Lasers in Manufacturing Conference 2017

Hollow core waveguide for simultaneous laser plastic welding

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Abstract

Welding of plastics is a very important process in many industrial fields such as electronic packaging, medical applications, textile joining and automotive. It is often used when finished structure is too large to mold, for cost effectiveness or when dissimilar materials have to be joined. It is also employed in MEMs and Bio-MEMs applications, for example for microfluidic devices, where joint areas are very small, and need an amount of precision that other techniques can't provide.

This work focuses on description of transparent laser plastic welding technique, comparing simultaneous and quasi-simultaneous welding, and the development of an experimental setup for an automotive application. There are different laser welding methods, like simultaneous welding, where all the joining interface is irradiated at the same time and often includes a hollow guide to direct laser beam, and quasi-simultaneous welding, for example contour welding or scanning welding, where the laser spot is driven on joining interface via movement of the source or changing the path of the laser beam. An innovative tool end experimental setup was made to evaluate the simultaneous versus quasi-simultaneous welding to join polymeric material for an automotive application. A DFSS design of experiment was used. A LIMO laser bar diode @808nm with a maximum output power of 50 Watts, was coupled to a multi-mode 400 µm glass core optical fiber (Boscottica) with a numerical aperture of 0.22, by a LIMO Beam Transformation System HOC 150/500 (1401.612). The beam at the output of the fiber was guided through two different optical systems to the welding joint to test the two methods. A SANYO stepper motor was used for the quasi-simultaneous welding. Different kind of plastic materials were joined, Hostacom TRC 787N and THERMORUN TT875NE/BE. We performed static pull tests and dynamic pull test, and found optimum and baseline configuration.

Keywords: laser; joining; transparent laser welding; simultaneous welding;

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1. Introduction

Laser technology is widely used in Manufacturing, for macro processing as welding, cutting, surface machining, process control, and micro processing as micro-joining, controlled drilling, material ablation, surface micromachining. It is also used in rapid prototyping, as selective laser melting, stereolithography or two photons polymerization for 3D printing.

Laser welding has become very attractive in recent years due to its cost/effectiveness great ratio, which comes from optimal energy conversion of the laser sources, combined to the possibility to heat the materials only in the junctional area, leaving unaltered the surrounding zones. It has many possible uses in several fields such as electronic packaging, medical applications, textile joining and automotive and has also been investigated for other applications.

Laser welding exploits the electromagnetic wave interaction - material, to soften and melt the junction area to join two similar or dissimilar material. Wavelengths in near infrared (@ 808 nm - 980nm) are used despite of they carry less energy than lower wavelengths, because their interaction with molecular structures causes vibrational motions that turn into heat.

Like other welding processes, there are several types of laser welding: head, edges, overlapping, brazing using a third alloy different from the two materials that need to be welded, as well as it is possible to weld various materials such as metals, plastics etc. A particular laser welding technology is *Transparent laser plastic welding* which is the welding of polymers in transparency. As the name suggests, this is an overlay welding where the base material is a strongly absorbing material to the wavelength used, while the superimposed material is a transparent material to electromagnetic radiation.

The two polymers, which are to be joined, must be of the same plastic family with similar melting/softening temperatures (*Vicat Softening Point)* to be joined successfully. It is possible to weld the most common thermoplastics, such as: PA 6, PA 66, PP and PE in their pure form or in composite form.

There are four distinct types of transparent laser plastic welding:

- Contour welding
- Masked welding
- Quasi-simultaneous welding
- Simultaneous welding.

In this brief document, a design of experiment developed to compare two different transparent laser plastic welding approaches, simultaneous welding and quasi-simultaneous welding, is reported, to join two dissimilar materials used in automotive field for airbags rail carriers.

Two distinct types of pull tests were performed, static and dynamic, to obtain an optimal configuration and a baseline configuration.

2. Experimental detail

2.1. Experimental setup

To perform and compare two different transparent laser plastic welding approach, simultaneous and quasi-simultaneous laser welding, the following experimental setup was developed.

A LIMO laser bar diode @808nm with a maximum output power of 50 Watts, driven by a homemade air-cooled laser driver, was coupled to a multi-mode 400 µm glass core optical fiber (Boscottica) with a numerical aperture of 0.22, by a LIMO Beam Transformation System HOC 150/500 (1401.612), composed of three optical glass lenses.

