ROBOT-BASED IMPLANT RESISTANCE WELDING OF CARBON FIBER REINFORCED THERMOPLASTICS

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Abstract

Joining technologies like riveting and bolting, developed for assembly processes of metal structures, are frequently used for joining of carbon fiber composites. Due to the fiber interruptions generated by drilling of holes, the named methods of joining are counterproductive to the idea of optimized carbon fiber composites for high technology lightweight structures. In order to exploit the potential of composite structures, automated, material appropriate joining technologies are inevitable. Automated assembly processes are necessary to manage the increasing production rates and to ensure maximized process stability, reproducibility and traceability. Thermoplastic welding technologies like resistance welding offer high potential for automated, material appropriate joining of carbon fiber reinforced thermoplastics (CFRTP). In this paper the adaption of the resistance welding process to an automated approach for welding of carbon fiber reinforced thermoplastics is demonstrated. Compared to the welding of clips onto a frame or skin structure, clips out of Polyetheretherketone (CF/PEEK) clips are automatically welded onto a CF/PEEK plate. For this use case, an automation system has been developed and its reproducibility and reliability is evaluated.

1. Introduction

In modern aviation carbon fiber reinforced plastics are used in large quantities. To make their advantages usable in high-volume passenger aircrafts, the production and assembly rates of these parts have to improve significantly. An important target is to reduce fasteners like bolts and rivets and implement dustless joining technologies with a high automation level. One promising approach is to utilize the fusibility of the thermoplastic matrix systems under increased temperature to weld thermoplastic composites. For this propose the Institute of Structures and Design has developed the implant resistance welding of carbon fiber reinforced thermoplastics (CFRTP) parts especially for PEEK and PEI matrices for several years [1].

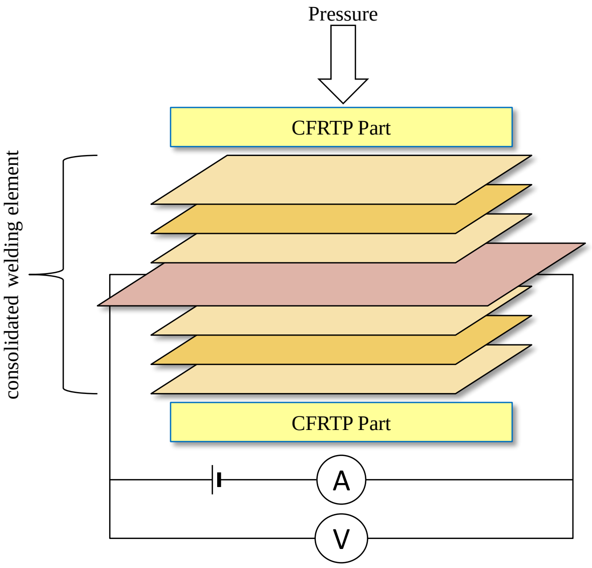
As a next step towards technology maturity and cost reduction the process has been modified to enhance its robustness and to realize fully automated joining. This paper presents the improved layout of the implants, and a demonstrator that has been developed to evaluate the feasibility and reliability of the new process. As a handling platform a standard industrial robot is used to ensure accessibility even in small assembly spaces. With the automated joining of thermoplastic clips onto frames, the robot cell addresses a common use case in the aircraft fuselage. It has been abstracted to a CFRTP bracket which is welded on to a flat CFRTP sheet. The dimensions of the CF/PEEK clips (equal-sided 90° angle section) are 40 mm x 40 mm x 70 mm.

2. State of the art

Welding is particularly suitable for the connection of structural components made of composites with a thermoplastic matrix. Advantages of welding over alternative joining technologies are the fast manufacturing of flat and tight material locked connections and the avoidance of fibers damages. The different welding processes can be differentiated according to the type of heat input. At resistance welding heat is directly generated in its desired destination, in the welding zone.

For implant resistance welding of thermoplastic composites an electrical conducted resistor element in between two thermoplastic parts is used as welding element or heat source. Therefore basically two different approaches, one using a metal mesh [1], [2] [3], the other one using carbon fibers [4], [5] as electrical conductors are known. Furthermore, different approaches to insulate the electrical welding conductor against an electrical conductive joining partner exist [1] [6], [7] .

In this paper an implant resistance welding element using a stainless steel mesh (ISO 1.4301) with a wire diameter of 0.065 mm and a mesh width of 0.3 mm, according to C.Freist [1] was used. The welding element itself consists of the electrical conductor in the middle, with a 0,1 mm PEEK film, GF/PEEK Semipreg (161 g/m²) and further 0,2 mm neat PEEK film [8] stacking on each side. The following Figure 1 illustrates the schematic structure of the resistance welding element for welding CFRTP parts.



