Research need in adhesive technology

Adhesive technology – Key to future of lightweight design?

Sustainable lightweight design is an essential factor to increase the energy efficiency of future vehicles (Figure 1). Current lightweight design concepts demonstrate opportunities to reduce the weight of today's vehicles by using different materials. In the competition of these materials and construction methods the joining technology plays a major, or even the decisive role.

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Adhesive technology is already an important part of existing joining concepts. In future, the consequent usage of the variety of materials and the increasing application of fibre reinforced plastics will be dependent of adhesive joining methods more than ever. The following explanations give an overview of adhesive technology in the context of lightweight design as well as an outlook on design, material and process challenges from the perspective of automotive research.

Lightweight construction in automotive high volume production

Today's vehicle architectures are marked by metallic structures. Due to the area of conflict of product properties, production requirements and costs, in the automotive volume production the steel shell design is established. The conditions of the assignment in high volume productions do not leave space for alternative concepts or even radical lightweight design ideas. During the last years reductions of mass were realised by the development of high-strengths steels and enhancements in the field of light metals. The construction set for body structures includes a wide range of different materials, reaching from deep-drawing grades of low strength to high-strength steels up to 1900 MPa tenacity /1, 2/, which are specifically supplemented by aluminium casting, rolling alloys or sometimes magnesium. Caused by growing efforts to realise lightweight design, the body construction will be determined by an intensive material diversity in future (Figure 2). Next to metallic materials, fibre reinforces plastics will gain in importance /3, 4/.

The potential of the different materials are known as far as possible. One material solutions will not reach the required weight savings. More than ever, progressive lightweight design concepts are needed, which systematically connected, realise material, function and production suita-

