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Laser-bonding of long fiber thermoplastic composites for structural assemblies

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Abstract

The use of laser light for bonding of long fiber reinforced thermoplastic composites (LFTPC) offers new possibilities to overcome the constraints of conventional joining technologies. Laser specific transmission welding procedures are known in manufacturing of short fiber thermoplastic composites. The technical basics of the joining process and an outline of some material inherent characteristics using long glass fiber reinforced composites with PA resin are discussed. The technical feasibility and the mechanical characterization of laser bonded LFTPC are demonstrated. The results show that the laser provides an alternative joining technique and offers new perspectives to assemble structural components emerging in industrial manufacturing.

Keywords: Laser welding of thermoplastic composites; composite bonding; laser bonding

1. Introduction

As a result of their growing potential for high performance applications, continuous fiber reinforced thermoplastic matrix composites (TPC) are becoming of greater interest for the industry. TPC have some additional advantages compared to thermosets, i.e. improved toughness, better environmental resistance, and shorter processing times. Those new materials represent a breakthrough in the development of thermo-formable engineering composites applications (high performances, recyclability, low cost production, flexibility…). Instead of thermoset resins which are mainly joined using glue or mechanical fixing, thermoplastic matrix can be welded. Different fusion bonding methods have been investigated, as ultrasonic, vibration, induction or laser process [1-3].

1.1. Technical process background

Laser welding is a well-known process for joining injected plastic parts. It is already used in more and more industrial application such as automotive parts welding due to the accuracy and flexibility of the process and the quality of weld seams [4-8]. To meet industrial needs specific welding processes (contour, quasi-simultaneous or

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simultaneous) or adapted materials (when necessary) have been developed [9, 10]. Two plastic parts with similar chemical properties (the same polymer matrix), in order to have a good welded zone are needed [b]. Applicability of the laser welding essentially depends on optical properties of plastics at the laser wavelength, especially absorption or transmission of laser radiation.

In most applications, materials having different optical properties are used. One part is optically transparent (part A) at the wavelength of the laser beam and the other one is absorbing the laser energy (part B) (cf. figure 1). Generally, the transparent plastic is composed of a natural polymer matrix and the other part, the absorbent material include a black carbon pigment.

During the welding process the laser beam is transmitted through the transparent part and the totally absorbed by the absorbent part. The light energy is transformed into heat and the non-absorbent material is heated up indirectly by heat conduction. Fusion of their contact interfaces, followed by cooling (consolidation) under pressure, enables the bonding to of the components.

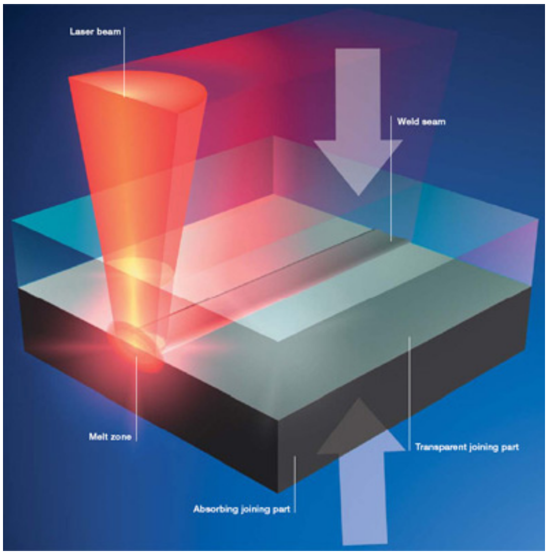

Fig. 1. Transmission laser beam welding configuration using a transparent and an absorbing part

The focus of the current investigation is specifically concentrated on long fiber reinforced materials using glass fiber with PA or PP resin. In the case of carbon fiber reinforced materials this transmission welding process in general is not suitable. The principal process parameters are the welding speed, the laser power (energy line) and clamping pressure.

Most thermoplastic polymers are more or less transparent in the wavelength range of diode laser (near infrared). Pigments, fillers, additives and other components of polymer formulation strongly affect laser interaction with plastics [10]. They can affect the ability of polymer to absorb the infrared radiation and they can lead to various amounts of reflection and scattering too (figure 2).

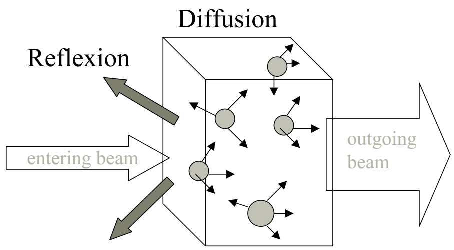

Fig. 2. Principle phenomena during irradiation of reinforced thermoplastic.

