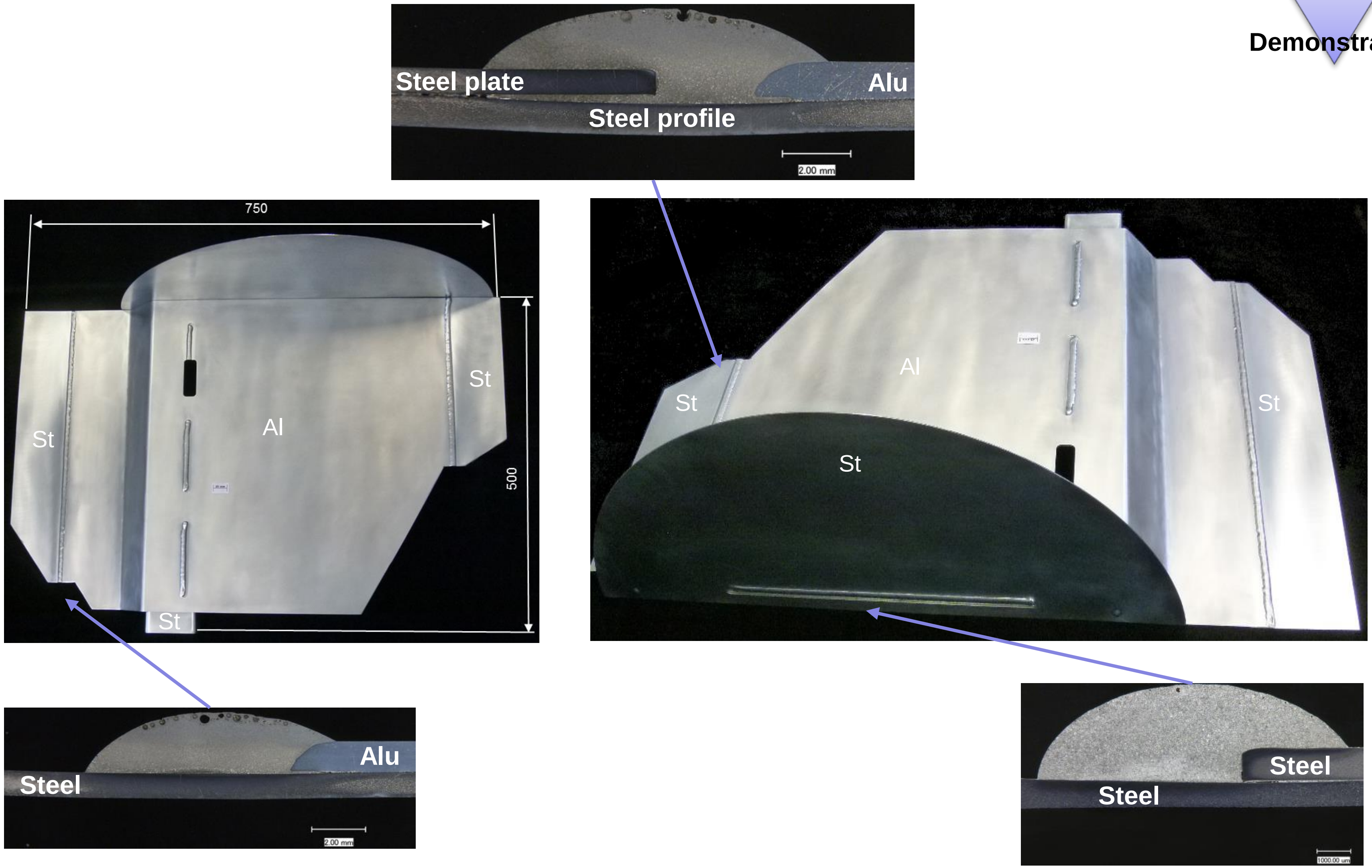
Steel plate (0,8 mm)

Steel profiles (1,0 mm)

- The application of steel profiles and aluminum plates shall allow crash- and also lightweight relevant functions in a vehicle underbody.
- Demonstration of the possibility of joining different materials with different thickness and surface coatings.

