Glass Fiber-Reinforced Polyphenylene Sulfide Made Weldable

Novel Laser Welding Technology Can Also Be Used for Higher Filled PPS Types

Especially in the automotive industry, high-performance polymers are increasingly replacing assemblies made of metal and conventional engineering plastics, but their properties often present new challenges for joining technology. With novel laser system technology, even demanding materials can be joined.

Cross-section of a weld seam: The microsection of the seam shows a joining zone and characteristic melt flow for quasi-simultaneous welding © Evosys, DIC

Thanks to their superior properties, such as high heat and chemical resistance, low weight and dimensional stability, high-performance polymers are increasingly replacing assemblies made of metal and conventional engineering plastics. In the automotive industry in particular, this trend is being boosted by the increasing system complexity and integration of functionalities, while at the same time demanding a reduction in installation space and weight. Last but not least, ever stricter global emissions legislation is forcing further measures to reduce vehicle consumption and thus weight, and is driving forward the development of new powertrain concepts for electromobility.

Typical areas of use for high-performance plastics are applications with high thermal and mechanical stress along the entire engine and drive train, assemblies and hoses for thermal management, but also components specifically for electromobility, such as battery carriers, actuators or electrical and electronic systems in general.

PPS Connected in a Process-Safe Way

As a representative of these high-tech materials, polyphenylene sulfide (PPS) is a highly stable, semi-crystalline polymer with a remarkable degree of molecular stability against thermal degradation, chemicals and hot water. In addition to this unique combination of properties, it is known for precision molding to tolerances, outstanding low creep behavior and inherent non-flammability (UL94 V-0), which eliminates the need for flame retardants. **Figure 1** shows an example of a water pump containing components made of DIC.PPS in highly stressed areas.

In addition to material properties, joining technologies such as laser plastic welding are also in demand to meet these requirements. For example, PPS could previously only be joined to a limited extent using laser radiation due to its optical properties. In a joint project between Bühler Motor GmbH, DIC Cor- »

Fig. 1. Water pumps such as Bühler Motor's bFlow C5A-60x feature components made of polyphenylene sulfide in highly stressed areas © Bühler Motor

poration and Evosys Laser GmbH, it was shown that a new type of laser system technology can be used to join even a demanding material such as PPS in a reliable process.

In order to meet the requirements for dense packaging in electronic assemblies and other applications, the connection technology used should not restrict the freedom of design. It should also ensure a particle-free, media-tight and robust connection and expose sensitive electronic assemblies to the lowest possible mechanical stress during the joining process. From these points of view, laser transmission welding of plastics has already established itself as an ideal and often alternative-free process. In this technique, a joining partner that is transparent for the laser radiation is connected to a laser-absorbing part in a lap joint. The laser beam is focused through the laser-transparent part onto the absorbing part, causing it to melt on the surface. By pressing the two components together, the laser-transparent plastic part is also plasticized via heat conduction, so that a stable, material-locking connection is created.

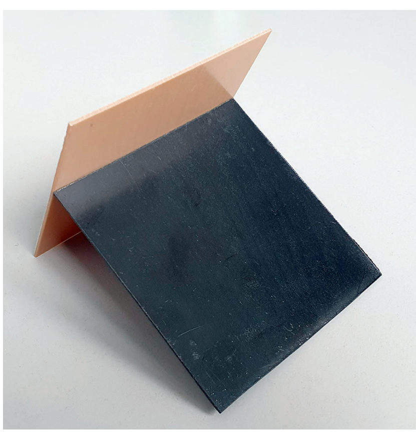

Fig. 2. Laser-welded PPS sample plates: The black plate contains particle carbon black and therefore absorbs the laser radiation © Evosys, DIC

Laser Welding of Glass Fiber Filled Materials

Most thermoplastic polymers, unfilled, are transmissive enough for the wavelength range of the commonly used laser sources (typically 808–1064 nm) to be used as laser transparent joining partners. In contrast, the desired absorption behavior is usually achieved by using additives, in the simplest case by particle soot. A typical overlap configuration of laser transparent (natural) and laser absorbing joining partner (black) is shown in **Figure 2** using laser-welded PPS sample plates from DIC Corporation.

