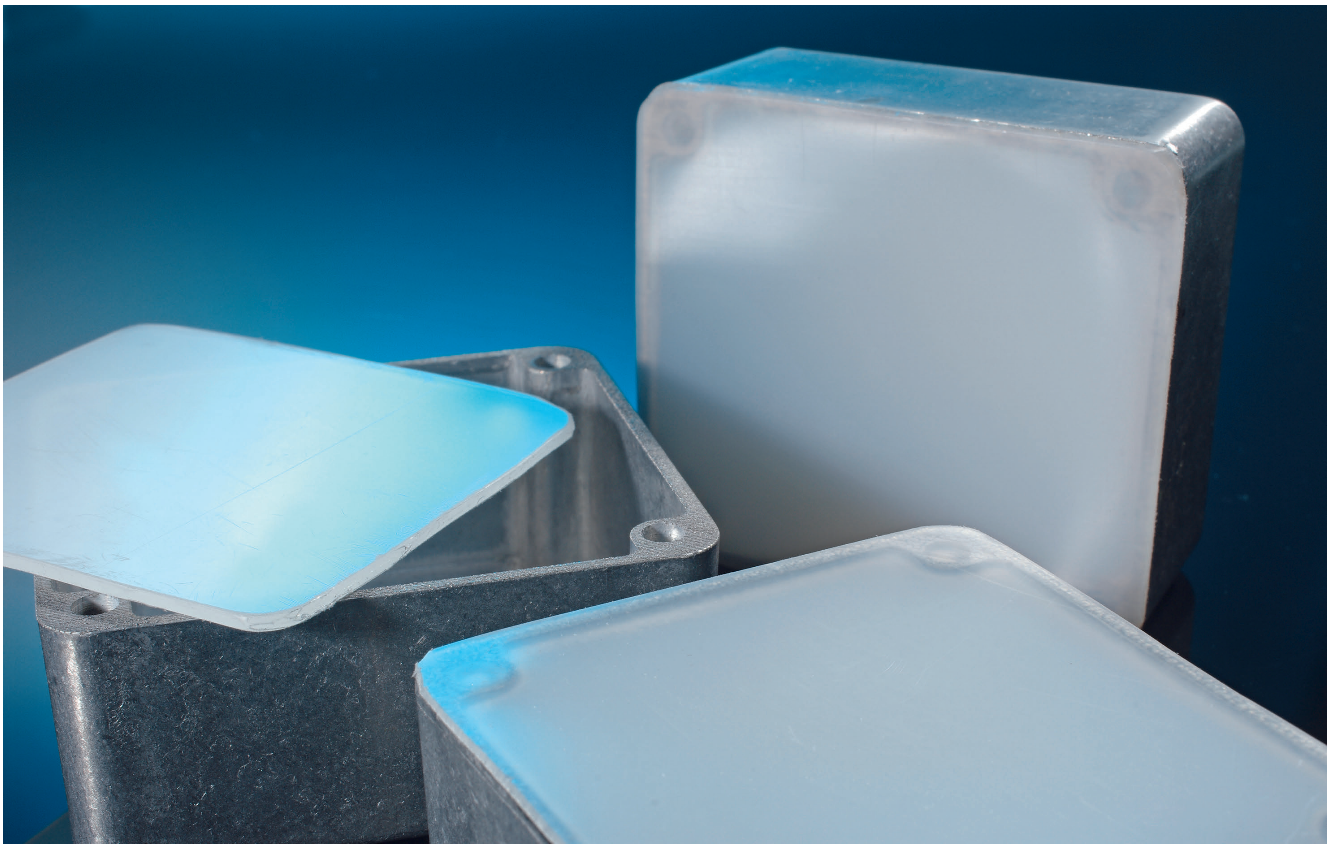
SPECIAL:
Hybrid Technology

[VEHICLE ENGINEERING] [MEDICAL TECHNOLOGY] [PACKAGING] [ELECTRICAL&ELECTRONICS] [CONSTRUCTION] [CONSUMER GOODS] [LEISURE&SPORTS] [OPTIC]

Alternatives to Gluing and Mechanical Joining

Thermal Direct Joining of Plastic-Metal Combinations for Industrial Applications

The joining of dissimilar materials is a special challenge for joining technology. Thermal direct joining together with suitable surface treatments enables stable joints between very dissimilar materials combinations, thus offering an alternative to classic procedures for joining hybrid parts.



