Lasers in Manufacturing Conference 2017

Hybrid joining of high reflective and thin metal substrates with polymers by laser micro-structuration with short and ultra-short pulsing lasers

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Abstract

The research of new assembly technologies for dissimilar materials is growing up continuously due mainly to the high demand for transport application of obtaining lighter structures reducing as a result energy consumption. In other sectors as medical and micro-electronics, the benefit of laser hybrid welding is in the possibility to create new components with complex geometries, new properties while ensuring the functionality of the product. The present study proposes a method, based on short and/or ultrashort pulsed lasers, for welding metal having complex properties for the joining process with a polymer. High reflective, high thermal conductivity and thin metal plates, as aluminum, stainless steel, copper and titanium are studied in this present work.

Keywords: Laser hybrid joining; reflective metal; thin metallic substrates; polymer; ultra-short pulsing laser; micro-machining.

1. Introduction and Motivation

At the present time, different laser technologies are used to weld metal with polymer. High powerful lasers, typically in the kW range, CW or long pulsed, are commonly used for the global process, structuration and joining, as presented by Verhaeghe and al., 2017, in their research. This technology is well adapted for automotive industry for improving the lightweight constructions constituted by opaque polymer at the laser wavelength inducing the joining by conduction, i.e. by heating directly the metal plate. Amend and al., 2013, proposed another approach combining monochromatic laser radiation and additional polychromatic radiation for the joining process. The structuration process is carried out with short pulsed laser. This

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approach has shown the possibility to weld aluminum with transparent polycarbonate (results presented by the author in 2016) but without reach the rupture of the polymer while keeping intact the joining junction with the metal. The present study proposes a new methodology for structuring high reflective, and with high thermal conductivity metallic plates and thin metallic foils for hybrid joining based on short and ultra-short pulsed lasers. Moreover, this new methodology allows to combine metal and polymer for applications having some technical limitations in terms of temperature reached during the joining phase or chemical modification (for example oxidation) of the metallic foil. Indeed, in the medical sector, Mian A. and al., 2005, have shown the interest to combine, by laser, a thin metal sheet with polymer in the medical implant application. On one side, the encapsulation materials for permanent active medical implants seems to be more performant and to ensure total air tightness when polymer is used. On another side, the laser process is a performant substitute technology for preventing damage effects due to traditional technologies such as hot-plate bonding, friction bonding or electromagnetic welding, as presented by Amanat N. and al., 2010. The difficulty in the joining between completely different materials is the adhesion between them. In order to be independent to this feature, the present study is based on a two steps process: the first for ensuring the setting up of micro-structuration playing the role of a clamping tool and the second one for heating progressively the polymer in order to melt it. The influence of the laser source in the hybrid joining process is studied in this research.

2. Experimental

2.1 Material

Four metal plates have been studied: titanium alloy (Ti90Al6V4, thickness t = 100µm) commonly used in implants, copper-O.F.H.C (thickness t = 200µm), stainless steel (15-7PH, thickness t = 250µm and t=800µm) and aluminum (EN AW-1200A, thickness t = 1mm, EN AW-6063 and EN AW-5182, thickness t = 2mm). Concerning the polymer part, following the metal, the polymer to use can vary depending on the application. Indeed, for electronics applications, stainless steel, aluminum and copper will be associated to polycarbonate (various thicknesses will be tested; t = 500µm, 1mm and 2mm). For medical applications, alloy of titanium will be joined with Poly-L-lactic acid (biopolymer, thickness t = 50µm).

2.2 Laser machines

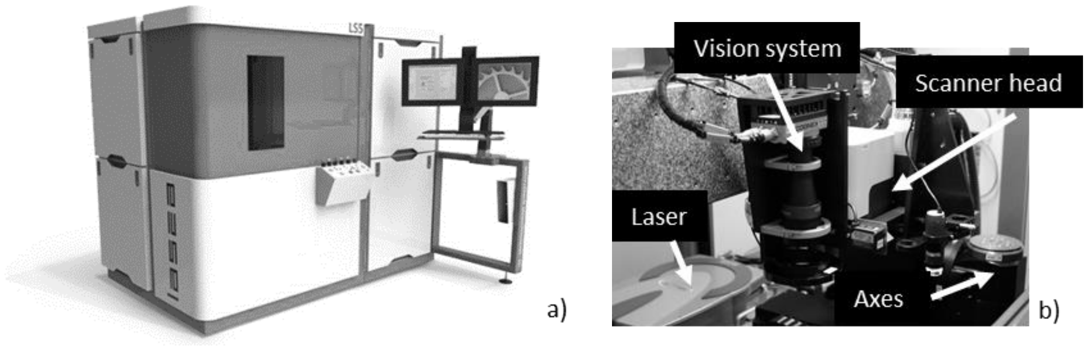

Fig. 1. (a) Lasea's machine for the laser hybrid joining, (b) picture of the inside of the machine

The Fig. 1 shows Lasea's machine used for producing hybrid joining between various couples of metals and polymers. The machine can have short and ultra-short pulsed lasers for the micro-structuration and CW lasers for the joining. Composed of linear and rotational axes, the machine can process complex geometries. In the study, three laser sources have been compared for the micro-structuration process: nanosecond pulsed laser (λ = 1064nm, P_{max}=20W, d_L=7.5mm, t=100ns), picosecond laser (λ = 1064nm, P_{max}=30W, d_L=9mm, t=150ps) and femtosecond laser (λ = 1030nm, P_{max}=20W, d_L=2.5mm, t=300fs). A CW diode laser (λ = 980nm, P_{max}=200W, d_L=5mm) has been used for the welding process. Complex vision system is also integrated inside the machine for ensuring exact positioning of the sample and quality control.