However, it is this dependence on the optical properties of the joined parts that makes laser welding of high-performance plastics a demanding task. This is because they often have a very low transparency for the laser radiation even when unfilled, due to the material and pre-process conditions, for example because of their microstructure. Filling them with glass fibers further impairs the optical properties of the transparent joining partner, since the laser radiation is increasingly reflected and scattered at the fibers. As a result, the beam profile is spatially widened so that the radiation intensity and the energy input into the joining zone decrease. In relation to the same area in the welding zone, this means in concrete terms that the proportion of transmitted radiation decreases – this represents an additional challenge for the welding process.

In order to meet the challenging process conditions, Evosys has developed a package of measures for demanding applications, which combines a special optical system (Next Generation Optics, NGO) with a special process control to improve the irradiation strategy and energy input into the assembly [1]. Together with the DIC Corporation, Evosys has already published results from tests on DIC.PPS, which prove the effectiveness and better weld seam quality in conjunction with NGO – characterized by higher seam strengths and shorter process times [2]. For more than 30 years, the material has proven itself to be the high performance material of choice for a wide range of applications, enabling engineers to realize significant cost savings in the automotive, electrical & electronics, household appliance and food market segments.

Analysis of Differently Filled Types

Welding tests were carried out on the compound DIC.PPS FZ-2115, a specialty filled with 15 % glass fibers based on linear PPS, which has a very low viscosity and thus enables thin-walled injection molding. Due to the good results, the next step was to extend the tests to DIC.PPS FZ-2140, which with 40 % glass fiber filling is a typical PPS standard material and is used in various applications due to its balanced performance. However, it has a transmission which is about 15 % worse than that of the less filled compound (**Fig. 3**, measured with a Pictor Planar testing device from Intego GmbH, Erlangen, Germany), which means a correspondingly lower energy input into the joining zone for the same laser parameters. Generally, however, the laser transmission for the laser-transparent component and for a conventional laser system technology should have a value of at least 20 % in order to be able to join the components reliably.

For this reason, the partners again carried out an extended series of tests at Evosys on a concrete automotive application. The welding task consisted of joining a flat, free-formed upper part with a lower part in a lap joint. The joining interface consists of several, complexly shaped segments, which are realized by welding ribs with a 3D geometry. This means that the weld seam contour not only runs in the (horizontal) plane, but also rises in the vertical direction. The thickness of the upper joining partner as well as the width of the weld rib is approx. 1 mm with a total seam length of approx. 100 mm. In addition to laser welding, ultrasonic welding was also tested as an alternative joining method. However, laser welding proved to be the preferred process, especially because of the higher flexibility with regard to the weld seam geometry, the simpler system technology and the mechanically gentle, vibration-free processing of the sensitive assembly.

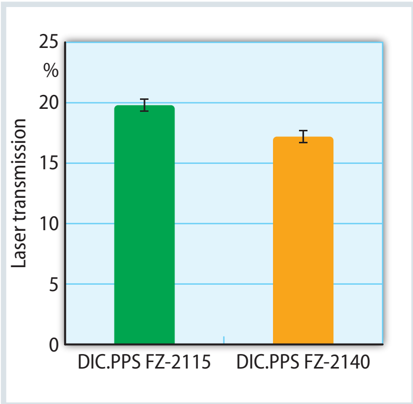

Fig. 3. Laser transmission of DIC.PPS at λ = 980 nm and a material thickness of 1 mm