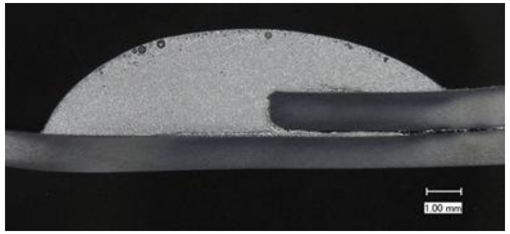
Production of a Demonstrator Part

Demonstrator

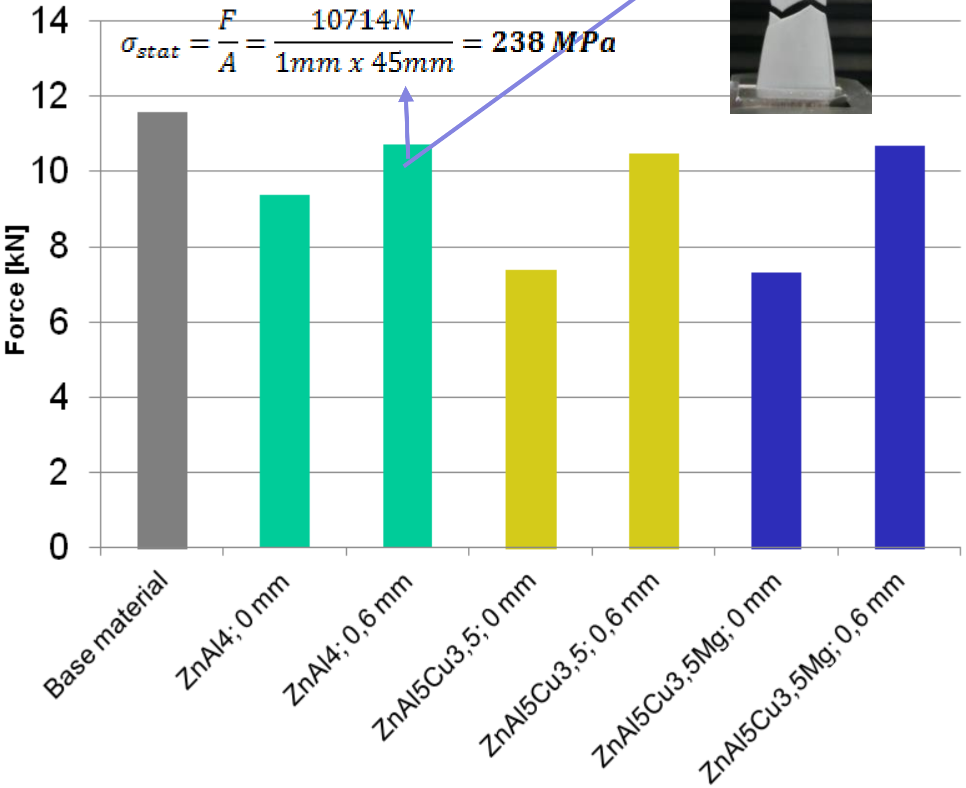


Finished Demonstrator Part

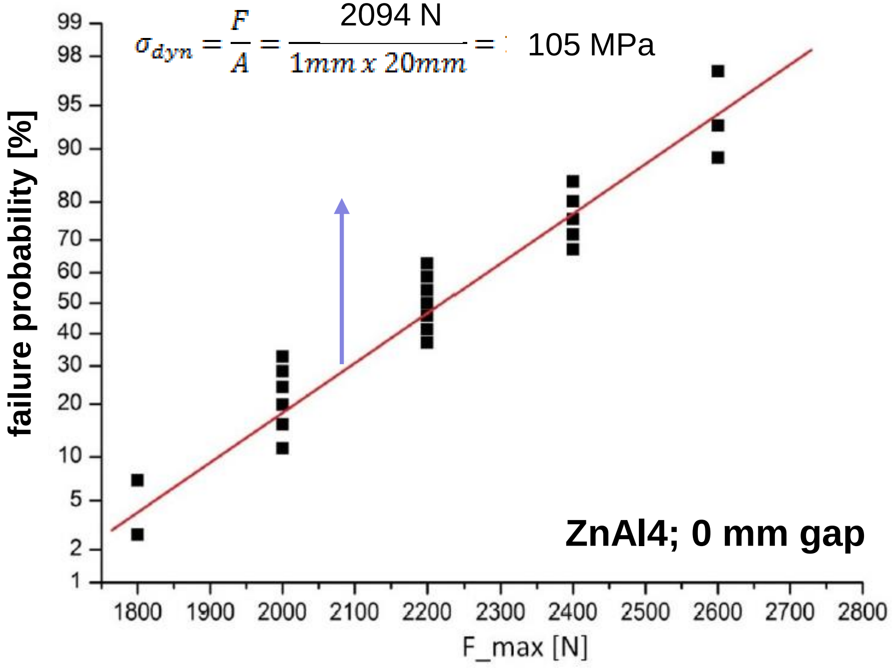
Application Case



