LASER ND: YAG WELDING OF GLASS FIBER POLYPROPYLENE, POLYAMIDE AND POLYESTER COMPOSITE TO THERMOPLASTIC POLYAMIDE

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Abstract - Polymer matrix composites are currently used in a wide range of activity sectors, ranging from consumer electronics to the aeronautics and space industries. The excellent mechanical properties and low specific weight form the basis of the increasing volume of structural applications. The joining of two components in composite material is usually done through bonded, screwed or riveted connections. The first case, which is the most usual one, has a major limitation, that is the glues need a certain curing time, so it is not possible to send the worked set to the next stage of the manufacturing process immediately after gluing. But the screws and rivets have another problem. In fact, they require the machining of holes in the parts to be connected, which introduces defects and concentration of stresses that can cause the structure to fail. Laser welding of composites has two major advantages: it is extremely fast; and it is very accurate and easy to automate. However, only recently the laser welding of composites has been tested. This work analyzes the laser weldability of glass fiber polypropylene, polyamide and thermoplastic polyester composite to thermoplastic polyamide. Single lap joint was laser welded and was used the shear test to find the feasibility of the joint. The results are promising. In fact, some welded joints present a mechanical shear strength of 20 MPa, which value is similar to one bonded joint.

Index Terms - Laser welding of composites, welding of glass fiber polyamide, welding of thermoplastic polyamide, weld ability of composites.

I. INTRODUCTION

Due to the increase demand of lightweight materials to be used in the automotive and aerospace industry in order to reduce weight and increase performance, thermoplastic composites and carbon reinforced plastics (CFRP) present themselves as a good option to replace the common and heavier structural materials [1]. Recent trends in lightweight design show the growing importance of carbon fiber reinforced plastics in order to reduce component weight due to its high specific properties.

These materials are commonly characterized by their improved properties of material handling, component manufacturing, and recycling [2]. Thermoplastic composites also exhibit very low level of moisture uptake, which means their mechanical properties are less degraded under hot/wet conditions not to mention their higher damage tolerance and increased reparability potential as compared to thermosetting matrix laminates [3].The market already presents technologies for assembling of composite structures such as mechanical fastening and adhesive bonding. However, there are some disadvantages associated with these methods such as stress concentration induced by drilling holes in mechanical fastening or extensive surface preparation during adhesive bonding [3], [4]. Joining can also be achieved using various welding methods such as electric resistance, ultrasonic vibration, hot plate, electromagnetic induction, dielectric/microwave and infrared welding [3]. Another welding technique available is laser transmission welding. During laser transmission welding, the laser radiation passes the natural finish, transparent part due to its transparency in the near infrared spectral range. Parts of the radiation are absorbed by the matrix material and affected by reinforcements like glass fibers, which scatter the laser radiation [5].Thermoplastic material containing carbon fibers (CFRP) or the additive carbon black absorbs the near infrared radiation and generates heat. Due to heat conduction between both joining members, the transparent part also melts. To support constant heat conduction between both parts, they have to be clamped with a constant pressure over the weld seam.

Furthermore, carbon fibers in the absorbing member have an effect on the weld seam development. Carbon fibers have a high thermal conductivity compared to the matrix material. Consequently, the heat is conducted along the carbon fibers and the weld seam geometry is affected by the local orientation of these fibers relative to the weld seam [5], [6]. Laser transmission welding can be divided into four main techniques: contour, quasi-simultaneous, simultaneous and mask welding. In contour welding the laser bean passes the weld seam once, this welding technique can be used to generate long three-dimensional weld seams.

In quasi-simultaneous welding the laser beam is guided over the weld seam multiple times with a high speed by a scanner optic introducing a slower heat

development inside the welding zone [7].Mask welding is a combination of contour and quasi-simultaneous welding and provides the possibility to generate quasi-static temperature fields [7], [8].