This electronics housing composed of an aluminum die casting with PA6 covers is a potential application case for thermal direct joining © Fraunhofer ILT

Plastic/metal hybrid parts are being used increasingly in numerous branches, such as the automotive, aerospace, or electronics industries. The joining of dissimilar materials continues to present a special challenge to joining technology. In recent years, thermal direct joining of thermoplastics and metals has developed into a promising joining technology capable of replacing gluing or mechanical joining.

This joining process consists of two process steps: surface treatment of the metal joining partner and the thermal joining procedure. Depending on the materials combination and case

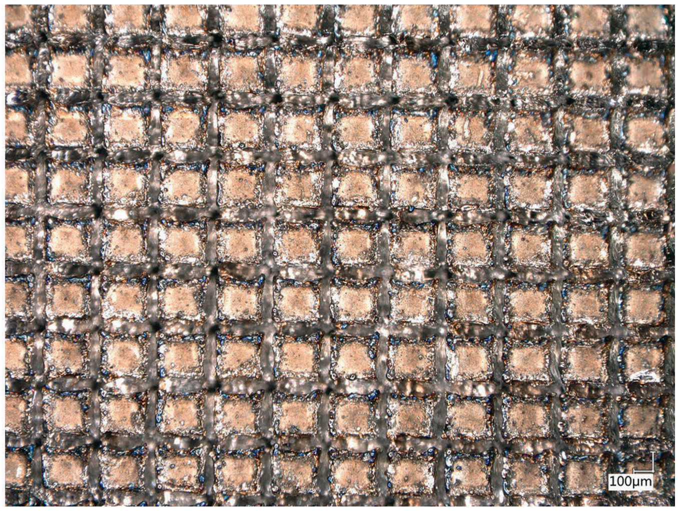


Fig. 1. Cross-section of a laser microstructured DC06-galvanized metal sample (left) and a reflected light image of the structure pattern (right)

of application, the various pretreatments and joining methods influence the properties of the hybrid joint. The required know-how is still insufficient to transfer thermal direct joining to industrial series production. This applies to the effect on bond strength from the various surface pretreatments of each materials combination, as well as to the effect of ageing behavior, e.g., under temperature changes. Precisely these influences are being investigated by the AGeD, a joint project of the ILT, the Fraunhofer Institute for Laser Technology, and the ISF, Institute for Welding and Joining Technology of the RWTH Aachen, Germany, to investigate various pretreatment and joining methods in respect to ageing behavior and performance following thermal direct joining of metals and plastics.

Interplay between Surface Pretreatment and Joining Process

Suitable pretreatment is a decisive factor for achieving long lasting connections between thermally joined partners. Bond strength is largely influenced by the energetic state, morphology, geometry, and chemical structure of the surface. Surface pretreatment aims at activating the surfaces, and/or increasing the bond between the joining partners through geometrical alterations to the surface. In addition to chemical surface pretreatments, emphasis has been placed on corundum blasting and laser microstructuring to create undercuts on the metal surface.

In corundum blasting, the metal surface is irradiated with a blasting material at high pressure in order to roughen the surface with irregular, unreproducible structures. Whereas undercuts result from corundum blasting only in rare instances, laser microstructuring modifies the metal surface by sublimation and remelting in such a way that the surface becomes larger, and defined undercuts occur that enable mechanical interlocking between the joining partners.

In the AGeD project, a single mode fiber laser is used to create linear cavities in the metal surface that exhibit an undercut. To do so, the laser beam is deflected linearly over the workpiece by a laser scanner. The material is partially evaporated and melted by the highly intense laser radiation. Steam pressure drives the melt out, and it partially solidifies at the structure neck. A teardrop-shaped undercut is formed by traversing the scan contour several times (**Fig. 1, left**). Targeted arrangement of the structures and increased structure density, e.g., in a cross-grid pattern (**Fig. 1, right**), can increase bond strength [1].