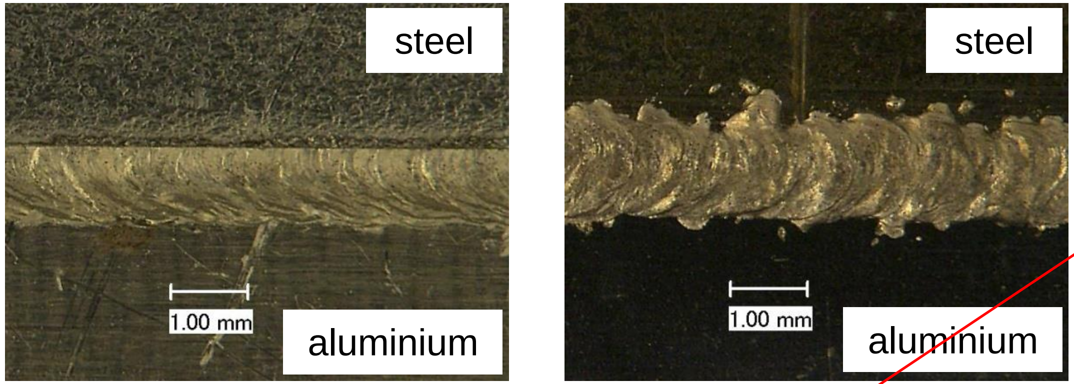
Static Strength



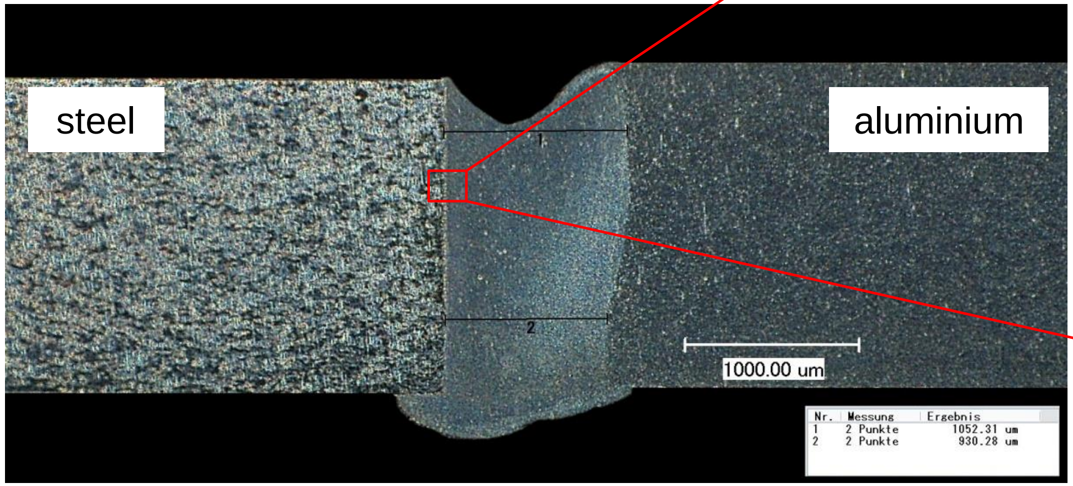
Cyclic Strength

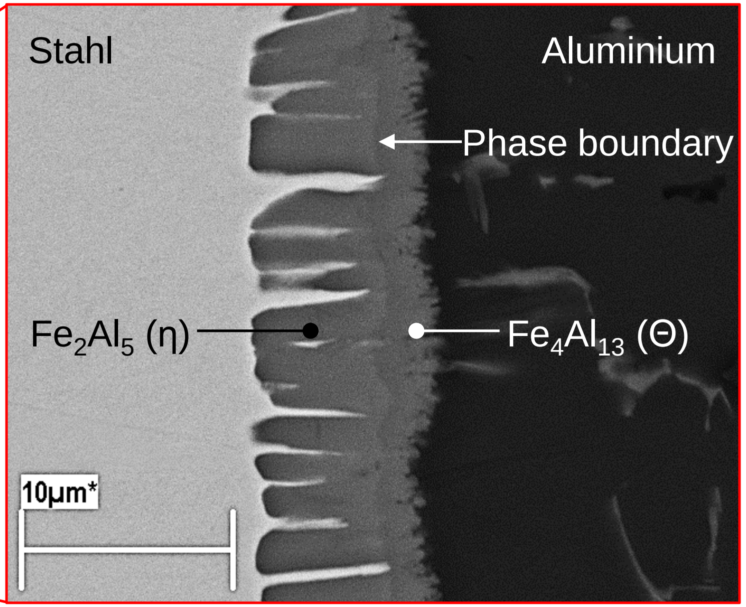


- $R = \frac{\sigma_u}{\sigma_o} = 0$ (tensile force)