II. EXPERIMENTAL SETUP

This experiment consists in using a Nd:Yag diode laser (Sisma SWA 300) with 12 kW pulse peak power to weld two pieces, a composite and a thermoplastic. Were performed five replicates of each type.
The absorbing part is a woven and randomly laid glass fiber composite with a matrix of black polypropylene, polyamide and thermoplastic polyester, commercially called GMTex while the thermoplastic is common transparent polyamide 6 commercially named Ertalon 6 (provided by Quadrant Plastics Company).
First the parts were cut to form appropriate samples to be weld and tested in compression (single lap joint), the composite was cutted in order to perform a square (30x30x5 mm), while the thermoplastic was cutted from a rod with a diameter of 30mm in order to be 1.5 mm thickness, 23 mm width (Fig. 1).
Before submitting the parts to the laser these were pressed together using a device composed by two plates and screws in order to obtain a uniform pressure around the parts to be welded.
The pieces were clamped together perpendicular to the laser.
The laser was then driven in automatic mode in a straight line along the setup at constant speed of 5 mm/s.
The first experiment was performed to find the optimum laser parameters, in this case, the peek of power and laser diameter, because these characteristics are the most important ones. In the first trials, it was used an optimum amount of energy for welding thermoplastics obtained in a different experiment [9] (Table 1).
The weld reveal unsuccessful due to the lack of conductivity of heat between the absorbing part and transparent part.
In the second experiment in order to improve the conductivity between the two parts, a small metal rod was inserted between the pieces so when the laser heats the metal rod it will heat up transmitting the heat to the two pieces until they melt around the metal rod performing a viable weld. In order to fix the metal rod, a gap was opened in the composite to help secure the rod during the assembling of the clamping device and positioning under the laser.
New tests were performed to find optimum peek power and laser diameter. In these new tests the laser was totally focused on the metal rod between the two pieces. After successful welds with aluminum rods, the same procedure was tried with steel rods and brass rods. Finally the welds that didn't break by hand, were tested in compression in order to obtain the stress-strain curves. A last experiment was made in order to evaluate the influence of the gap made in the composite. The same procedure was done but this time without opening the gap on the composite. For this experiment only steel rods were used.

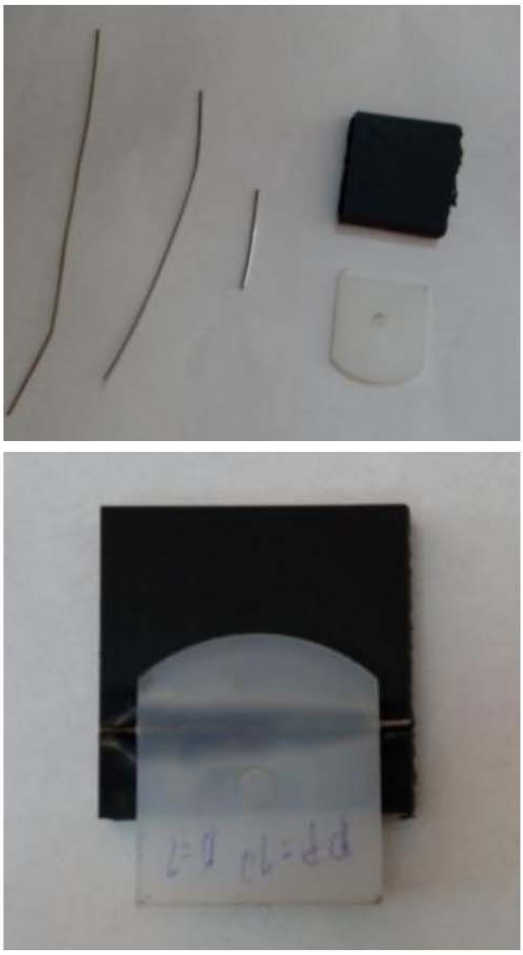


Fig. 1 – Cutted samples (above); Welded sample (center); Position for test (bottom).

Table 1 – Start point laser parameters and optimized laser parameters.