Source: Evosys; graphic: © Hanser

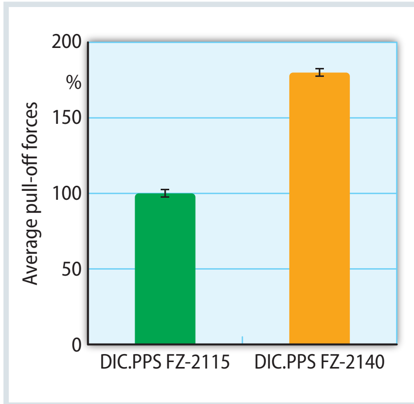

Fig. 4. Average pull-off forces of laser-welded DIC.PPS samples (n=3)

Source: Evosys; graphic: © Hanser

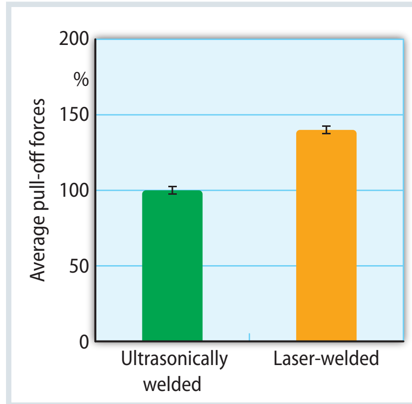

Fig. 5. Average pull-off forces depending on the welding process, DIC.PPS FZ-2140 (n=3) Source: Bühler Motor; graphic: © Hanser

The materials used for the laser-transparent joining partner were the aforementioned natural-colored compounds DIC.PPC FZ-2115 and DIC.PPS FZ-2140. The second component consisted of the black material DIC.PPS FZ-2140 Black, which has a high absorption for the laser radiation.

Comparison of Joining Methods

Contour welding and quasi-simultaneous welding with controlled joining collapse were selected as process variants and the process parameters laser power, laser feed, clamping pressure and joining collapse were varied in various combinations. The optical configuration consisted of a diode laser with a wavelength of 980 nm as beam source, the NGO as part of the beam forming and a galvanometer scanner with focusing optics for beam guidance. Subsequently, the seam quality was evaluated by means of a fractographic analysis, microsections and the achievable pull-off forces of the upper part by Bühler Motor. The results of this mechanical test are shown in **Figures 4 and 5**, respectively, in a comparison between the differently filled materials and the ultrasonic and laser welding processes (each with optimum parameters).

On the one hand, the results show that the pull-off forces do not deteriorate due to the increased glass fiber content, but even increase with a comparable joining collapse for DIC.PPS FZ-2140. A significant influence here can be the mechanical properties of the material itself, which have a beneficial effect on the deformation and the stress distribution in the component during testing (e.g. the higher stiffness). Nevertheless, it can be emphasized that with NGO only approx. 10% more laser power was required for the same welding time to compensate for the poorer transmission of the material filled with 40% glass fibers and to achieve a comparable joining collapse. This moderate increase in power also did not lead to any negative effects on the welding process, such as burns on the component surface. Here, too, the homogeneous irradiation strategy by means of NGO has a demonstrably positive effect.

On the other hand, the laser-welded samples exhibit significantly higher pull-off forces in comparison with ultrasonically welded assemblies and exceed these by up to 40% for DIC.PPS FZ-2140 with optimally selected parameters in each case. In addition to process engineering advantages such as greater design freedom, very flexible system technology and mechanically gentle material processing, laser welding therefore also offers a significant plus in weld seam quality.

Summary

Laser plastic welding has already established itself as the preferred joining technology in many fields of application due to its advantages. The Next Generation Optics (NGO) from Evosys makes it possible to transfer these advantages to the high-performance material PPS, which could previously only be joined by laser under favorable conditions due to its limited laser transparency. The welding tests on a concrete automotive application of the two differently filled PPS types DIC.PPS FZ-2115 and FZ-2140 prove that with NGO even higher filled PPS types can be laser welded process-safe and in high quality. This opens up a wide range of new fields of application and thus makes a significant contribution to meeting the increasing demands for weight reduction, higher packaging and increased cost efficiency. ■

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References & Digital Version

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