The incidence of fibers on the optical properties of composites is the main limitation to apply laser welding. Glass fibers mainly induce a diffusion (scattering of the beam) and reflection effects due to the difference of refractive index between the thermoplastic matrix and the glass. This means that glass fibers doesn't absorb the laser radiation but act as multiple reflectors which modify the energy distribution of the incoming beam and decrease the rate of the energy transmitted at the interface. Injected thermoplastic materials reinforced with short glass fibers have already been laser welded. The incidence on optical properties of short GF rate in a polyamide matrix have been measured using a spectrophotometer and are presented in the figure 3[11].

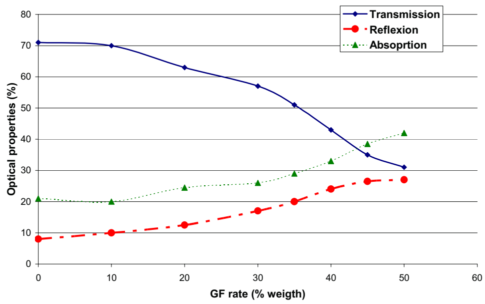

Fig. 3. Influence of short glass fiber rate on optical properties of a 2 mm thick polyamide plate [11]

2. Experimental Set-up

2.1. Equipment

Welding has been realized using a laser diode (λ = 940 nm). The dimension of the focal point was approx. 2mm dia.The welding speed has been fixed at 10 mm/s to meet industrial requirements.

2.2. Material

Joining of two types of composite materials has been investigated. A composite material made from a polypropylene matrix reinforced with 40% glass fibers and a composite material made from a polyamide matrix reinforced with 40% glass fibers were used in welding trials.

2.3. Lap shear specimens

Large plates (100x125 mm²) were welded with 25 mm of overlapping and then lap shear specimen were cuted using a carbide-tipped band saw. Figure 4 shows the geometry of the tested specimen.

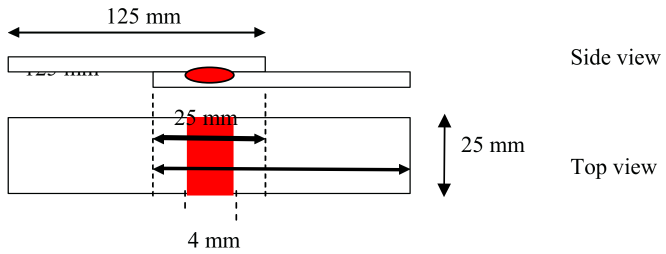

Fig. 4. Lap shear specimen configuration. The welded area in each specimen was 25 x 4 mm²

Lap shear strength is by far the most commonly used test method for investigating the strength of the bonds achieved through welding process. It is a standard tensile test that involves axial pulling of the welded specimen until breakage. The lap shear tests were conducted on an MTS testing machine using a cross head of 2 mm/min. Analyses of the interface before and after mechanical tests have been done using optical microscopy.

The variance in transmission the laser light due to the material properties imposes an on-line power regulation to avoid overheating or lack of bonding. Fig. 5. provides an overview of the experimental set-up.

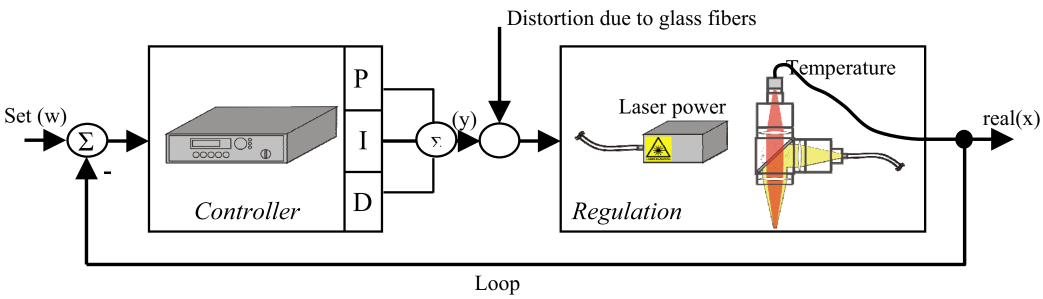

Fig. 5. On-line temperature driven laser power control for welding

3. Results and discussion

It is well known that the welding quality is influenced by many processing factors, such as laser power, welding speed and clamping pressure. Limited by the framework of the study, this selection was aimed toward investigating the effect of power of the laser on the weld quality (strength) and nature (adhesive or cohesive bonding).

3.1. Laser welding of composites

In continuation of the analysis given in [11] the purpose in this study was to identify specific GF configurations with regard to the manufacturing of structural components. The results of welding trials with the PP or PA composite material showed the process to be capable to produce efficient joints. Visual observation of the weld seam and interface of tested specimens can also provide certain information about the weld quality.