	Thickness [mm]	**Grammage [g/m²]**
	raw material	
CFRTP Part		
PEEK film	0,2	
GF/PEEK Semipreg		161
PEEK film	0,1	
Stainless steel mesh	-	
PEEK film	0,1	
GF/PEEK Semipreg		161
PEEK film	0,2	
CFRTP Part		

Figure 1 *Schematic stacking sequence of the implant resistance welding element and welding setup*

The welding element itself is manufactured in a separate vacuum consolidation step in an oven at a peak temperature of 380°C.

For the resistance welding process, the welding element is placed between two CFRTP parts and external pressure is applied. The stainless steel mesh is connected to the power supply using copper clamps. A constant current flow through the stainless steel mesh leads to joule heating and melting of adjacent thermoplastic parts. The glass fibers in the welding element on one hand ensure the electrical insulation against the electrically conductive carbon fibers and on the other hand support a homogenous temperature distribution in the weld zone.

3. Design of the welding element

Previous work had shown potential but also challenges in implant resistance welding. The possibility of current leakage and edge effects [6], [9], [10] are adverse to high joint strengths and the temperature distribution proceedingfrom the welding zone. While current leakage describes the passing of current flow through the electrical resistive carbonfiber parts, resulting in an electrical short-circuit, the edge effect describes the thermal overheating of part edges towards the clamp connection. Different studies [1], [6], [10], [11], are dealing with these phenomena.

The edge effect occurs due to differences in heat transfer between welding element and part (by conduction) compared with the behavior of it at welding element and the ambient air (by convection).

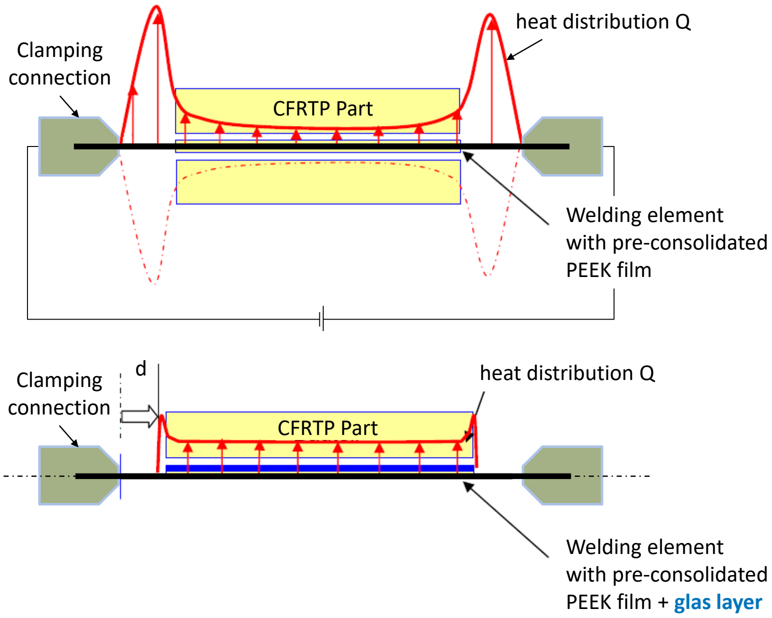


Figure 2 *Schematic illustration of edge effect depending on different welding element insulations (PEEK, top; GF/PEEK, bottom) and clamping distance* ***(adapted from Ref.*** *[10]****)***

Figure 2**Fehler! Verweisquelle konnte nicht gefunden werden.** illustrates the heat distribution in the CFRTP part depending on the stainless steel mesh insulation and the distance of the clamping connection. C. Freist [1] developed a GF/PEEK insulated resistance welding element (Figure 2**Fehler! Verweisquelle konnte nicht gefunden werden.**, bottom) that reduces the edge effect significantly. Welding tests showed that a minimization of clamping distance d leads to a further enhancement with homogeneous heat distribution. But reduction of clamping distance to a minimum showed a insufficient reproducibility of the welding results caused by appearing flash-arcs between clamping connection and CFRTP part in spite of electrical insulation of its adjacent contact.

For the realization of an automated resistance welding process for CFRTP parts and verification of a high process stability and reproducibility, troubleshooting the flash-arc problem at the clamping connection is necessary. In addition, a high inherent rigidity of the overlapping clamping region of the mesh is required to enhance the automated handling and clamping of the welding element.

The following Figure 3 shows the improved welding element and clamping connection configuration, as well as an automatically welded Clip-Plate-Joint.