	Peek power (W)	Wave pulse (ms)	Overlap-ping (%)	Laser beam diameter (mm)	Welding Speed (mm/s)
first try	360	10	65	2	5
Optimum Parameters	1200 - 2400	10	70	1	5

III. RESULTS AND DISCUSSION

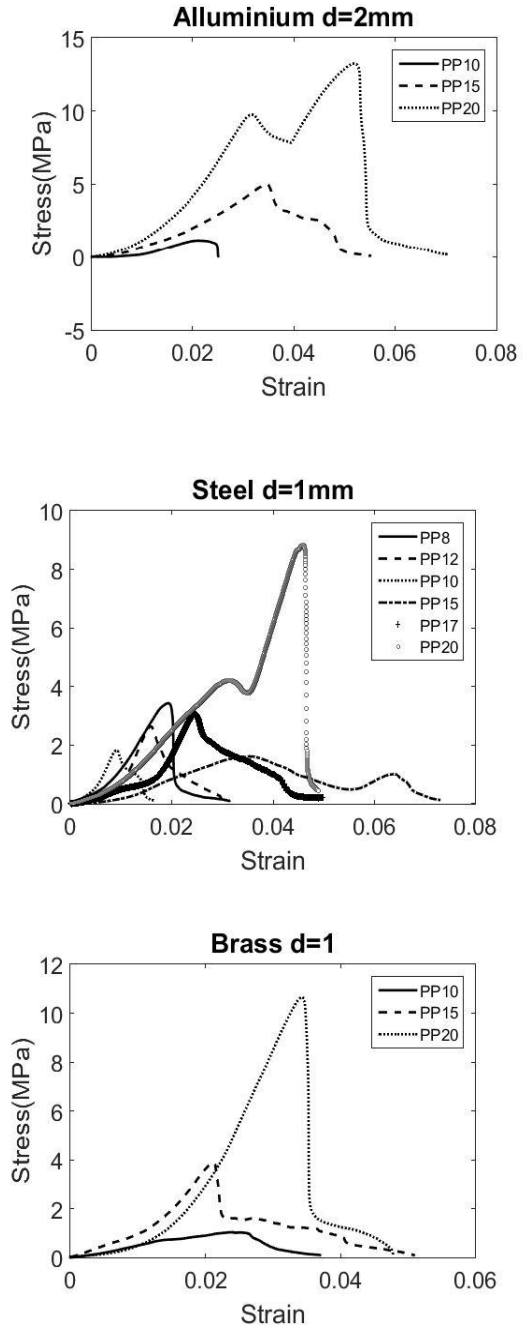


Fig. 2 – Stress-strain results for each sample containing a different metal rod welded in the optimum laser parameters; Comparison between the metal used in the sample welded at a peek power (pp) from 8 to 20% of the maximum 12 kW and a laser diameter (d) of 1mm.

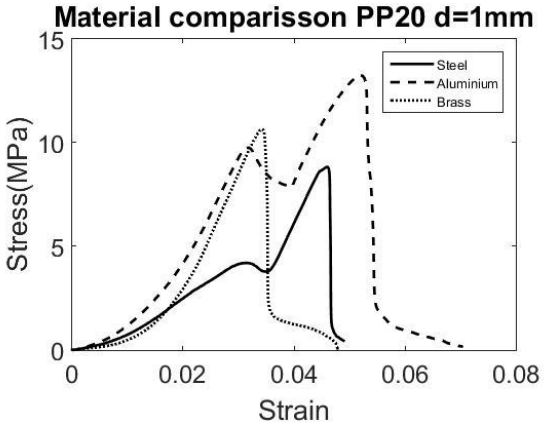
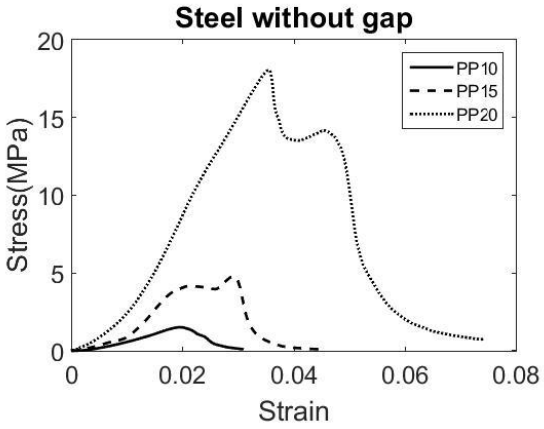