3.2. Optical transmission of long fiber material

Considering the laser welding process, optical properties of thermoplastic composites are crucial parameters, especially the laser transparency is a decisive criteria. In the case of long fiber reinforced composites additionally the orientation and density of the glass fibers are to be considered.

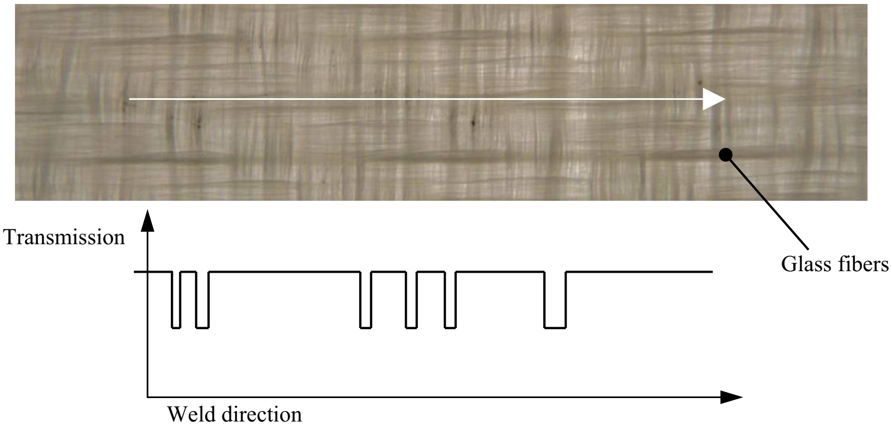

Fig. 6. Variation of transmission between 28% and 39% @ λ = 940 nm in 2-layer/90° GF plate

Additional multi layer configurations have been tested. Up to 6 layers with different orientations of the glass fibers were investigated. The temperature driven laser power regulation allows controlled energy deposition into the weld seam without overheating. Reliable and repeatable welds can be obtained. This process can be used for long weld geometries as they are required for assembly of structural components.

The temperature profile of typical weld geometry is shown Fig. 7.

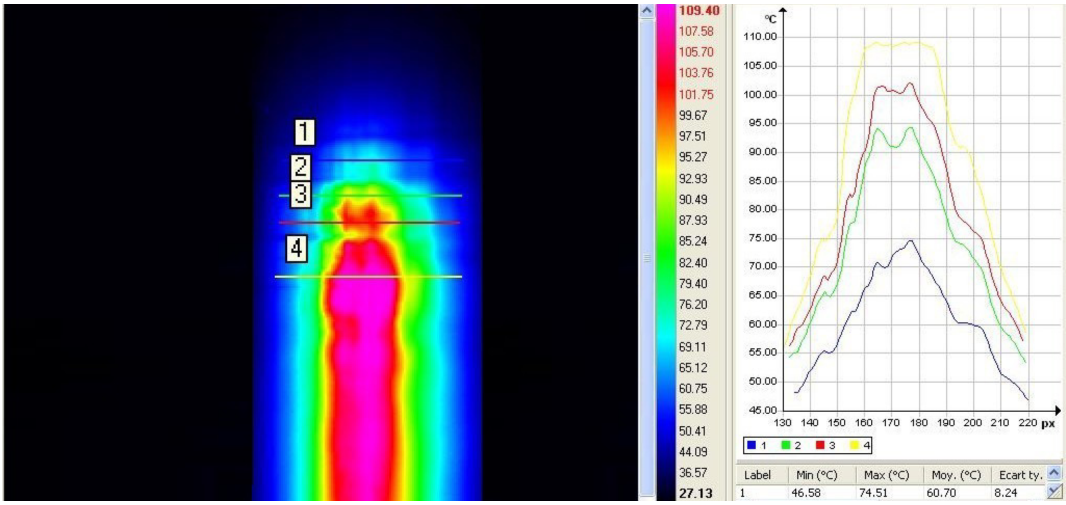

Fig. 7. Typical temperature profile for laser weld @ λ = 940 nm in 2-layer/90° GF plate

3.3. Microstructure analysis of the welded zone

The microstructure analysis of the laser welded zone is made by SEM images. In this zone, fibers arrangement is like composite before assembly, at mesoscopic scale (figure 8).

