Towards increased reliability of resistance welded joints for aircraft assembly

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Abstract:
This study focuses on the opportunities and challenges of applying the static resistance welding process to a full scale upper shell fuselage demonstrator. An adapted resistance welding setup and process which produces high quality welds over the whole welding surface with a defined weld seam is described. The effects of scaling and the challenges that arise during the welding of the demonstrator are discussed. Approaches to solutions are presented to meet the required reliability of resistance welded joints in application.

Keywords: Resistance Welding, Thermoplastic Composites, Upscaling, Manufacturing Engineering, Process Control and Monitoring, Multifunctional Fuselage Demonstrator

Introduction

Carbonfiber-reinforced thermoplastics (CFR-TP`s) are currently in focus due to their advantageous characteristics in processing and especially in assembly. The weldability of thermoplastics offers new possibilities for a dustless assembly and allows a reorganization of assembly processes. The Center for Lightweight Production Technology (ZLP) Augsburg and its project partners AIRBUS, Premium AEROTEC and Aernnova are involved in the European Clean Sky 2 Large Passenger Aircraft (LPA) project and face the challenges of producing an 8 meter long thermoplastic upper shell segment of an aircraft fuselage.

The Multifunctional Fuselage Demonstrator (MFFD) structure will be manufactured out of carbonfiber-reinforced low melt polyaryletherketone (CF/LM-PAEK) CETEX® TC1225 provided by Toray Advanced Composites. While the skin of the upper shell will be manufactured in an in-situ tape laying process, the stringers will be integrated by continuous ultrasonic welding. The residual stiffening elements like frames, frame couplings and cleats will be integrated into the demonstrator by electrical resistance welding. This study focuses on the opportunities and challenges applying the static resistance welding process to a full scale upper shell fuselage demonstrator

Resistance welding principle and opportunities

Resistance welding principle

Resistance welding technology uses joule heating to melt the polymer at the interface between two components. For welding of electrical conductive components a welding element consisting out of an electrical conductor (here: Toray 5HS, T300JB carbon woven prepreg, 277gsm) in combination with an electrical isolation layer (here: Toray 4HS, EC5 E-glass prepreg, 105gsm) on each surface towards the welding partners is used. The electrical conductor projecting beyond the welding surfaces is contacted by means of copper blocks and closes the circuit via the power supply. A current flow through the welding conductor heats up the interface between the welding partners which are consolidated by applying an external welding pressure (Figure 1).

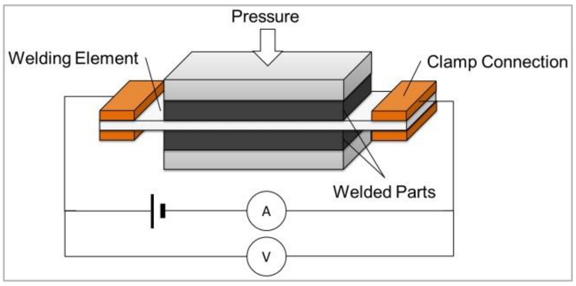

Fig. 1: *Schematic resistance welding setup (adapted from* [1]*)*

Weld performance

A great advantage of resistance welding technology is the ability to produce joints independent of the component thickness. This can be explained by the direct temperature application via the welding element in the joining zone. Since the welding element remains in between the joining partners it might lead to a reduced strength value compared to the part laminate values. However, earlier investigations on resistance welded CFR-TP's confirmed high welding factors (Tab. 1) and their transferability to different thermoplastic matrix systems.

***Tab. 1**: Welding factors as relationship between welded and press consolidated reference achieved for different matrix systems at single lap shear testing*

Matrix	PEEK	PEKK	PPS
Welding Factor	0,83 [2]	0,82 [3]	0,77 [4]

In addition, resistance welding technology offers the possibility of producing a completely closed connection as well as homogeneous weld seam properties with low damping losses in the ultrasonic scan (Figure 2). The picture shows a nearly flawless backwall echo in the C-scan. In the B-scan small damping indicated by two lines in the center of the weld represent the transition of the ultrasonic signal between glassfiber fabric and carbonfiber fabric.