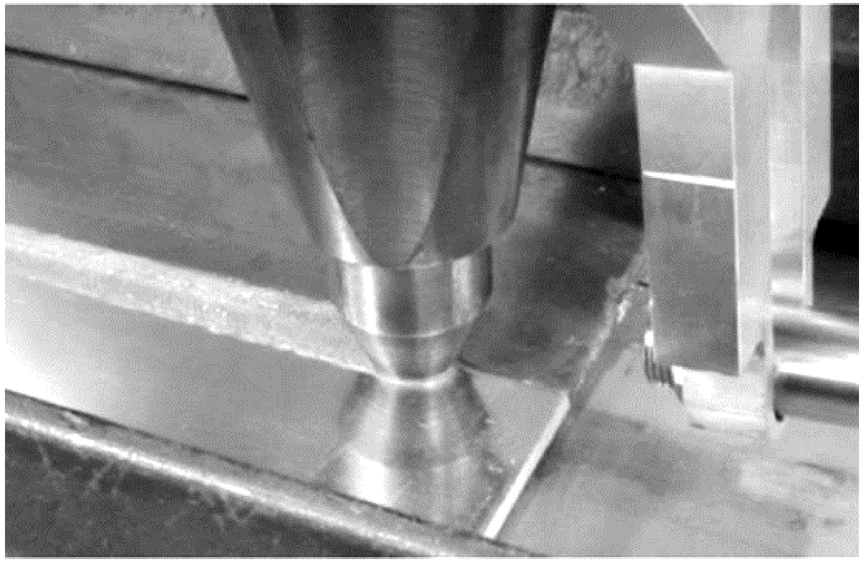


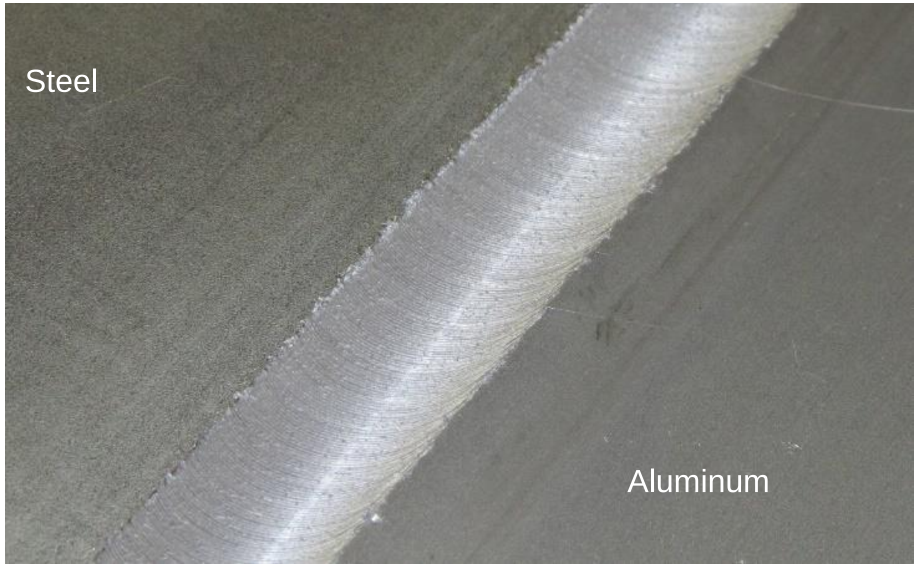
Weld surface

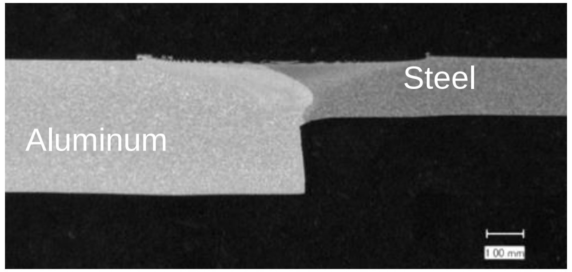


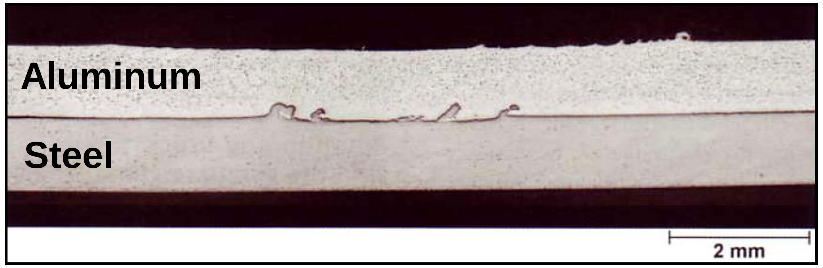


Cross section