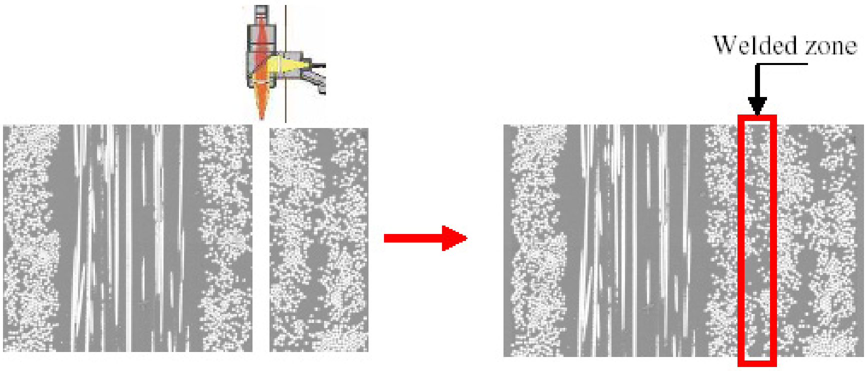

Fig. 8. SEM microstructure of laser welding, with magnification 46

The quality of the welded zone is very dependant on the material itself especially the volume fraction of fibers. A good welding depends on the transparency of the constituents and a relatively low volume fraction of fibres. By cutting out a sample welded with the microtome, one finds the thickness of the welded zone, which is around of 500 micrometers (figure 9). The volume fraction of this zone is 35.5%.

3.4. Mechanical results

The mechanical tests were performed on a tensile testing machine. Some shear tests are made on the base material to be compared with the laser welded seam. The resultats for base material show a scattering after elastic strain, figure9.

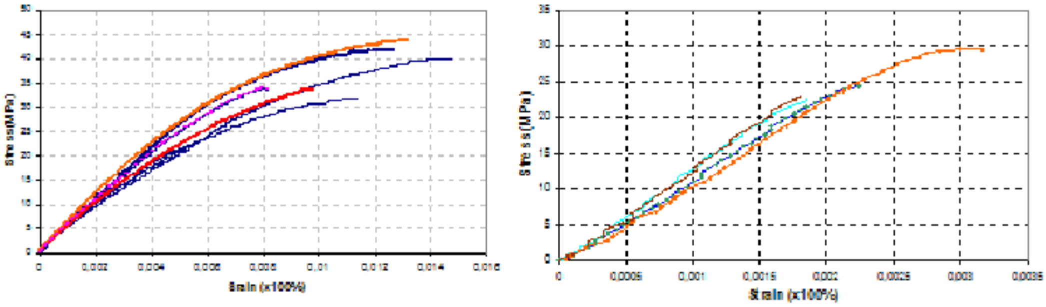

Fig. 9. SEM microstructure of laser welding, with magnification 46

The lap sheer test obtained with optimized laser process parameters have been compared to conventional bonding technique (gluing and resistance welding) and typical results for the given material are shown in table 1.

Table 1. Typical sheer strength for different welding techniques

Welding technique	Strength min. value	Strength max value
Gluing	10 MPa	15 MPa
Resistance welding	20 MPa	22 MPa
Laser	23 MPa	32 MPa
Base material	32 MPa	44 MPa

The combination of temperature control and weld seam geometry allow assembly of structural components in different configurations. An example is shown in fig. 10.

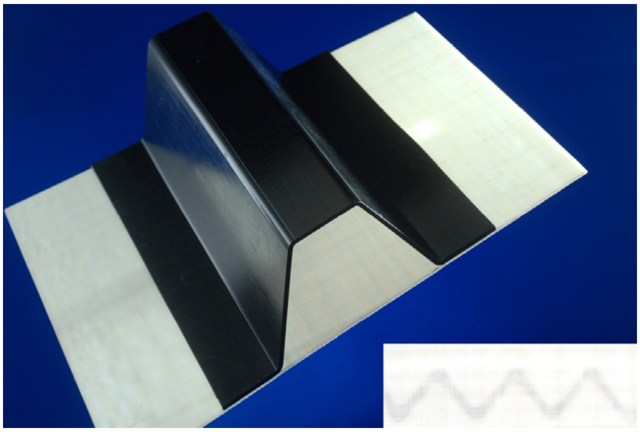

Fig. 10. Structural assembly of GF plates with sinusoidal weld seam geometry

4. Conclusions

The performed study evaluates the laser welding method for joining structural components made of long glass fibre reinforced thermoplastic plastic composites. The results demonstrate that laser welding is a suitable and environment friendly assembly technique. The technique is applicable as long as optical transmission characteristics of the material are appropriate and temperature control can be ensured during the process. The design of the components to be assembled by this technique must consider the fact that both parts have to be in physical contact while welded. Consequently new recommendations for the weld geometry have to be applied. The possibility to have variable welding lines allows strong bonds for different assemblies. Optimum weld geometries with regard to structural stiffness and performance of the components are under investigation.

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