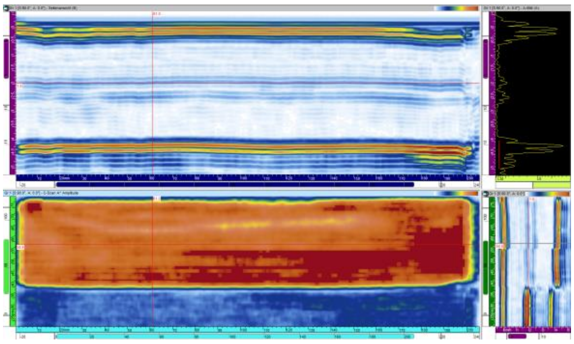

***Fig. 2:** Ultrasonic scan of a 200mm x 40 mm CF/PPS weld specimen*

Process control

The conventionally used welding conductors, such as stainless steel meshes or carbonfiber fabrics, show a temperature-dependent resistance behavior. This value can be used to generate a direct temperature feedback and to in-situ monitor and control the process.

Another way of controlling the welding process can be done by measuring the weld displacement [5], like performed in diverse welding technologies for unfilled and low filled thermoplastics. Due to the short welding paths in resistance welding, especially without additional matrix material in the bondline, this measuring method is preferably used for welds with matrix excess. In this way overpressing of the laminate can be avoided and the fiber volume content can be adjusted.

Resistance welding challenges

Tolerance Management

Tolerance compensation is one of the biggest challenges in the production of large aerospace structures. The welding of continuous fiber-reinforced CFR-TPs offers few possibilities to compensate for component tolerances and requires early consideration in the design process. The coincidence of welding partners is therefore essential as the presence of additional, gap-filling matrix leads to a non-homogeneous weld seam thickness followed by variations in bonding strength.

However, the resistance welding process offers a wide range of welding pressure levels that are able to deal with pressure variations in between the weld due to surface irregularities. In literature a welding pressure on the order of 1.0 MPa [5] is described to result in high quality welds while higher pressure levels lead to excessive squeeze flow with no further increase in weld performance [6].

Part diversity

The dimensional variation of individual components (e.g. clips) increases the number of variants of welding- tools since full surface contact pressure is required. With respect to the resistance welding process, this also means an increased variation of the welding process parameters. These depend decisively on the thermal conductivity of the components and the welding tools, as well as on the geometry of the welding elements.

Accessibility of components

The resistance welding process requires perpendicular accessibility to the joint for contacting and pressure built-up. Furthermore, accessibility is required on two opposite sides in the plane of mating parts in order to be able to establish sufficient electrical contact with the welding conductor. In order to ensure optimum load transfer between the components, their interface is designed to be as large as possible. In conclusion, this results in a higher force requirement for the pressure application in the joining area and reduced accessibility. A general reduction of the welding and contact pressure on the other hand allows the use of slimmer welding tools and thus facilitates the accessibility of the components.

Approaches to increase reliability

Process modifications

In-situ consolidation of thermoplastic composites is still under development and does not reach the same topological surface quality compared to press molded laminates. In order to achieve homogeneous heating of the welding element a constant contact pressure onto the surface of the welding elements is necessary.

Differences in pressure value lead to local differences in contact resistance followed by an uneven heating behavior. In order to minimize possible resistance fluctuations, two different tests are validated to increase reliability at later resistance welding.

On the one hand, a local post-consolidation of the T-AFP surface takes place by means of a heated die. In this additional process step the laminate is locally heated above the crystallite melting temperature and cooled down under constant pressure application. This is intended to reduce the surface waviness of the laminate and assure a homogeneous contact surface pressure at later resistance welding.

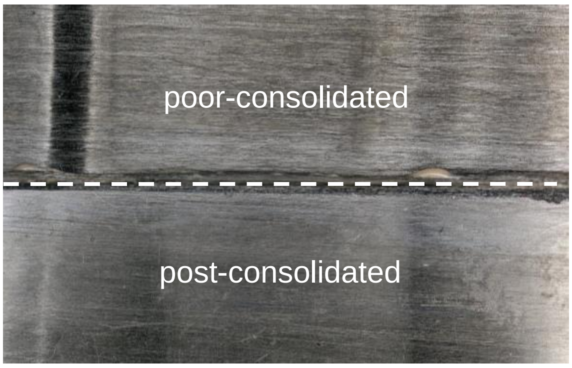

Fig. 3: *Comparison of poor- versus local post-consolidated unidirectional laminate using a heated die*

The second approach that is being pursued concerns a contact resistance reduction at the welding element through zigzag stitch perforation using a commercial sewing machine.