2.3 *Laser micro-structuration process*

The geometry developed during the research is based on broken lines having various orientation forming pattern. After many experimental validations for selecting the most appropriate design, the chosen one consists in concentric lozenges. This design combines the effect of grooves with different orientations improving the clamping aspect and the achievement of a suitable ratio between the microstructure surface and the global joining area. Fig. 2 shows the geometrical parameters studied during the research. The dimensions of each design are a function of the line width '*a*' which depends of the laser source. The distance between concentric lozenges, named '*x*', takes different values proportional to the line width. Furthermore, the distance between lozenges and the size of them are also variables studied during the research. The global micro-structure density (GMD) on the joining area has been defined for comparing the optimized results. The joining surface treated by laser is 2.5 cm² on sample having 25mm width and 80mm length.

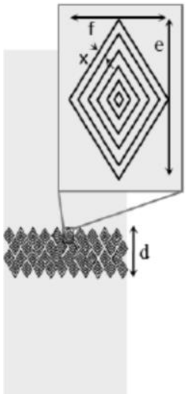

Fig. 2. Schematic representation of the lozenge design.

Fig. 3 presents SEM images for an example of micro-structuration performed by laser. Depending on the laser sources and metal sheet, the laser parameters have to be adapted for reaching the rupture of the polymer without detaching the join.

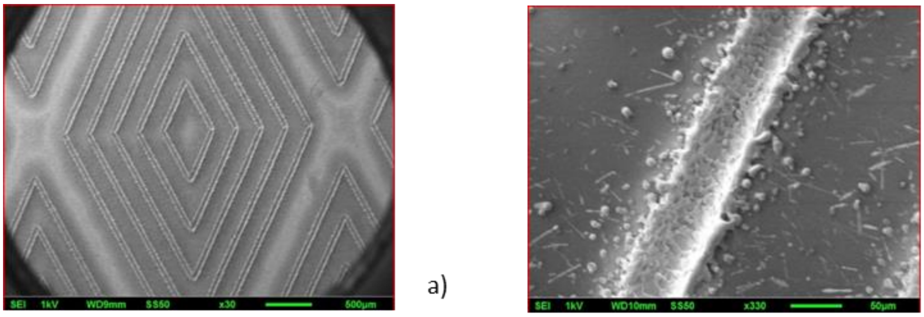

Fig. 3. SEM images of (a) lozenge design and (b) micro-structuration

For high reflective metal sheets, as aluminum plates, two laser processes can be used for ensuring the joining up to the rupture of the polymer part (see Fig. 4). The first laser process consists in a pre-treatment of the surface for ensuring higher absorption of the laser beam during the joining laser process. The second one is used for creating the micro-structures.

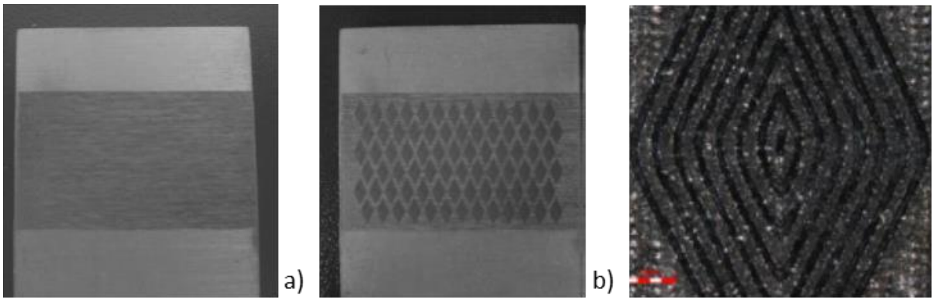

Fig. 4. Laser process for high reflective metallic sheet: (a) Pre-treatment (b) micro-structuration. (c) Picture of the combined laser processes

The micro-structure samples are analyzed by confocal microscopy (Olympus, OSLO4100) in order to determine the profile of the micro-structure and evaluate the GMD.

2.4 Laser joining process

In this present work, the joining process has been performed by passing through the polymer part which is sufficiently transparent to the laser wavelength. This joining methodology is named transmission joining (Fig. 5). The laser heats the metal plate. The heat is then transferred to the polymer by conduction. The polymer melts and fills the micro-structurations of the metal part. These last ones create a natural clamping system, keeping blocked the polymer inside the metal ensuring consequently the joining.