To obtain a long-lasting joint between plastic and metal in the actual joining process, the thermoplastic has to be locally heated to melt temperature, and external joining pressure applied in order to wet the metal surface and fill the surface structures. The metal surface is often heated for this reason, and the plastic melted indirectly via thermal conduction. Various heat sources can be used, such as induction, heating elements, or laser irradiation. »

The Author

Kira van der Straeten, M.Sc., is the team leader for polymer processing at the ILT Fraunhofer Institute for Laser Technology in Aachen, Germany;
kira.van.der.straeten@ilt.fraunhofer.de

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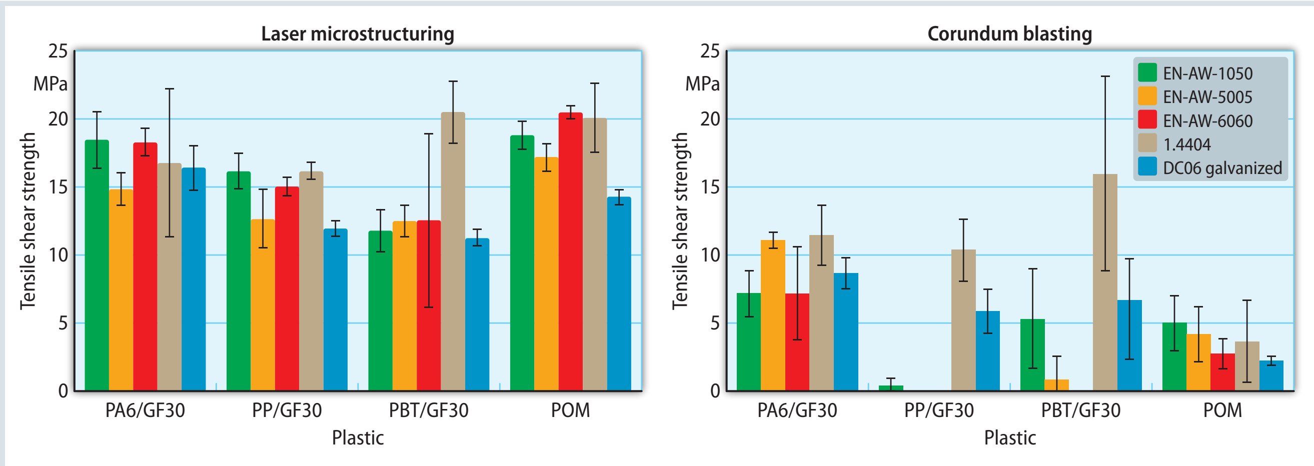

Fig. 2. Influence of surface pretreatment: tensile shear strength of various materials combinations subsequent to laser microstructuring (left) and corundum blasting (right) Source: Fraunhofer ILT; graphic: © Hanser

Each joining process has its particular pros and cons, so that processing requirements, part geometry, and materials properties are very important when selecting the process. For example, laser joining enables flexible reworking at short processing times, but the laser beam must have access to the joining zone. In induction joining, even hard to access parts can be joined.

On the other hand, the processing times are longer, and the inductors may have to be adapted and configured according to the geometry of the joining zone. No significant differences can be observed among the various joining procedures, as long as the procedure ensures that the metal surface and structures are completely wetted with plastic melt.

Materials Selection Affects Bonding Strength

The requirements for surface pretreatment and the prevailing bonding mechanisms differ according to the materials combination. Within the framework of the AGeD project, samples were joined and subsequently tested that combined plastics (PA6, PP, PBT and POM) with various materials (aluminum and steel) after different surface pretreatments (corundum blasting and laser microstructuring) by diode laser radiation. It turns out that roughing the surface by corundum blasting suffices to create a bond between many materials combinations (**Fig. 2**) This is in part due to the polarity of the plastic and the formation of specific adhesion forces between the joining partners.

However, clearly higher bond strengths can generally be achieved by introducing reproducible undercuts by means of laser microstructuring. Moreover, all materials combinations be combined with each other regardless of the polarity of the plastic. This is helpful if the process is intended to open up the broadest possible field of application. In addition, this promises to provide good results in investigations of ageing, since the mechanical interlocking of the plastic in the structures suggests that interfaces are less susceptible to external influences.

Other surface pretreatments, such as irradiation by atmospheric pressure plasma, or the use of adhesion promoters can only be used for a few materials combinations. Here the tensile shear strengths of the hybrid connection lie clearly lower than the results from laser microstructuring.

