MICROWAVE WELDING OF CARBON FIBRE REINFORCED THERMOPLASTICS

B. Navarro and C. M. Worrall

TWI Ltd. Granta Park, Great Abington, Cambridge, CB21 6AL
chris.worrall@twi.co.uk

Keywords: Cost-effective, energy-efficient, production, flexible

Abstract

The use of fibre-reinforced thermoplastic composites (FTRCs) is increasing dramatically in many industry sectors including aerospace, automotive, oil and gas, sports and leisure, and wind energy. Thermoplastic composites offer many advantages over their thermoset counterparts, including rapid automated processing. As part of the FibreChain project, TWI has developed a microwave welding process for joining thermoplastic composites such as carbon fibre/PEEK. Using a HEPHAISTOS microwave oven and freeze cast alumina tooling, single lap joints have been made and strengths of up to 24MPa have been achieved. Although still in the development stages, microwave welding should be considered as a promising and commercially interesting potential for joining advanced thermoplastic composites.

1. Introduction

1.1. Manufacturing Cell For Fibre-Reinforced Thermoplastic Composites

The use of fibre-reinforced thermoplastic composites (FTRCs) is increasing dramatically. To fulfil the increasing global demands, the project “Integrated Process Chain for Automated and Flexible Production of Fibre-Reinforced Plastic Products (FibreChain) [1]” aims at the development of worldwide first automated turnkey manufacturing system for FRTCs.

A robot-based manufacturing cell with the single turnkey systems comprises the whole functionalities of the FibreChain process chain (Figure 1), serving as technology demonstrator. A new tape laying unit will be developed and integrated into an articulated robot system for tape laying of customised FRTC plates and finish 3D-shaped parts as well as for the stiffening of thermoformed FRTC parts with additional stringers. Furthermore, the robot will accomplish and automated tool change in order to realise the handling of FRTC tapes, plates and parts, the cutting and trimming of tapes, plates and parts, the joining of parts and also the measurement of the part geometries. In addition, the manufacturing cell will contain a thermoforming system to provide the flexible combination of thermoforming and tape lying.

Laser-assisted tape laying/winding and the post-processing operations laser cutting and laser joining can be performed in a sequenced process with a single multi-functional laser source. In comparison to tape laying and thermoforming the processing lengths, material volumes and corresponding times of laser cutting and laser joint are insignificant. Hence, the sequence laser processes accomplished by a multi-functional laser source (laser beam switch) hardly affects the cycle time but reduces the need invest significantly. The control system and a CAD/CAM module will be developed and integrated to realise the user friendly control and short time rigging of all the FibreChain processes.

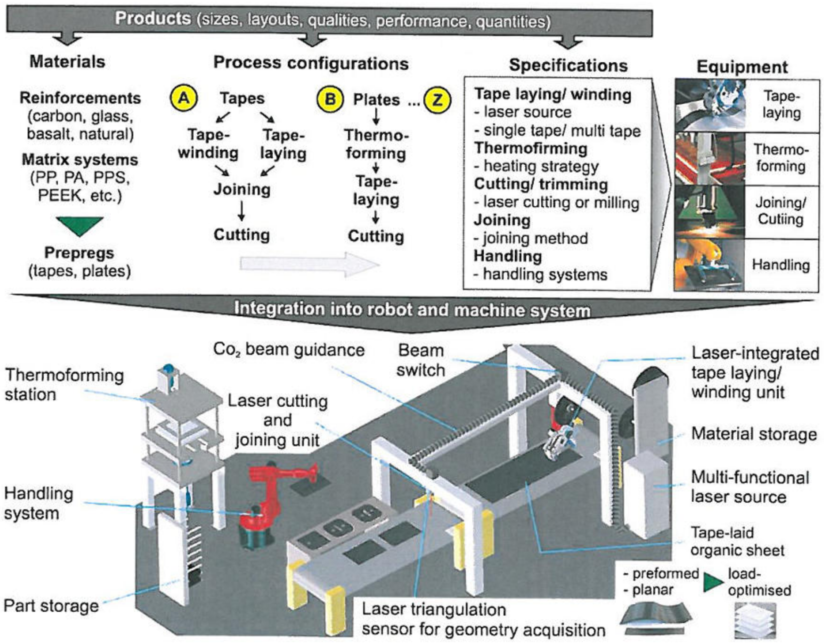

Figure 1. The FibreChain approach: from product (here robot-based) manufacturing system.

2. Welding Techniques Under Review

The objective is to examine the potential of alternative joining technologies to the laser process, choose two of the most suitable for scale up into the manufacturing cell and develop them to the point where identified parts have been successfully joined.

The list below shows some of the potential joining that could be considered:

- Induction
- Resistivece implant welding
- Vibration / ultrasonic / spin
- Hot plate
- Brazing
- Laser
- Microwave
- IR welding
- Hot gas
- Mechanical fastening
- Adhesive bonding

It is possible to reduce the types of bonds required to three basic arrangements: boss, seam and assembly. In order to have the greatest value to the project demonstrators the techniques chosen should be able to accommodate all the potential arrangements.