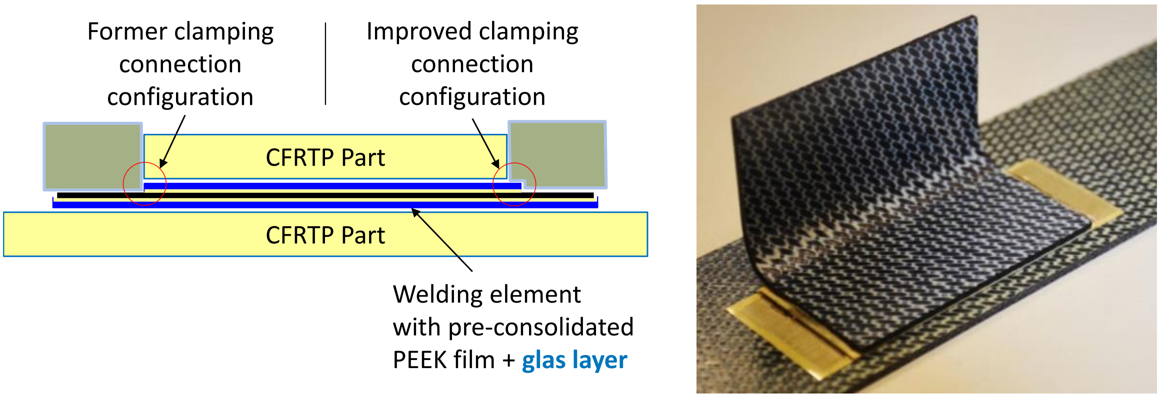


Figure 3 *Former and improved clamping connection and welding element configuration (left) and the automated welded demonstrator (right)*

With these improvements the requirements of good electrical contact, respectively electrical insulation towards the component, the heat transfer and the size accuracy could be realized.

4. Production of the CFRPT brackets

The clips used for the welding process are produced via vacuum consolidation in an oven process. For this purpose a tool with a defined angle was used. A polyamide separation foil (UPILEX-125S) was applied on the tool surface. The plain CF/PEEK fabric layers (±45°) are preformed by using a hot air gun and a suitable pressure piece. Glass fabric used as breather is placed next to the preform. An additional separation foil is put on top of the preform. A top tool was placed above the separation foil to apply a constant pressure on the layers and to get a defined inner and outer radius. The vacuum foil was placed as top layer. The consolidation in an AMS 2750E ready oven takes place at 380°C for 40 min. After the consolidation step the clips are cut to their final geometries.

5. End-effector design and process description

A specialized end-effector was designed for the automated resistance welding of CF/PEEK clips. A KUKA LBR Iiwa 14 R820 was used as robotic handling platform of the welding end-effector.

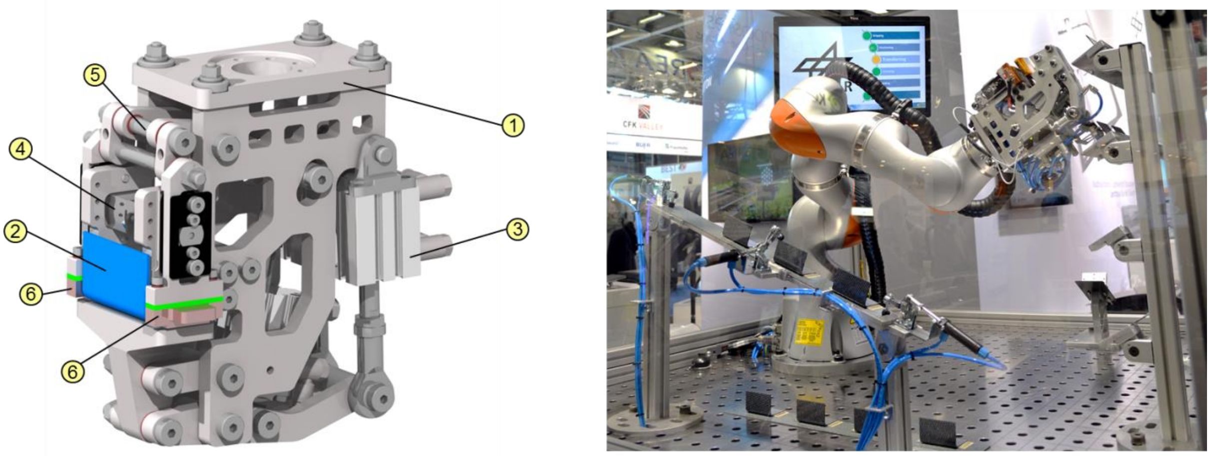


Figure 4 *Resistance welding end-effector (left) with (1) robot flange, (2) clip clamping unit, (3) pressure unit, (4) centering unit, (5) contact pressure unit, (6) contact stamp and electrical contact. Automated welding process in a robot cell (right)*

Figure 4 illustrates the designed end-effector and its components. The realization of the automated welding process is described in the following section. First a clip is gripped by a suction cup mounted in the clamping unit. The actuators of the end-effector are controlled by pneumatic valves connected to the KUKA sunrise robot controller using the EtherCAT fieldbus. This allows the control of all functions of the end-effector synchronously with the robot motions. To center the clip contact stamps on both sides of the clips are closed. The end-effector is moved onto the welding position where the welding counterpart is placed directly under the clip. Using proportional valves the contact pressure unit is closed with a slight pressure to hold the clip on the sheet.