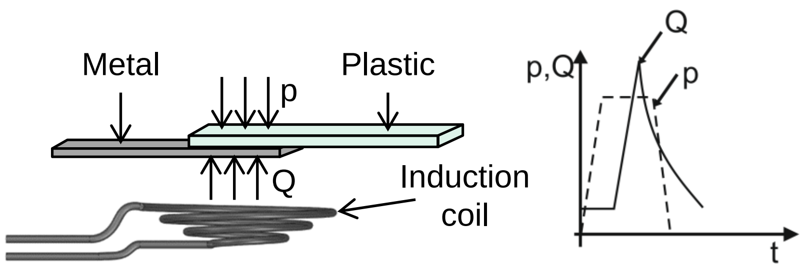



Steel
Aluminum

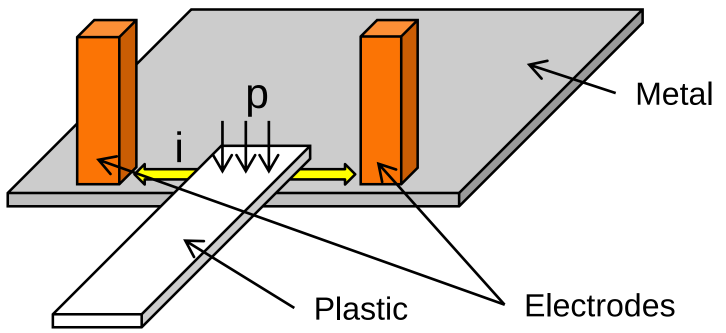

Steel
Aluminum


Aluminum
Steel
2 mm

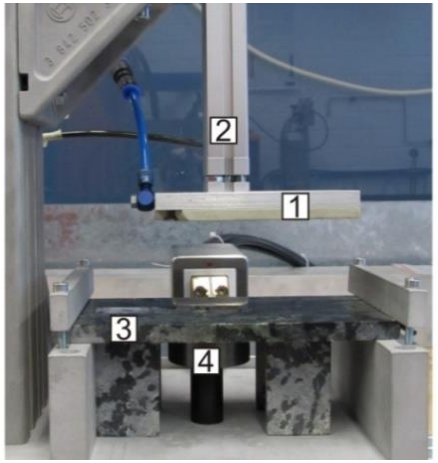
Principle induction technique



Principle resistance heating

