Abstract

The assembly of preforms is considered key element within modern preforming process chains for the manufacture of integral components made of carbon fibre reinforced plastics ("CFRP"). With the use of the ultrasonic welding technology for the assembly process new potentials can be released for binder based preforming approaches. During such operation ultrasound is induced into the preform under pressure within few seconds, heat is generated to melt the binder polymer and while the binder cools down under pressure, an adhesive bond is created.

As state of the art for preform assembly methods thermal based operations (convection oven) have been considered as well as textile based methods (sewing). Objectives have been quantified to achieve substantial benefits in comparison to these assembly routes: Reduction of process time, energy consumption and invest costs.

Specific welding seam requirements have been defined as well as methods to measure the according quantities. The required peel strength has been determined with 0.4 N/cm. The peel strength has been measured with dedicated specimen on a test bench. The maximum allowed fiber undulation in the welding seam has been quantified with 15 ° (local deviation from fiber nominal orientation) while an optical measurement method could be applied for its detection.

For the conduction of process studies, a dedicated test bench was equipped with an ultrasonic welding unit. This computer controlled test bench was designed to enable both continuous and spot welds with full parameter control, measurement of all relevant process factors and maximum reproducibility of the welding operations. The basic investigations have been conducted with a carbon fiber Non Crimp Fabric ("NCF", 254 g/m²) and a Co-Polyamide binder veil.

The mechanism of heat generation within the preform could be identified as mechanical friction of the fibers under insonification, which makes the process independent from the binder polymer type (unlike ultrasonic welding of plastics without reinforcement).

The process' degree of efficiency has been determined with 30.5 %. This is the fraction of the electrical power consumed by the ultrasonic generator that actually is converted into thermal energy within the preform. Most of the energy saving potential of the ultrasonic technology however lies in the fact that heat is only generated where needed: In the welding zone under the ultrasonic horn. Virtually no heating of tooling, air or surrounding preform takes place.

An ultrasonic frequency of 30 kHz has been identified as suitable; welding units of higher frequencies cannot deliver the required amplitude, lower frequency systems inherit disadvantageous large dimensions.

The welding pressure, amplitude and weld speed (respectively weld time for spot welds) are the main process parameters. Their influence has been studied and a parameter optimisation for a ten layered, bindered NCF has been conducted. A pressure of 0.68 MPa, an amplitude of 17 µm and a weld speed of 2.2 m/min has been identified as optimal for efficient insonification and acceptable distortions of the fiber architecture. The amplitude has the most significant influence on the weld result.

It has been observed, that during pressurized insonification, additional compaction in the preform laminate takes place. The degree of compaction increases with a decreased number of filaments carrying the acoustic load. After the end of the welding process a fiber volume content (FVC) of around 55 % has been measured in the welding seam of bindered NCF. With the welded preform samples, infiltration and cure has been conducted using the Resin Transfer Moulding technology (RTM) as well as the Vacuum Assisted Resin Infusion process (VARI). The VARI laminates with a FVC of around 52 % showed residual imprints of the weld process. These could not be observed in the RTM laminate with its FVC of 55 %.

The interlaminar shear strength (“ILSS”) has been measured for samples with different welding configurations. Each configuration has been attributed a possible defect induced by the welding operation. These defects were fiber squeeze out, damage of fiber sizing and fiber undulation. No reduction of the ILSS has been detected; neither for NCF nor for the woven fabric based laminate.

Measurement of the temperature development over the thickness of a preform laminate revealed a temperature profile which is strongly influenced by the thermal flux into the ultrasonic horn and the tool (“skin effect”). The temperature profile has been modelled based on the principle of the semi-infinite bodies. The system consisting of horn, laminate and tool has been divided in two sub systems. For each sub system the temperature profile has been calculated based on welding and material parameters. The profiles have been merged to the complete profile and compared to the measurements. An average accordance of 15,6 % has been observed.

Based on the results of the process studies a robot based welding head has been designed and integrated into a robot cell. A parameter based quality assurance has been integrated into the control system. As a demonstrator a frame-beam element has been chosen, which represents a typical section of a composite framework. The demonstrator has been manufactured in a fully automated routine.

With the manufacture of a representative element the potential of the technology could be confirmed and all objectives could be reached.