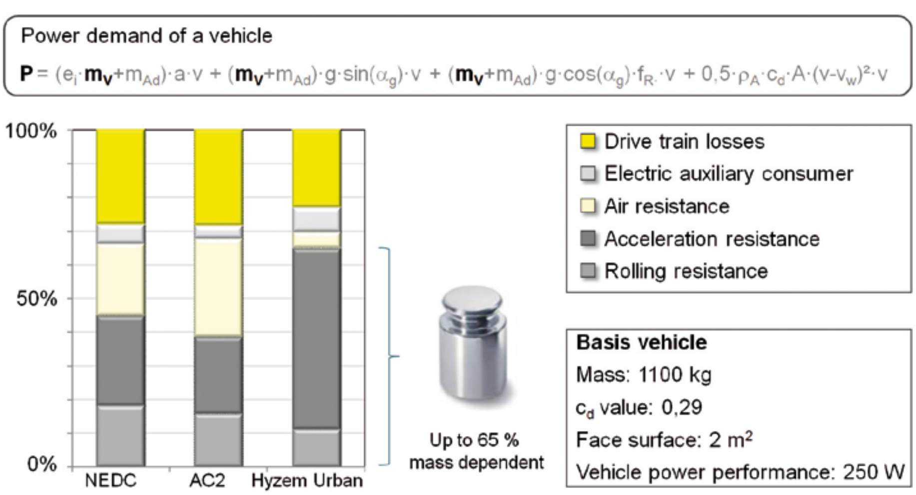


Figure 1: Power demand of an electric vehicle in different driving cycles

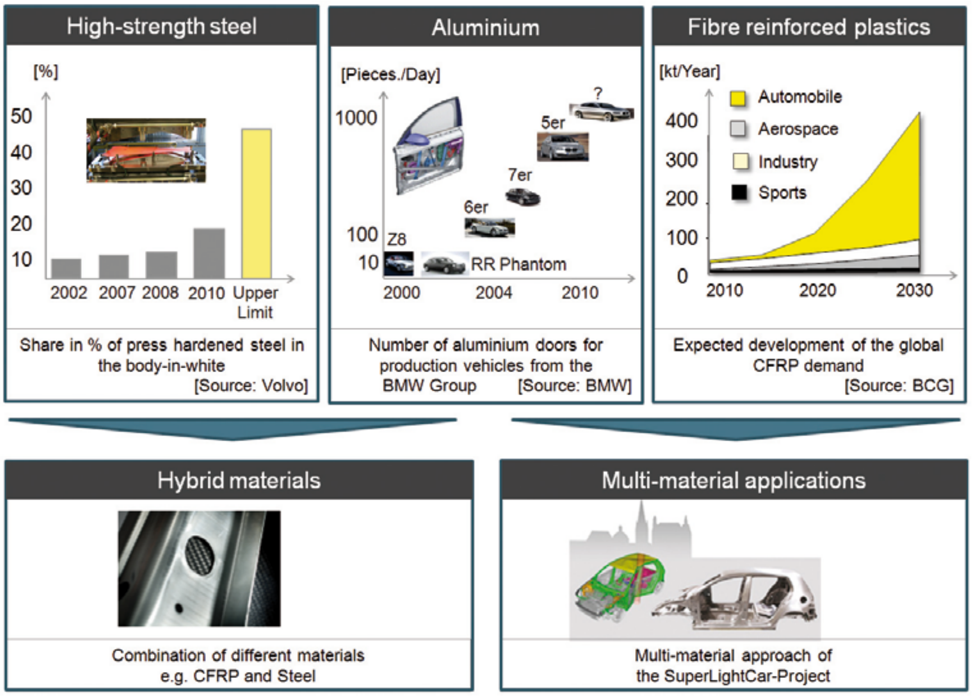


Figure 2: Current material diversity poses challenges for joining technology

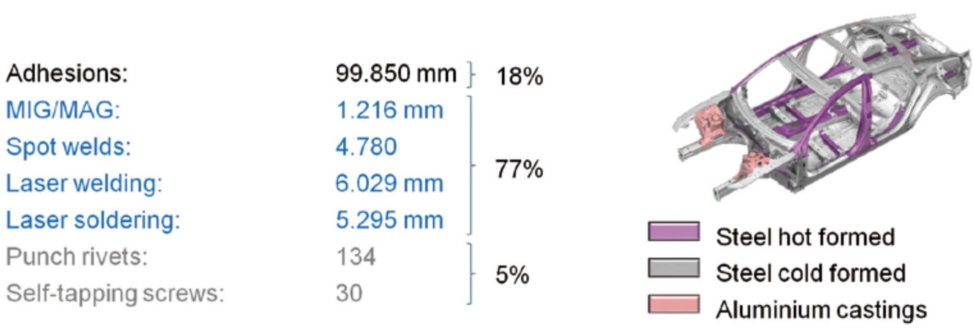


Figure3: Overview of joining technology of a current body concept

ble structures. Instead of only one optimal material, hybrid and multi-material structures meet the demands far better /5, 6, 7, 8, 9/. One of the main challenges is the combination and integration of different materials into one lightweight design structure. Facing this challenge will play a major role in realising those concepts.

The importance of joining technology

Outstanding material properties in terms of stiffness, strength and energy absorption capability are preconditions for the design of efficient lightweight constructions. Generally, only an adequate joining technology makes it possible to use the potential of high performance materials.

Adhesion technology is a central element of today's joining technologies and fulfils the mechanical load requirements with a high reliability related to manufacturing and climatic conditions /10/. In metal constructions, the adhesion technology is often combined with thermal joining methods like spot welding or mechanical joining technologies like folding, clinching, rivetting or screwing to improve the properties of the structure (Figure 3) /11/. Crashstable structural adhesives allow relevant deformations at high loads, and by means of a uniform and planar application of force and distribution of stresses, they help to reduce the mass by enabling better component stiffnesses, crash properties and endurance strengths. Further advantages arise from the low thermal impact on the materials, damping of vibrations and the opportunity of sealing /12/.

In a multi-material compound, adhesion technology offers joining of different material combinations. As a contrast to mechanical join connections, the adhesive is also in charge of electrochemical potential separation and often no further measures to avoid contact corrosion are needed. Adhesives also enable the equalisation of different thermal expansions, even if especially in thin structural bondings high stresses still may appear in the bond line.

Next to multi-material applications, new fibre-reinforced composite constructions also require the usage of adhesion technology to connect single composite structures or to integrate elements for force application. By using adhesive technology as joining method, harm of the laminate, and by this an influence on the properties of the laminate, can be avoided. Deficits of strengths can be approached by an adequate dimensioning of the join patch.

Challenges for adhesive technology

Goal of current lightweight design efforts is the consequent and efficient use of material varieties and more and more the usage of lightweight design potentials of fibre reinforced plastics in a material mixture. Against this backdrop, many material, design and manufacture process side challenges arise with respect to properties and in particular the necessary skills for applying the adhesive technology (Figure 4).

From the perspective of lightweight design, an enhancement of the properties of adhesives concerning strengths and stiffnesses coexistent with high breaking elongations is desirable, to increase the efficiency of the structure by using adhesives to connect the components. In the ideal case, the joint should be detachable to enable the required separation of materials for a sustainable recycling and to permit the disconnection of the assembly in case of repair. This “disgluing” is already issue of current research activities /14/.