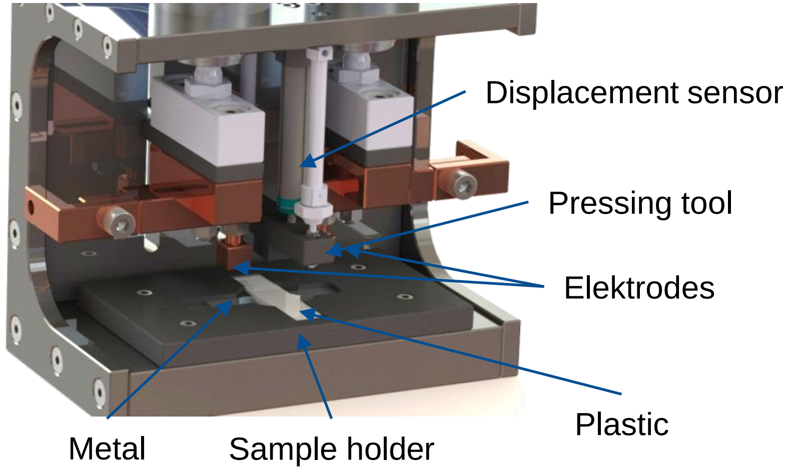


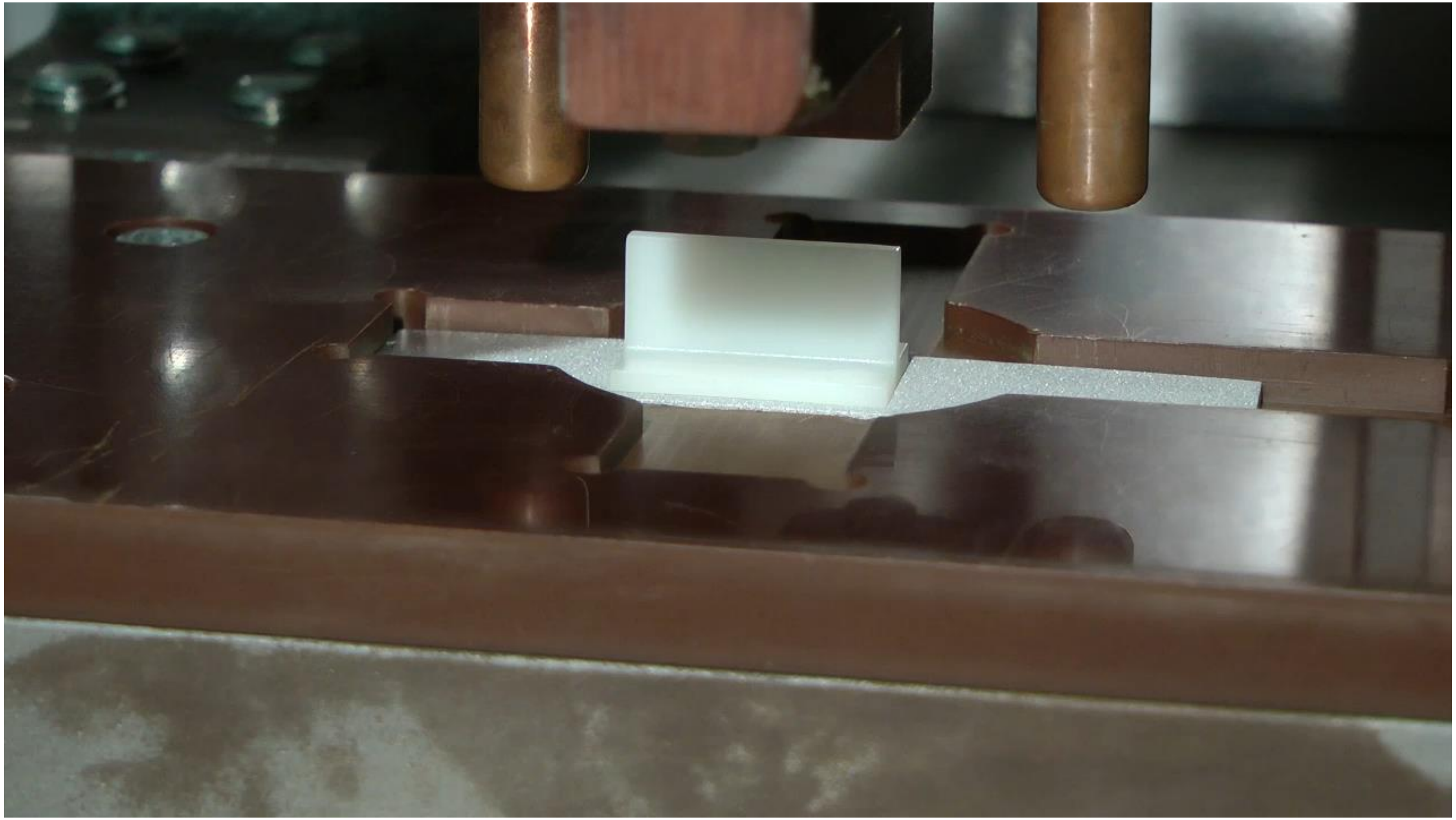
Experimental set-up induction technique



1. Upper sample holder (plastic part)
2. Pressing cylinder