The beam at the output of the optical fiber was guided through two different optical systems to the welding joint depending on the used welding method. A SANYO stepper motor was used to perform the quasi-simultaneous welding (Fig.1a).

An air-based compression system was designed and realized, consisting of a metal structure, a clear optical window made of PMMA and a polymeric inflatable pillow to put under pressure the two polymers to be welded. An external manometer was used to vary the pressure. A focused beam with a diameter of 3 mm was generated in the quasi-simultaneous welding set-up (Fig. 1b), while a collimated beam with a diameter of 20 mm was used for the simultaneous test. Both distributions were Gaussian.

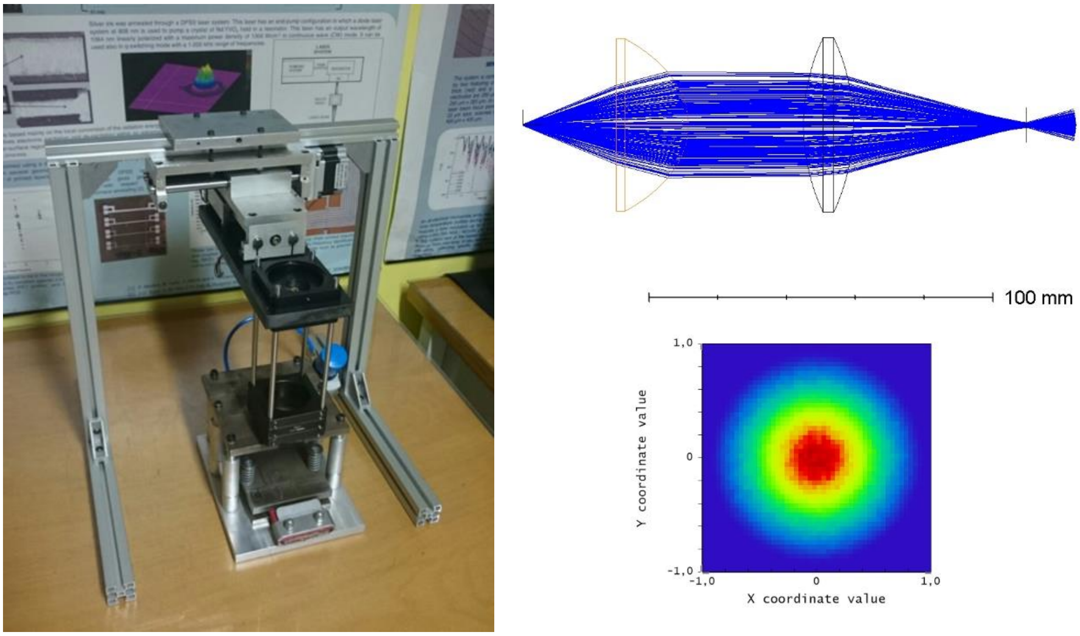

Fig. 1. (a) Experimental setup; (b) Ray tracing simulation of hollow core optical system

Hostacom TRC 787N samples with a thickness of 2mm were used as transparent material. Their transmission @808nm was measured to be higher than 35 % with a Power Meter Ophir Nova P/N 7Z01500. THERMORUN TT875NE/BE samples 2mm thick were used as absorbing material. Table 1 and Table 2 show the technical datasheets of the two polymers.

Table 1. Hostacom TRC 787 datasheet

Proprieties	Method	Value	Unit
Melt flow rate (230°C/2.16 kg)	ASTM D 1238	20	g/10 min
Density (23°C)	ISO 1183	1.03	g/cm^3
Tensile Stress at Yield (23°C)	ISO 527-1, -2	18	MPa
Tensile Strain at Yield (23°C)	ISO 527-1, -2	7	%
Flexural Modulus (23°C)	ISO 178	1850	MPa
Notched Izod impact strength	ISO 180		
(-30°C)		6.6	kJ/m^2
(23°C)		55	kJ/m^2
Heat deflection temperature B(0.45MPa)	ISO 75B-1, -2	103	°C