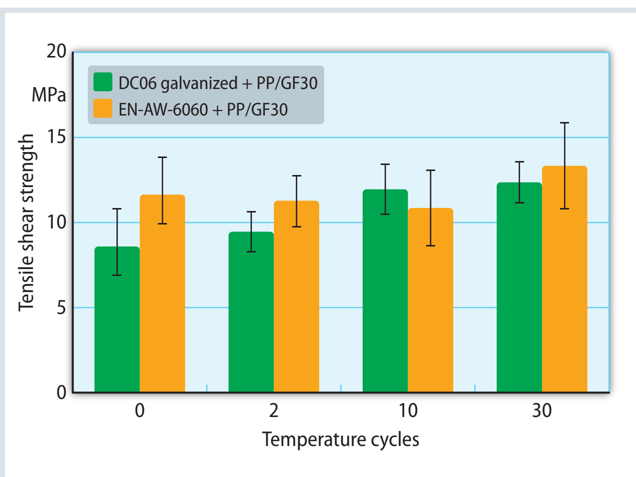

Fig. 3. Tensile shear strength of hybrid connections between glass fiber-reinforced polypropylene and steel (green) and aluminum (orange) prior to climatic change tests and subsequent to varying long temperature cycles from 80 °C to –40 °C

Source: Fraunhofer ILT; graphic: © Hanser

Climatic Change Resistance of the Hybrid Connection

Besides the selection of suitable surface pretreatment procedures and the joining process for a particular materials combination, the conditions of application also play important role in subsequent industrial implementation. Due to the different thermal expansion coefficients of plastic and metal, thermally changing loads can have great influence on bond strength.

In initial investigations, climatic change tests based on an automotive standard (VW P1200) were performed on hybrid connections of PP/GF30 joined with laser structured steel or aluminum. To this end, the samples were stored in a climatic exposure test cabinet at changing temperatures between 80 °C

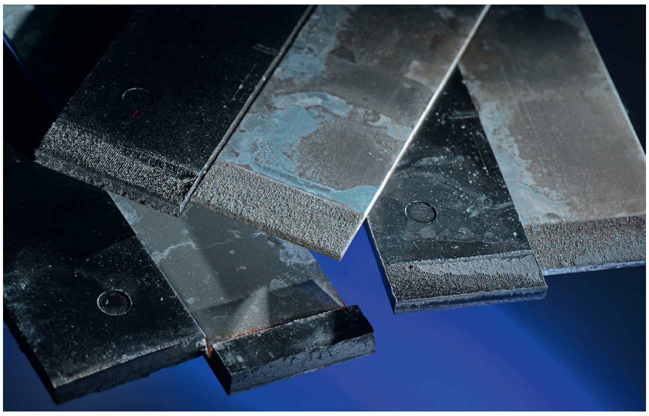

Fig. 4. Corroded tensile shear samples subsequent to ageing investigations © Fraunhofer ILT

and 95 % relative humidity and –40 °C and tested for bonding strength following 2, 10, and 30 cycles. The results **(Fig. 3)** show that the bonding strength of the hybrid connection is not significantly affected by temperature change. Even if the results cannot be transferred to all other material pairings, they provide a promising future for the use of thermal direct joining over a wide field of applications.

Joining Methods for the Future?

When suitable surface pretreatment methods and joining processes are selected, thermal direct joining offers a suitable alternative to conventional joining processes, such as gluing and riveting or screwing. High bond strengths can be achieved by laser microstructuring to create undercuts, almost regardless of the material combination.

However, for certain combinations of materials, strong connections can also be achieved by simple methods. Initial climatic change tests indicate promising results with respect to long-term join stability. These investigations should be expanded in the future to include further materials combinations and different surface pretreatments and joining processes.

For applications in the automotive field, the corrosion resistance of the join plays an important role in addition to thermal shock endurance. Media tightness is important above all for housing applications, such as for electronic components. In the near future, further investigations are planned within the framework of the project, e.g., corrosion tests according to DIN EN ISO 11997. The goal is to transfer the project results to a recommended action catalog in order to give users assistance when selecting the procedure for a particular industrial application. Since these results show high bond strengths and good long-term stability, short processing times, as well as high flexibility in the selection of materials, they are a good starting situation for rapid implementation in industrial series production. ■