3. Lower sample holder (metal part)
4. Induction coil

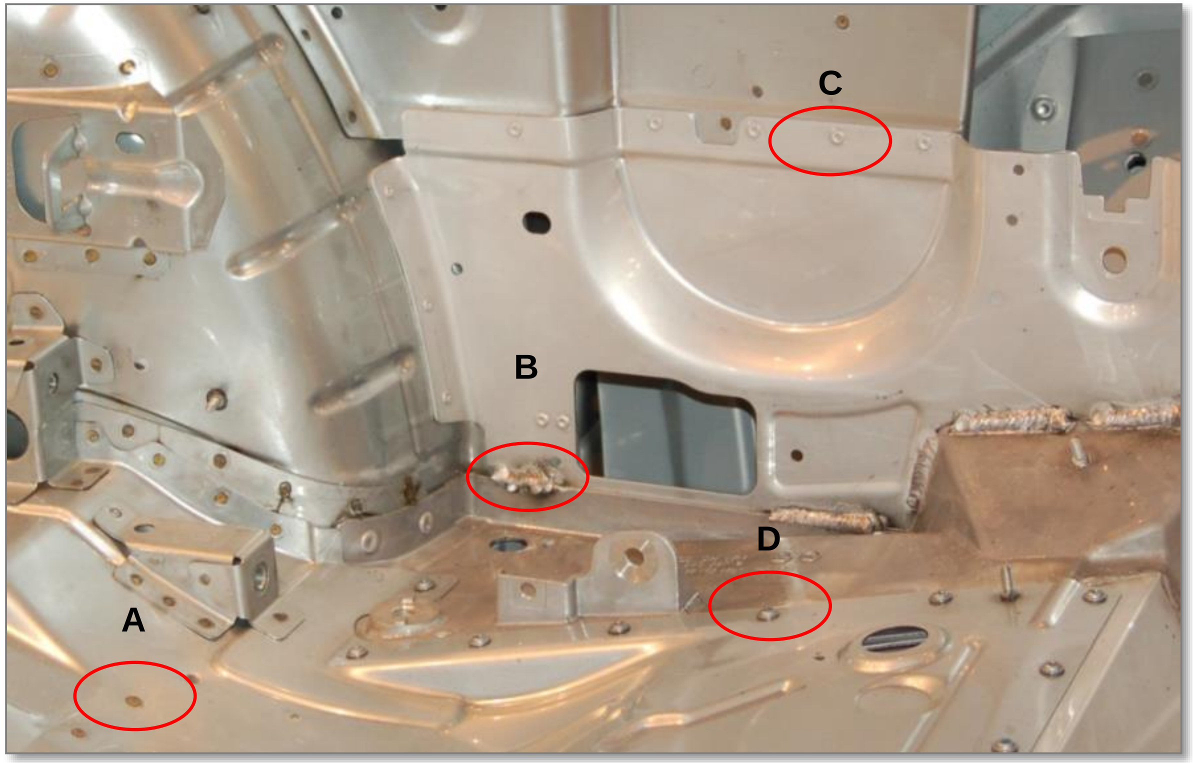
Experimental set-up resistance heating





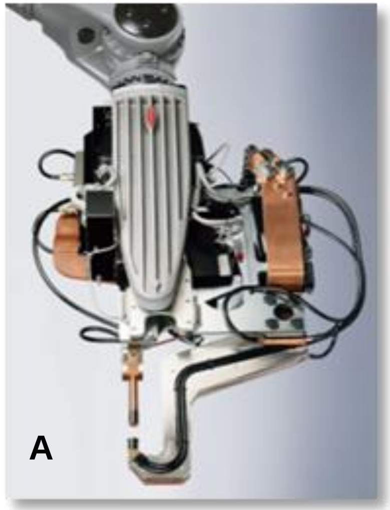
Thermal direct joining with resistance heating

