Kurzfassung

Thermoplastische Faser-Kunststoff-Verbunde (TP-FKV) rücken aufgrund ihrer guten Verarbeit- und Rezyklierbarkeit immer weiter in den Fokus der Automobilindustrie. Sie können effizient in serientauglichen Fließpress- oder Umformprozessen zu Bauteilen verarbeitet werden und bringen gute chemische, mechanische und thermische Eigenschaften mit. Die resultierenden Bauteile werden anschließend in Baugruppen eingesetzt, deren Strukturbauteile nach wie vor hauptsächlich aus Metallen bestehen. An der Schnittstelle zwischen TP-FKV und Metall entsteht ein Verbindungsproblem, das bisher meist durch Schrauben, Nieten oder Kleben gelöst wird. Allerdings werden diese Verfahren den speziellen Anforderungen der TP-FKV nicht gerecht und bringen zusätzliches Material in das Bauteil ein. TP-FKV eignen sich aufgrund der Schmelzbarkeit der thermoplastischen Matrix für thermische Fügeverfahren. Da die thermoplastische Matrix selbst als Klebstoff genutzt werden kann, entsteht eine flächige Verbindung, ohne dass Bohrungen oder zusätzliches Material notwendig sind. Außerdem kann durch eine geeignete Vorbehandlung der Metalloberfläche ein Formschluss erzielt und so die Festigkeit signifikant gesteigert werden.

In der vorliegenden Arbeit wurden ein diskontinuierlicher und ein kontinuierlicher, induktiver Schweißprozess entwickelt und optimiert. Dazu wurde ein Prüfstand entworfen und aufgebaut, der auf beide Prozesse angepasst werden kann. Beim kontinuierlichen Induktionsschweißen konnte die Prozessgeschwindigkeit durch den Einsatz einer Bauteilkühlung ohne Beeinträchtigung der Fügefestigkeit auf mehr als 1m/min gesteigert werden. Beim diskontinuierlichen Schweißen wurde die bisher verwendete, sehr fehleranfällige temperaturbasierte Prozessregelung durch eine Wegregelung ersetzt. So konnte ein stabiler, voll automatisierter Schweißprozess entwickelt werden. Zum Abschluss wurde die Eignung des Induktionsschweißens für die industrielle Anwendung am Beispiel eines Unterbodenblechs eines Nutzfahrzeuges gezeigt. Hier konnte durch diskontinuierliches Induktionsschweißen in Kombination mit der Vorbehandlung des metallischen Fügepartners durch Laserstrukturierung die gleiche Performance wie bei dem ursprünglichen, genieteten Ansatz erzielt werden. Es steht mit dem Induktionsschweißen also ein Fügeprozess zur Verfügung, der sowohl hinsichtlich Effizienz als auch Festigkeit für die industrielle Anwendung geeignet ist.

Abstract

European regulations regarding emissions of passenger cars and light-duty vehicles can only be met by significantly reducing the vehicle weight. The most promising materials for this purpose are fiber reinforced polymers und their combination with metals. Due to their good processability and recyclability, fiber reinforced thermoplastics are put into the automotive industry’s center of attention. The resulting components are then used in vehicles whose structural components still mainly consist of metals. Thus, a joining problem arises at the interface which is so far often solved by screwed and riveted joints. Still, the required holes destroy the reinforcing structure and preloading of screws leads to creeping of the thermoplastic polymer. Moreover, screws, rivets and adhesive increase the vehicle weight. These problems can be overcome by thermal joining methods which use the matrix polymer itself as adhesive. They offer the great advantage that a positive connection between the metal surface and the thermoplastic material can be established. For this purpose, the metal is treated, e. g. by a laser, so that a pattern of small, homogeneously distributed undercuts is produced on the surface. A very promising thermal joining technology is induction joining because it offers fast and efficient heating.

The aim of this thesis is the development of inductive joining processes for glass fiber reinforced thermoplastics and steel. There are two different approaches to induction joining. First, continuous induction joining, which is used to generate weld seams and second discontinuous induction joining, with which smaller areas can be joined. On the one hand, continuous induction joining was optimized to an extend that both stability and process speed meet the requirements of industrial application. On the other hand, discontinuous was brought from lab scale to an efficient and stable joining process. To that, the error-prone temperature based process control had to be revised entirely.

