Abstract

The demand for material, energy and weight saving in many industrial fields promotes the use of novel lightweight construction materials like fibre reinforced plastics (FRP). FRP with thermoplastic matrices provide a high potential for lightweight construction together with the possibility of process automation, a good medium resistance, a favourable impact behaviour and good recyclability. However, the employment of these materials raises joining problems since usual joining technologies can scarcely be used. Preliminary studies showed that welding technologies are superior to the conventional joining technologies riveting and adhesive bonding with regard to the mechanical seam properties.
Therefore, the aim of the present work was the development of plant configurations and process windows for welding thermoplastic FRP with which a material and component spectrum as big as possible can be joined economically. The investigated materials were fabric reinforced thermoplastics (polypropylene, polyamide 12, polyamide 6.6 and polyphenylene sulphide) with glass fibre and/or carbon fibre reinforcement and fibre volume fractions above 35%.

The evaluation of the existing welding technologies with regard to technological, economical and ecological aspects showed that vibration welding and induction welding are most suitable to welding of thermoplastic FRP. Therefore, these two welding technologies were investigated in detail in the present work.

For vibration welding the parameter influences determined in different works on unreinforced thermoplastics were confirmed qualitatively. However, for the examined fabric reinforced thermoplastics the process parameters differed quantitatively compared to those for unreinforced thermoplastics. The optimum welding pressure as well as the necessary welding time were three times that for unreinforced thermoplastics. Despite the abrasion of the reinforcing fibres due to the friction forces, a very good tensile shear strength was achieved. For a glass-fibre fabric reinforced polyamide 12, for example, a weld factor of 1 was achieved. A process-controlled welding pressure reduction during the vibration phase 3, which was proposed for unreinforced thermoplastics, was integrated into a developed system controller programme. In this the melt displacement course is analysed online and the pressure is reduced automatically. For T-profiles with welded braces of glass-fibre reinforced polypropylene this procedure led to an essential strength and rigidity increase. However, for single lap joints of FRP no strength increase could be observed.

As technological and economical alternative to the vibration welding technology, a continuous induction welding process was developed, the necessary plant was built and the process was analysed and modelled. Current flow in the laminate was identified as the dominant mechanism of induction heating of carbon-fibre fabric reinforced plastics, due to the contact of the crossing fibre bundles. The essential quality relevant feature of the developed process is the course of the laminate temperature during the four process phases. This was analysed and the influencing process parameters were determined and quantified.
A simple model based on fibre contact in the laminate was developed, with which the necessary induction heating time for different laminate structures was estimated. The differing fibre contact areas in the different fabrics were considered by the introduction of a fabric factor. In order to obtain a more exact determination of the temperature distribution in the laminate a finite element model was developed. With this model the temperature distribution and the absolute temperature in carbon-fibre reinforced laminates during induction heating were predicted. It was sufficient to model the inhomogeneous laminate in a simplified manner as monolithic material with anisotropic properties. The three cooling phases were modelled with Fourier´s law of thermal conduction in its three-dimensional form, which was solved with the Binder-Schmidt explicit method. The difference between measured and calculated values was less than 10 %. With the developed models it is possible to determine optimum process parameters with the aid of a few easy preliminary experiments.

Like for vibration welding optimum process windows for carbon-fibre and glass-fibre reinforced thermoplastics were developed for induction welding, too. The achieved tensile shear strength of induction welded single lap joints was only slightly lower than that of vibration welded specimens concerning equivalent laminates.

Finally, the developed welding technologies were compared with each other regarding technological and economical aspects. It was found that vibration and induction welding complement each other very well. Vibration welding should be used for mass production and simple shaped parts with small to medium sizes, while induction welding is more suitable for small series of parts with almost any shape and size.