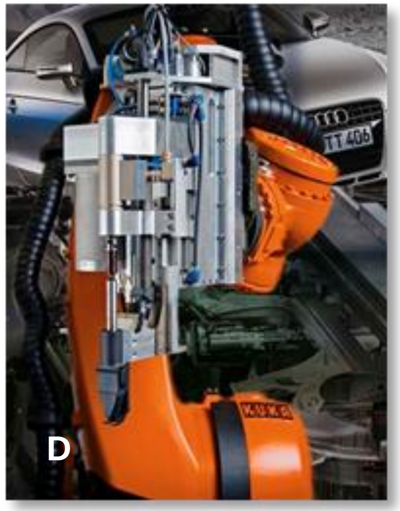
- Introduction
- Motivation
- Lightweight design and multi-material mix
- Challenges to joining technology
- Composite design and multi-material mix in production
- Summary

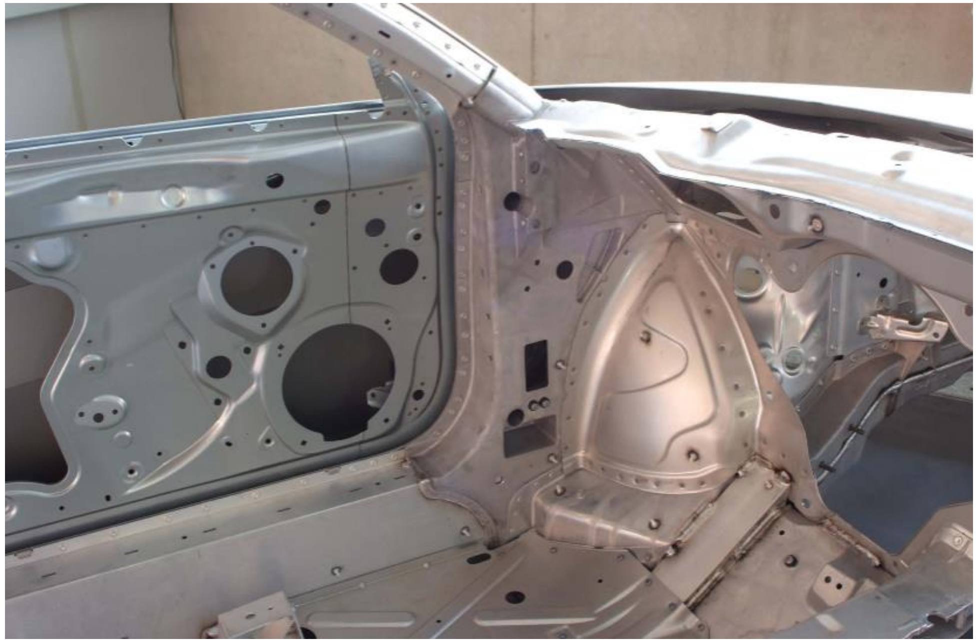


Audi TT, Source: Audi

A: Resistance spot welding
B: MIG welding
C: Rivetting
D: Flow-Drill Screwing







Technique	Process	Number per vehicle
Mechanical joining techniques	Rivetting Clinching Flow-Drill-screwing Solid rivetting	1615 piece 164 piece 96 piece 229 piece
Thermal joining techniques	MIG welding Laser welding RP welding MAG welding Stud welding	21462 mm 5309 mm 1287 spots 809 mm 234 piece
Adhesive bonding	Adhesive bonding	97156 mm

Source: DVS BV Schwaben, Franz J. Lange

Audi TT:

- 6 different wall thickness values
- 4 different rivet types
- 6 different materials Al
- 6 different materials St

Through the multi-material mix, the number of successor models has more than doubled

- Introduction
- Motivation
- Lightweight design and multi-material mix
- Challenges to joining technology
- Composite design and multi-material mix in production
- Summary

- Lightweight design is an important key for reducing the CO_2 emissions
- The singular steel-, aluminium and FVK (fibre reinforced plastic material) design is replaced by composite design and further by hybrid concepts
- New car body concepts pose new challenges to the joining technique
- Existing joining techniques are already capable to fulfill most of the joining tasks
- The current multi-material mix/composite design requires, as far as economic considerations are concerned, a very high number of joining technologies
- Economically speaking, the number of varieties within one joining technology is also too high
- Composite design requires joining techniques for a possibly large bandwidth of joining tasks