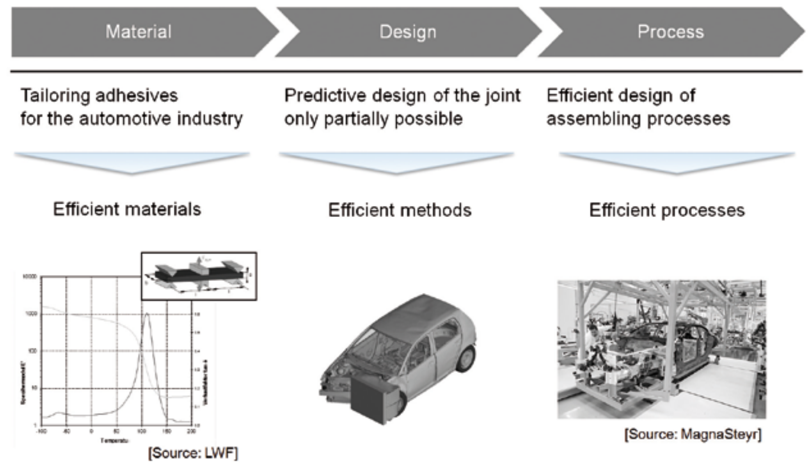


Figure 4: Challenges for joining technology from the view of automotive research

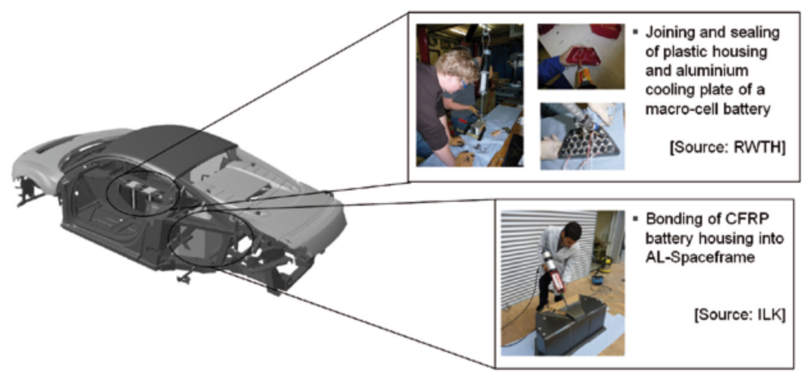
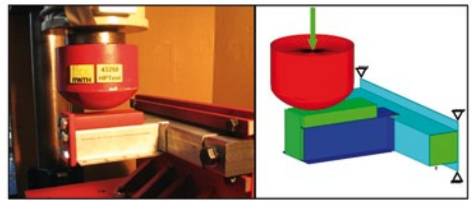


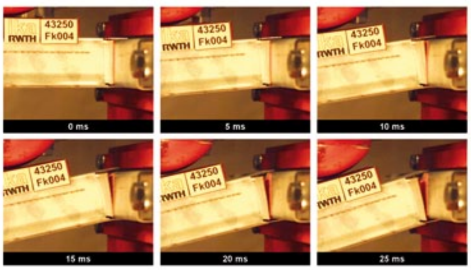
Figure 5: Use of adhesion technology in the research project e performance

Next to this rather visionary goal, for automotive application firstly a substantiated knowledge of the behaviour of today’s adhesive systems is required (Figure 5). The scope of parameters of different polymer systems and curing conditions, which influence the properties of the join connection, requires more complex surveys than necessary for mechanical and thermal joining technologies. A suitable surface preparation of the materials which should be joined is also decisive. In addition, the influences of different load, velocity, climatic conditions and ageing effects on the properties of the material must be well known. Furthermore to warrant a secure join connection, knowledge of crack initiation, crack extenstion and fracture behaviour is necessary.

In pursuing an efficient design of join connections, a variety of parameters for a possible adhesive connection is electable. The challenge for the engineer is to choose a suitable adhesive system. A guideline for the selection of the adhesive system and the processing conditions for different fields of applications is desirable.