Type	Possible Method	Process Chain
Boss	Spin	Simple stand alone units
	Ultrasonic	
Seam	Induction	Stand alone unit.
	Microwave	Chamber needed, possible batch processing
Assembly	Microwave	Chamber needed
	Adhesive	Dispensing equipment with secondary cure stage

Figure 2. Review of joint arrangements and associated techniques.

There are a number of factors that have been taken into account for this decision on top of the basic joint types, particularly:

- Appropriateness for the project demonstrators.
- Potential for innovation.
- Availability of technical knowledge and production potential.

Two techniques have been chosen for initial feasibility studies to understand their appropriateness for further work, these are: microwave welding and spin welding. Microwave welding is the subject of this paper.

3. Microwave Welding

Fast processing, volumetric and selective heating are offered by microwave processing, and this relatively new technique shows a very promising and commercially interesting potential for advanced composites. Microwave welding is still in the development stages, hence TWI's interest to develop industrial applications for this welding technique. The particular advantage of microwave welding over other forms of welding is its capability to irradiate the entire component and consequently produce complex three-dimensional joints. This characteristic makes this welding technique an energy-efficient process. In addition, microwave offers short welding times, and therefore faster production rates.

TWI's research in this field is focused on the study and analysis of the combinations of parameters involved in microwave welding; to identify the processing window of different carbon fibre reinforced thermoplastics. All the welding processes are governed by the parameters: heat, pressure and time. Many thermoplastics composites do not experience a temperature rise when irradiated by microwaves. However, the insertion of a microwave susceptible implant at the joint line allows local heating to take place. Several implants are being investigated. It seems that the type of insert affect the quality of the welds.

Mechanical testing (single lap shear strength) has been carried out to examine the quality of the joints. Further enhancements are expected with additional research developments as this welding technique has the potential to be suitable in a wide range of applications and industry sectors.

3.1 Equipment

The equipment used for these trials focuses on three areas:

- Microwave chamber.
- Supporting jigs.
- Joint material.

The microwave chamber used was a high power 10kW, computer controlled, 1m³ internal volume machine from Vötsch (VHM HEPHAISTOS 3).

Two types of support tooling have been used; machined aluminium and freeze cast alumina (FCA). The FCA has the advantage of being transparent to microwave radiation, allowing more even energy distribution in the joint. In addition, two kinds of fillers (PEEK film and PEEK powder) have been used to facilitate the joint formation by creating matrix rich area.

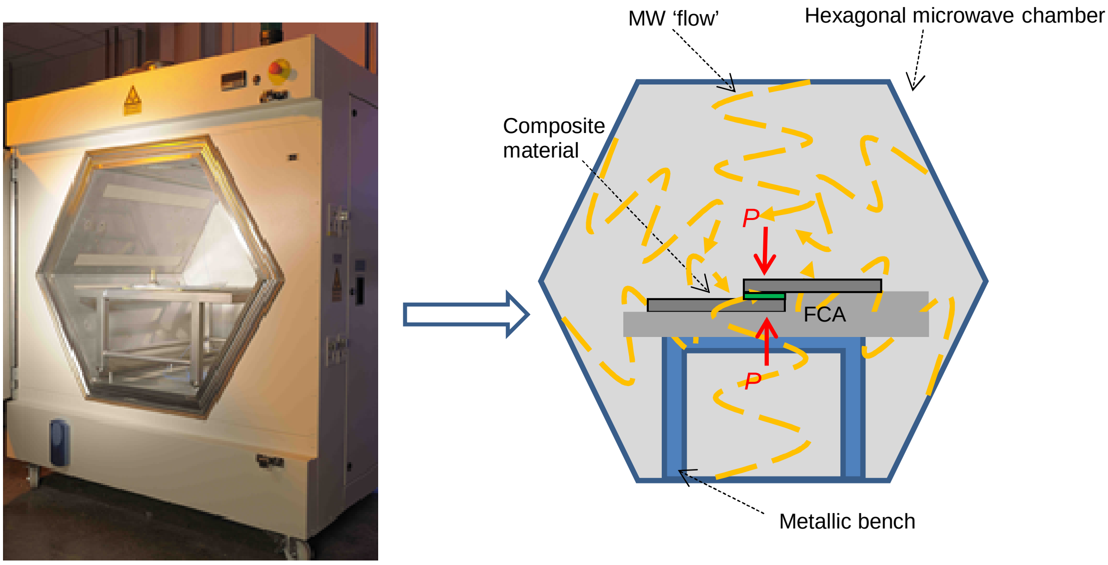

Figure 3. Microwave chamber (view from the outside and inside) used in the trials.

3.2 Preliminary microwave melding trials

Initial trials have been carried out to scope out the feasibility of this welding technique and the associated equipment and determine the suitability for future development.

The primary material focus for joining was carbon fibre reinforced PEEK (CF/PEEK). Other materials could be joined by this technique, with some modifications, but that has not been tested within this project.