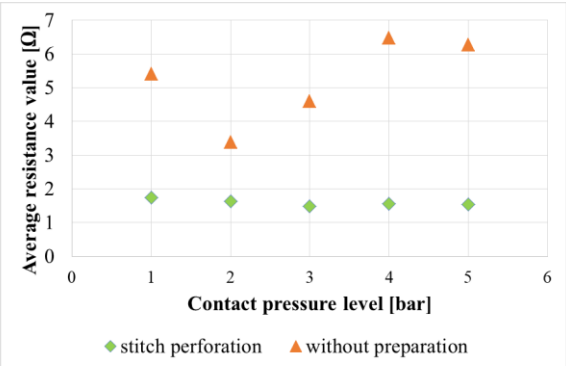

Fig. 4: *Measurements on contact resistance reduction due to a stitch perforation compared to a welding element without preparation*

The stitch perforation reduces the overall resistance value and leads to a reduced dependency of the resistance value on the contacting pressure level (Figure 4). The two approaches, a local post-consolidation of the laminate and a perforation of the welding conductors in the contacting area showed in preliminary investigations the potential to increase the reliability of the welding process for demonstrator manufacturing.

Intelligent tooling design

The resistance welding process is especially sensitive against local overheating at the transition between contact blocks and laminates (edge effect) due to possible air gaps. Overheating can be avoided by minimizing the gap distance in combination with solid copper blocks with high thermal conductivity.

For welding CFR-TP clips, an end-effector (Figure 5) with copper blocks adjustable towards the laminates was developed. The ability to flexibly compensate variations in the transition gap between component and copper block significantly increased the process reliability. In order to reduce the size of the pneumatic cylinders and minimize the end-effectors dimensions, the pressure application was realized here via a deflection lever [7].

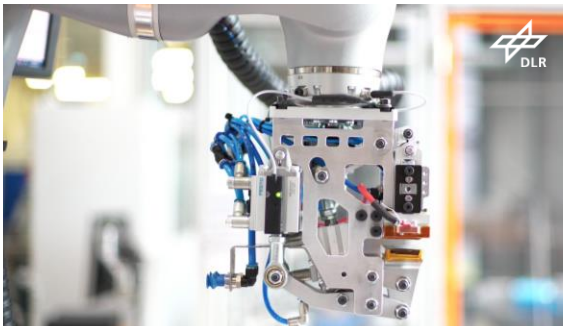

Fig. 5: *End-effector for automated resistance welding of thermoplastic clips* [7]

The kinematic principle was subsequently transferred from the clip welding end-effector to the welding modules for frame integration of the MFFD`s upper shell. Here, the integral C-frame additionally complicates the accessibility of the joining surface.

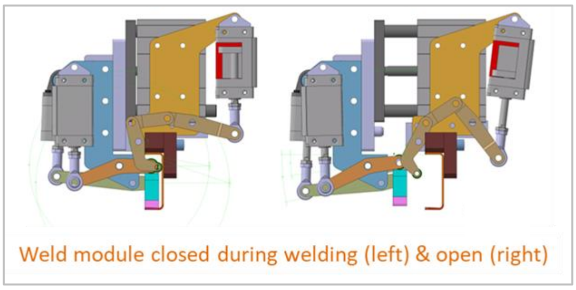

Fig. 6: *Weld module for C-frame integration*

Figure 6 shows the weld modules in open and closed position. These modules are later attached to a frame integration device and ensure proper pressurization of the welding surfaces at the positions of the attached flanges to the skin. A second lever mechanism provides for the positioning and pressurization of the copper blocks at the contact surfaces of the welding elements.

Integrated quality assurance

The integrated quality assurance offers the possibility of in-process monitoring and forms the basis for process control. Various welding parameters are monitored during the production of the demonstrator to ensure high quality welding. Besides necessary parameters for process control like pressure-, current- , voltage- and power values additional welding no-start, abort and approval criterion follow the reliable execution of the welding process.

Summary and outlook

This paper presents an outlook of the welding activities for the upper shell Multifunctional Fuselage Demonstrator. The resistance welding process is described followed by its opportunities and challenges that occur during manufacturing of a full scale structure. Welding strength values and possibilities for process control are highlighted to be an opportunity of this process. Tolerance management, a high variety of parts and their accessibility are described as the biggest challenges during demonstrator assembly.

Furthermore process modifications to assure a homogenous heating of the welding element are described. An intelligent design of the welding toolings already confirmed its increase of reliability in the past and was transferred to the MFFD tooling. Finally, integrated quality assurance was named as a necessary part of the process itself. It provides direct information about process control, increases reliability and strengthens confidence in the welding process.

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