Thereby it is crucial, that the predictive design of the join connection is possible in the numerical simulation for static and dynamic load cases. For the simulative design of bonded joints under crash load, suitable models and FEM modules are available. But still, the design of bonded join connections is related to high development efforts. Next to making material characteristics of adhesives in appropriate databases available, the description of the elastoplastic properties and the cohesive failure of adhesives is a central condition. Material models are able to estimate the behaviour of adhesives for engineering-based applications. However, further experimental and theoretical investigations are required /15, 16/. Even in near future the design of join connections will only be possible by assuming cohesive adhesive failure. In regard to the design of lightweight structures an extension of the development methods is necessary to consider specific parameters such as





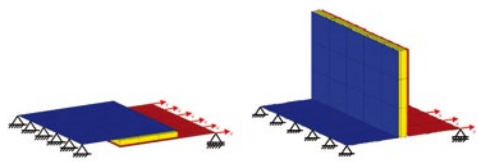


Figure 6: Comparison of experiment and simulation during the design phase of a multi-material front end

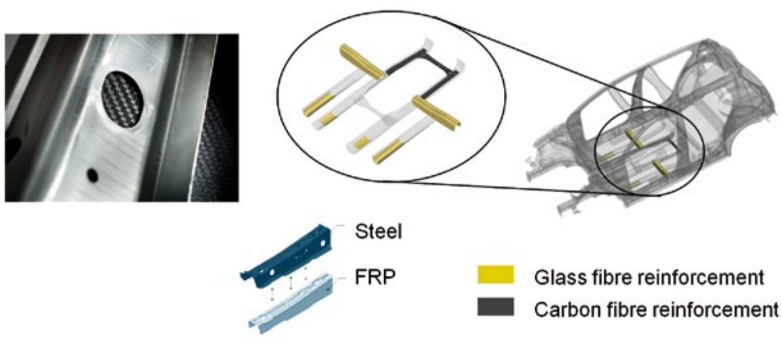


Figure 7: Challenge of hybrid design – Joining of FRP with metal

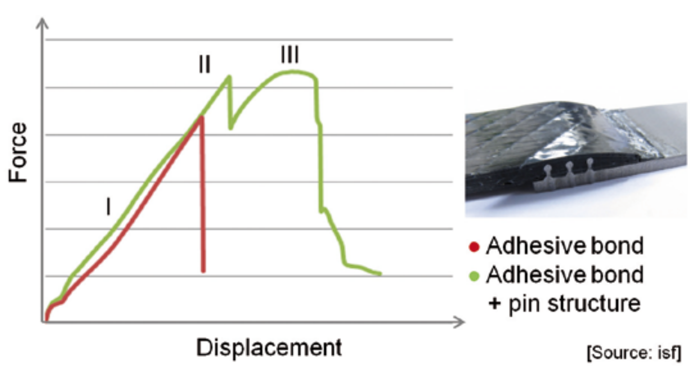


Figure 8: Potential for the future – new and smart hybrid compounds by bonding, form-fitting elements and damage

temperature dependence, influence of moisture and thermal stresses, which, at thermal and mechanical joining methods only are of low importance.

In the automotive industry, processing of adhesives is already implemented in mass production. Nevertheless, possibilities for improvement, which are necessary to use lightweight design potentials, can be seen. Due to high application speeds, bonding can provide an advantage over conventional joining methods concerning processing times /17/. However, to ensure the handling strength at the required cycle time, often additional joining methods are necessary. On the route to a completely bonded vehicle, adhesives and processing methods are required, which enable short curing times as well as meeting the requirements of today's structural adhesives. For current adhesive systems, this demand provides a trade-off between a low heat entry and a high temperature resistance of the cured joint. In future, new types of adhesive systems and reaction mechanisms may provide new solutions /18, 19/.

Developments of processing methods may offer improvements to design join connections. Thus, the bonding of opposite or mutually perpendicular surfaces, as required in some applications /20/, is not yet robust or able to ensure the demanded quality requirements. Secure bonding with precise dosing and less rework under the requirements of tolerance compensation is another challenge.

A promising approach for the design of adhesively bonded metallic and FRP connections (Figure 7) is the combination of adhesive bonding with interlocking structures in order to realize an ideal combination of material and force closure. Next to excellent mechanical properties this enables to integrate additional functions in the joint, such as the selective detection of failures (Figure 8).

Figure 9: Efficient joining technology for lightweight design — Innovative electric vehicle concept of the Institut für Kraftfahrzeuge — SpeedE

Summary

On the way to sustainable lightweight design concepts of future vehicles, adhesive technology seems to be a promising joining technology. The use of this joining method, however, requires a high development and partially research effort to design the connection /21/. The long term goal must be to standardise the selection of materials, the methods and procedures of adhesion technology, to overcome today's obstacles and to open adhesion technology to a wide range of applications. Numerous studies confirm these tendencies /22, 23, 24, 25/.

In this task the Institut für Kraftfahrzeuge (ika) at RWTH Aachen University and the Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka) are working intensively together with adhesive experts from industry and research to develop efficient and progressive lightweight design concepts with the right joining technology (Figure 9). ■

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