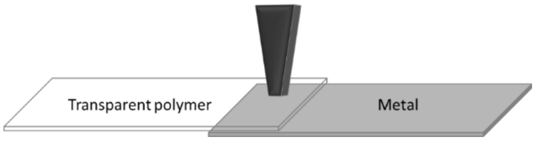

Fig. 5. Schematic picture of the transmission joining

A tensile test is performed thanks to a traction machine for determining the resistance of the joining and analyze, in this way, the influence of the global micro-structure density.

3. Results and Discussion

With the specific geometrical design and adapted laser parameters, the research has led to join various combination metal/polymer up to the rupture of the polymer without affecting the joining area for different combinations of metal and polymer. Some examples of joining between aluminum plate and polycarbonate are shown in the Fig. 6. The critical point of the aluminum is its high reflectivity combining with high thermal conductivity. Due to the thickness of aluminum plate presented, the heat transfer between metal and polymer is decreased leading to a complex joining.

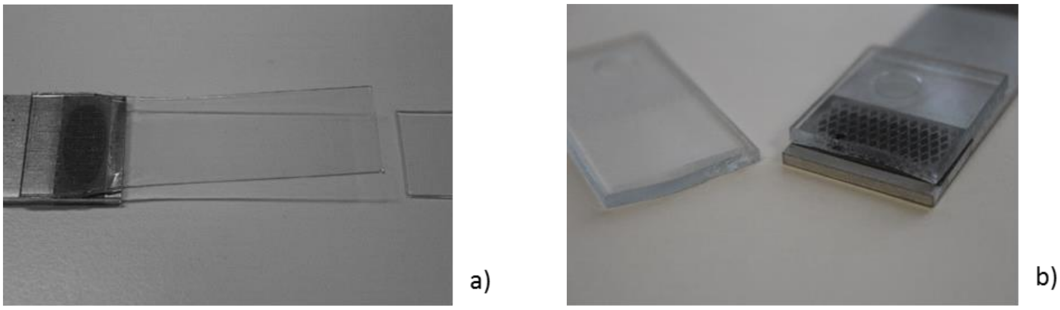

Fig. 6. Pictures of (a) aluminum plate (EN AW-5182- 2mm thick) joined with polycarbonate film (1mm thick) and (b) aluminum plate (EN AW-6063, 2mm thick) with polycarbonate plate (2mm thick)

With copper, thermal effect inducing oxidation can be a critical drawback in specific applications as micro-electronics. The evaluation of different laser sources shows the possibility to decrease considerably the oxidation of the copper by using femtosecond laser (see Fig. 7) while conserving the joining quality.

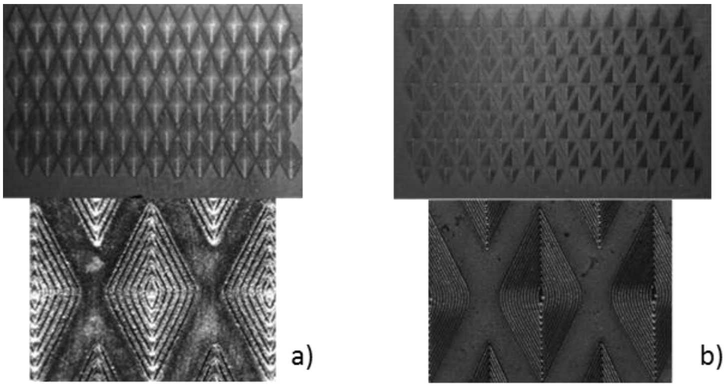

Fig. 7. Pictures of copper processed with (a) nanosecond laser source and (b) femtosecond laser source

In case of the titanium alloy, the drawback induced by nanosecond laser consists in a bending of the foil (see Fig. 8). The heat affected zone produced by femtosecond laser being considerably lower, the foil doesn't bend making easier the welding and insuring the integrity of the metal foil and the quality of the results. The obtained rupture resistance is equivalent to the resistance of the polymer.

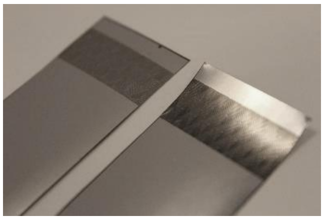

Fig. 8. Pictures of titanium alloy processed respectively with femtosecond laser (in left) and nanosecond laser (bending effect, in right)

4. Conclusion and outlook

Depending of the targeted application, the laser source will be adapted for reaching quality joining. Indeed, thermal effect and oxidation are, among others, undesirable effects which have to be avoid in the medical and the electronics sectors to quote only these. This present study proposes a laser solution for joining metals with complex properties (reflectivity and thin thickness) and polymers while obtaining high joining quality and strength, i.e. up to the rupture of the polymer part without affect the joining area. Based on micro-engraved structures with laser in the metallic part, this methodology is relevant for various metal/polymer couples and laser sources.

Acknowledgments

We would like to acknowledge the assistance of the Wallonia Region for its financial support, in the frame of the project ID 9775.

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