In preliminary trials, the influence of basic process parameters on the joint strength of glass fiber reinforced polyamide 6 (GF/PA6) and steel was investigated in a lab-scale press, independent from the actual joining process. It was found, that the optimum joining temperature is 290 °C, and that higher and lower temperatures reduce the joint strength. In addition, a linear relationship between temperature and displacement was determined. Joining pressure, in contrast, has no significant influence on the joint strength as long as the wetting of the steel surface by molten polymer is ensured. Moreover, it was analyzed within which temperature range of the cooling phase pressure must be applied. The highest strength was achieved, when the specimens were subjected to pressure from 270 °C to 200 °C. But also at 240 °C to 200 °C very good results were obtained. This small temperature range enables a fast process, because a short phase of pressure application is sufficient.

The effect of surface pretreatment was investigated using discontinuous joining. It was found, that even thermoplastics which offer good adhesion, such as PA6 require at least corundum blasting. Laser structuring of the steel surface, which generates undercuts, leads to a significant increase in strength, especially when materials with a poor adhesion, such as polypropylene, are used. In the latter case, laser structuring is necessary to establish a sound connection. In case of laminates reinforced with fabrics (in this case GF/PA6 and GF/PP), the cavities generated by laser structuring cannot be filled completely, because there is not sufficient molten polymer available. In case of glass mat reinforced thermoplastics (GMT), which has a high flowability in its molten state, the entire structure can be filled. Thereby, the positive effect of the laser structuring can be exploited optimally.

Subsequently, continuous induction joining was investigated with a focus on increasing its process speed. By using a substitute system, which main component is a measuring plate consisting of 24 thermocouples which are incorporated into glass fiber reinforced polyphenylene sulfide (GF/PPS), the temperature distribution and evolution during continuous induction joining were analyzed and optimized. It was shown, that a homogeneous temperature distribution can be achieved by choosing a suitable induction coil (line coil with flux concentrator), an advantageous position of the cooling nozzle (near the roller), the right stacking sequence (steel on top) and an optimum progression of the coil current. This enhanced process was then used to investigate the relationship between process speed, cooling and joint strength. The process speed could be increased to more than 1 m/min (16.67 mm/s) by using an active cooling and without a loss in joint strength. In order to determine, whether pressure can also be used for process optimization, an additional substitution system was developed to measure the pressure in the narrow joining zone with Fujifilm's

Prescale. The assumption, that the joining pressure does not influence the joint strength, was confirmed.

The knowledge from the preliminary trials was also used to further develop the discontinuous induction joining process. The current error-prone temperature control was replaced by a displacement control. Displacement is connected to the temperature in the joining zone and can be measured easily during the joining process, quite unlike the temperature. First, the discontinuous process was optimized by determining the influence of various process parameter (force, holding time, coil current, preset displacement) in the accuracy of the displacement control. The final setting was used to investigate the interdependency of the displacement and the joint strength. That way, a stable and fully automated joining process could be developed in which other parameters, such as force, coil current, and holding time can be varied without significantly impairing process stability.

Finally, the suitability of induction joining for an industrial application was shown by the example of an underbody shield of a commercial vehicle. Originally, mounting brackets were riveted to this underbody shield to then mount it to the body. The riveting was replaced by discontinuous induction joining. To enhance the joint strength, the surface of the aluminum bracket was structured by a laser. The resulting structure could be filled very well, because the joining zone of the underbody shield consists of GMT. Thus, an excellent bond could be generated, which even did not fail during mechanical testing. The base material of both riveted and induction joined components failed instead of the joining zone. The first underbody shield demonstrators were manufactured by conventional discontinuous induction joining. Therefore, the joining of one demonstrator took ten minutes. By using the new, displacement control joining process, the duration of one joining operation could be reduced to one eighty seconds. This example shows, that induction joining shows great potential for industrial application thanks to specific process optimization.