Fig. 2 – (Continued)



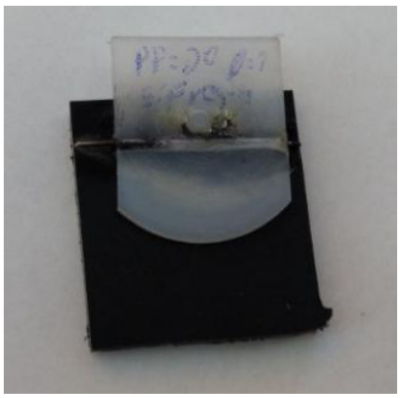


Figure 3 – Stress strain results for weld made with steel rods without a fixating gap in the composite (above); the steel rod tore the thermoplastic due to a higher concentration of energy (bottom).

Fig. 2 shown representative compressive tests (sample in shear) results for each type. The first experiment, where there is only the absorbing composite and the transmissive thermoplastic, the weld did not reveal itself successful for any peek power and laser diameter. It was observed that for big diameters and low peek of power the composite matrix melts as expected but there is not enough heat transfer to the thermoplastic for it to melt and perform a reliable

weld. For greater concentrations of energy, high power peak and small laser diameter, it is observed an increase of penetration of the laser in the composite matrix that leads to the evaporation and destruction of the matrix exposing the fibers in the composite. This also leads to an unsuccessful weld because, even when using more energy, the matrix is destroyed before transferring the sufficient amount of heat to the thermoplastic. In this first experiment, we can conclude that the thermoplastic and the composite don´t share the same melting temperature.

In the second experiment, where an aluminum rod with 2 mm diameter was inserted between the composite and the thermoplastic we observe a different behavior, mainly because the laser was aimed to the metal rod in order to heat it up. For lower energies the heat transfer between the metal rod and the two parts is not enough to melt a sufficient portion of the composite and the thermoplastic to perform a reliable weld. For higher energies, we observe the metal rod become incandescent and melt all the material around it performing a reliable but fragile joint, because the transparent part will become very fragile after cool down. For an intermediate amount of energy (peak power from 1200 to 2400 W, laser 1 mm diameter), the metal rod doesn´t turn incandescent and melts a good portion of material around it to perform a reliable weld like it is shown on the graphics containing the experiments with Aluminum, Steel and Brass (Fig. 2).

In a third experiment where the aluminum rod was substituted by brass and steel rods, we observe a similar behavior to the ones using aluminum rod. It would be expected that, for the same amount of energy, the use of a brass rod would improve the weld strength compared to the steel or aluminum rods, due to the higher thermal conductivity of brass comparing to the others. In fact, the stress-strain curves show this didn´t happened with the aluminum rod. This can be explained by the slightly bigger diameter of the aluminum rod comparing to the steel and brass rods that increases the area of contact with the surfaces to melt. Disassembling the successful junctions, we can observe the melted material in the gap made for the rod, leading to the conclusion that the presence of the metal rod is doing what was expected to do. When using higher concentrations of energy it is noticeable the bending of the rod due to the rapid heating (Fig. 3), it tends to bend in direction of the thermoplastic, this can be explained by the existence of the gap in the composite that is thicker and stronger than the thin thermoplastic forcing the rod to bend upwards. This phenomenon was more noticeable in the steel rods than in the aluminum and brass ones.

In an extra experiment it was evaluated the influence of the small gap made in the composite to help fixate the metal rod during the experiment where it was tested for the optimum amount of energy. It is shown by the graphic (Fig. 3), as expected that the samples without the gap can't reach an higher tension like the samples with the gap. This can be explained by the free space around the metal rod between the surfaces that isn´t in contact leading to a worse weld seam.

In the graphics we can observe that higher concentration of energy increases the weld strength as expected once there is more material melting and interacting with other. By the small peaks present in the graphics we can conclude that fibers are also joined in the weld seam and take their part in the process of rupture.

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