Table 2. THERMORUN TT875NE/BE datasheet

Proprieties	Method	Value	Unit
Melt flow rate (230°C/21.2 N)	ISO 1133	10	g/10 min
Density (23°C)	ISO 1183	0.89	g/cm^3
Tensile Stress at Break	ISO 37 Type 1A	13	MPa
Elongation at Break	ISO 37 Type 1A	740	%
Flexural Modulus	ISO 178	470	MPa
Tear Strength	ISO 34-1 Method B	85	N/mm
Notched Izod impact strength	ISO 180		
(-40°C)		83(P)	kJ/m^2

2.2. Robust design - Taguchi method

Five different control factors were identified to develop a Taguchi method for a robust design:
- Welding approach
- Time of exposure to laser
- Dose, valued as power density times time
- Pressure of compression between the two parts that have been to be joined
- Distance between junctional area and the edge of the specimen.

Table 3 shows the distribution of the five control factors that were used. The approached Taguchi method allowed to minimize the number of test by maintaining reliable results. Meaningful data were inserted into the table accorded to previous experimental tests, where good process parameters were found.

Table 3. Eighteen combination of control factors for Taguchi Method.

	Welding approach	**Time [s]**	**Dose [W· s/mm^2]**	**Pressure [bar]**	**Distance [mm]**
1	Simultaneous	20	3.5	2	2
2	Simultaneous	20	4	2.5	5
3	Simultaneous	20	4.5	3	10
4	Simultaneous	25	3.5	2	5
5	Simultaneous	25	4	2.5	10
6	Simultaneous	25	4.5	3	2
7	Simultaneous	30	3.5	2.5	2
8	Simultaneous	30	4	3	5
9	Simultaneous	30	4.5	2	10
10	Quasi-simultaneous	20	3.5	3	10
11	Quasi-simultaneous	20	4	2	2
12	Quasi-simultaneous	20	4.5	2.5	5
13	Quasi-simultaneous	25	3.5	2.5	10
14	Quasi-simultaneous	25	4	3	2
15	Quasi-simultaneous	25	4.5	2	5
16	Quasi-simultaneous	30	3.5	3	5
17	Quasi-simultaneous	30	4	2	10
18	Quasi-simultaneous	30	4.5	2.5	2

Thirty-six specimens, two for each of eighteen combinations of control factors, was realized joining two parts with an L section, with a junctional area of 50mm^2. (Fig. 2)

Fig. 2. Tested samples

Samples were tested by pulling tests in the two extreme conditions:

- +85°C, 5 mm/min
- -30°C, 100 mm/min

3. Results

Every specimen with the process parameter showed in Table 3 was correctly welded, thanks to the previous experimental tests which allowed to carefully select the parameters to be used. As expected, the specimens with the welded joint close to their edge exhibited better mechanical properties than the ones with the welded joint near to their center.

An Optimum and an Intermediate or Baseline configuration have been identified, as illustrated in Table 4.

Table 4. Optimal and best configurations found after pull tests.

Configuration	Optimal	Baseline
Welding Approach	Simultaneous	Simultaneous
Time [s]	20	25 s
Dose [Ws/mm^2]	4.5	4
Pressure [bar]	2	2.5
Distance [mm]	2	5

Simultaneously welded samples showed better mechanical properties both at +85 °C and -30°C than quasi-simultaneously welded samples. In fact, both optimal and baseline configurations were obtained with a Simultaneous welding approach. Higher doses also positively influenced samples characteristics. The best result was obtained with a pressure of 2 bar and a distance from the edge of the sample of 2 mm.

4. Conclusions

In this work, two laser welding approaches were used to weld two compatible polymers by a transparent welding method. Two welding set-up were realized to perform simultaneous welding tests and quasi-simultaneous welding tests. Thirty-six specimens were welded by using a robust Taguchi method. As initially hypothesized, simultaneous welding has yielded better results than quasi-simultaneous welding. Mechanical properties of the simultaneously welded samples were better than quasi-simultaneously welded samples. Also, an optimal and a baseline configuration were found, based on the results of the mechanical characterization. To summarize, simultaneous welding appears to be a more reliable process than quasi-simultaneous welding for polymers joining, allowing to obtain better mechanical properties of the welded materials.

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