In the next step the electrical contact is applied with a resulting pressure value of 5 bar in the contact region to reduce the electrical resistance between the electrical contacts and the stainless steel mesh. Pneumatic cylinders raise the pressure in the welding zone, using the clamping unit, to a level of 5 bar (1100 N). Before welding of the CFRTP parts, the contact quality between the copper clamps and stainless steel mesh is validated. Therefore a low current of 1 A is applied which allows to measure the resistance of the welding element. In case of poor connection the welding process is automatically interrupted.

The power supply used for welding allows remote control of output voltage and current using analog voltage inputs (0-10 V DC). These inputs are connected to the failsafe programmable logic controller (PLC) which allows the robot controller to specify the desired voltage and current if certain safety precautions (cell door is closed, no emergency stop is active) are met. If any precaution fails, the output voltage and current are set to zero, and the power lines are interrupted using contactors.

During the welding process a current of 40 A is applied for 18 s before the current is reduced to 36 A for 20 s. At the end a cooling phase of 30 s under maintained clamping force is necessary. Parallel to welding the process is completely monitored to ensure traceability and reliability.

6. Results

The described setup was supplemented with a clip and sheet storage to eliminate human impact on the reliability of the welding process. In the commissioning the welding cycle (as mentioned in chapter 5 has been developed and occurring heat was calculated in dependency to the voltage drop. Using this welding cycle over 58 welds have been conducted. These suggest that the high reproducibility of the automated process leads to a significant reduction of current leakage. Furthermore the new design of resistance element avoided edge effects.

To ensure a sufficient welding connection, microsections of the welding zone as well as thermograpic pictures of the welding process are done.

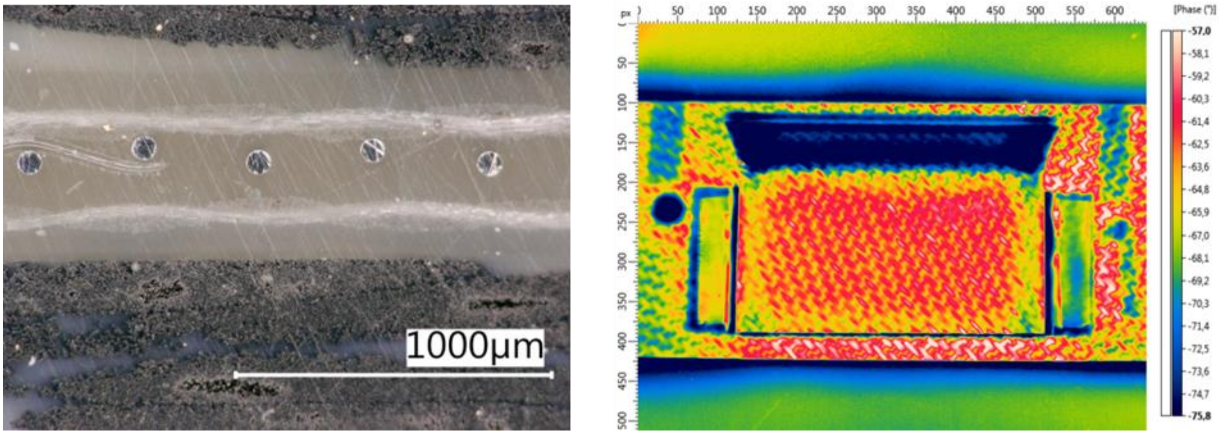


Figure 5: *Microsection of the welding zone (left), thermogram of a welded clip (right)*

Figure 5 illustrates a microsection with carbon fibers on the top and bottom, the resin (grey), the glass fibers (white) and stainless steel mesh (silver). It shows a void and gap free connection of the CFRTP parts. The thermogram on the right shows good heat conduction over the welding zone indicating the lack of isolating voids.

In summary the presented automation system, including changes on the resistance welding process, shows a reliable and robust joining process. Integration in a robotic cell has shown acceptable tolerances and applicability of standard automation hardware. The work shown is driving the technology towards a potential industrialization. Nevertheless further investigations regarding strength and failure behavior should be conducted. Therefore the system could be adapted to produce test specimen as defined in the corresponding standards [4], [5], [6].

7. Conclusion

The paper illustrates a possible solution to advance the electrical resistance welding process away from experimental setups to an automatic solution. Further work should be concentrating on more flexible systems for example a one-sided machining direction, larger welding areas and a system for multiple welding parts.

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