The use of the microwave shows rapid heating of the joint and good bond strength by using PEEK film at the interface as filler. The infra-red (IR) thermal image (Figure 4), shows the joint after the chamber has been opened after welding, and the higher temperature of the joint area is clearly visible. The final joint (Figure 5), shows the potential of the technique.

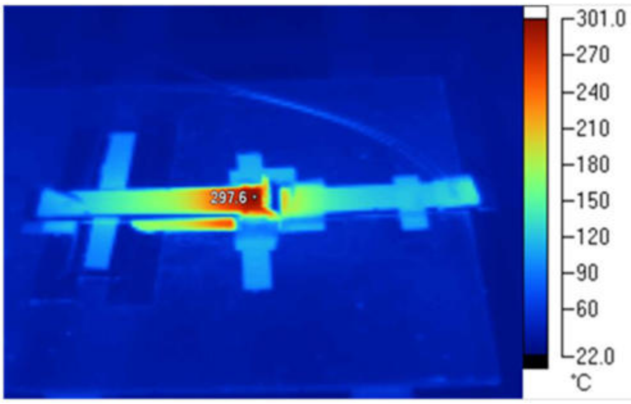

Figure 4. Thermal image showing the hot area of the bond after microwave joining.

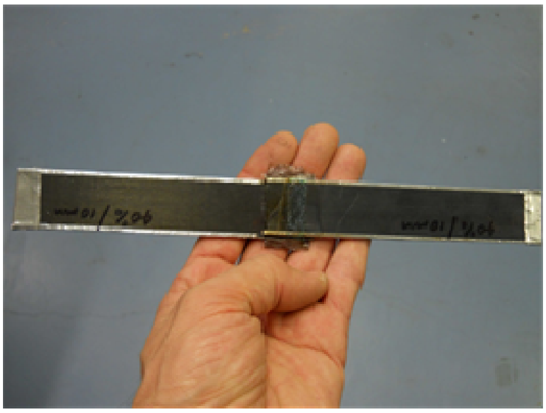

Figure 5. Microwave welded CF/PEEK joint.

Next trials have been executed to identify the processing conditions for this welding technique using carbon fibre reinforced PEEK. This involved carrying out a number of welding trials in order to define the processing window of this material in terms of the upper and lower limits for the welding process.

In order to obtain a good joint, the welding parameters must be chosen carefully. Different parameters are involved in this welding technique. The input parameters to control the welding process are power, welding time and the type of filler. Hence three parameters have been analysed to define the area where the material under study could be welded.

Welding can be an economic balance between fast (expensive high power equipment that offers high production rates) and slow (cheaper equipment but at the expense of production rate). In this research, a maximum welding time of ten seconds were used.

Two types of fillers were used to aid the welding process: PEEK film and PEEK powder. After the welding process, Lap Shear Strength (SLS) tests were carried out to examine the quality of the welded joints.

Specimens welded using PEEK film as filler seems to have better welding performance that the ones joined using PEEK powder. This fact is showed in the Figure 6, where the welding power was set to 30% of the maximum power of the chamber (10kW) and the welding times was varied between five and ten seconds.

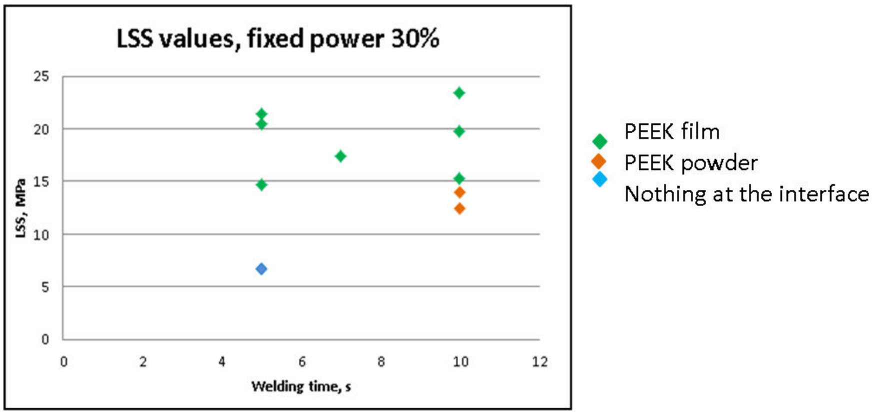

Figure 6. Mechanical properties of microwave welded lap joints.

The contact using PEEK film at the welding interface is more intimate and homogenous than using PEEK powder. More trials need to be carried to check the repeatability of the effect of the type of filler.

4. Conclusions

TWI's research in this field is focused on the study and analysis of the combinations of parameters involved in microwave welding in order to identify the processing window of carbon fibre reinforced PEEK. The insertion of a microwave susceptible implant at the joint line allows local heating to take place and it seems to aid the welding process.

The project is still ongoing; therefore further enhancements are expected with additional research developments as this welding technique has the potential to be suitable in a wide range of applications and industry sectors.

5. Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme managed by REA Research Executive Agency [FP7/2007-2013] under grant agreement no 2633385.

The authors also acknowledge Dr Lambert Feher for critically reading the manuscript.

6. References

[1] http://www.fibrechain.eu