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Through Transmission Laser Welding of Polymers using 1064 nm CW diode laser

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Abstract: *Through transmission laser welding provide high-speed, noncontact techniques for joining thermoplastics. A CNC machine provided by 1064 nm CW diode laser was used. Two sets of PMMA (Polymethylmethacrylate) specimens (Read with Black and Blue with Black) were welded. The mechanical and microstructure properties were measured. The shear strength was calculated for a clamping pressures of 3,5,7,9,&10 Bar with a welding speeds of 0.606 and 0.667 mm/sec where the second set of specimens (Blue with Black.) have a high shear strength than the first set under the same clamping pressure and welding speed conditions.The hole depth and width were calculated for the two sets and from this we observed that the increasing in the clamping pressure and welding speed affect the melting pool dimensions. The best results for the through transmission laser welding were achieved with a pressure range from 5 to 7 Bar and welding speed of 0.667 mm/sec.*

Keywords: *laser welding, PMMA, shear strength, clamping pressure.*

I. Introduction

Thermoplastics are a group of polymers that can be classified according to their structure into two classes of amorphous and semi-crystalline polymers. They have applications in the automotive, aerospace, medical and electronics industries. Because of their excellent strength - to - weight ratio, they are chosen successfully for many applications where metal and ceramics have traditionally been used [1].

The using of laser in processing polymers has increased significantly. Infrared and excimer laser have been used for welding, cutting and modification of polymers as well as cutting of polymer-based resins. More recently, however, the unique properties of laser beams have been applied with spectacular success to the development of laser welding. The ability of lasers to generate the exact amount of energy and deliver it at speed to a well-defined location can be used for welding [2].

There are many different methods of joining plastics, with the selected process being dependent upon such variables as type of plastic, assembly requirements, and application area. These processes include welding, adhesive bonding, and mechanical fastening. Transmission laser welding involves localized heating at the interface of two pieces of plastic to be joined to produce strong, hermetically sealed welds with minimal thermal and mechanical stress, no particulates and very little flash. Cycle times can be as short as a second, and relatively light clamping pressure is required— just enough to keep the parts stationary and ensure there is no gap. Transmission Laser welding can be used for rigid or flexible materials and small or large parts [3].

II. Through transmission laser welding:

It relies on the fact that many polymers, in their natural state, are not strong absorbers of NIR radiation. The window of NIR wavelengths that can be used, beyond the visible spectrum, from 800nm to approximately 2000nm, is illustrated in Fig.1.

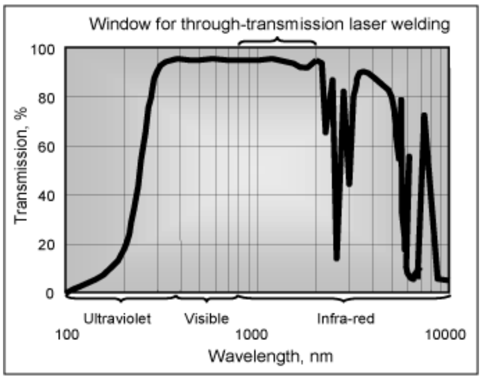

Fig.1. Absorption spectrum of a typical polymer[4]

The process differs from most other plastics joining processes, and from the use of lasers for joining metals, in that the energy from the laser is concentrated at the joint rather than melting material from the surface inwards. The process is illustrated in Fig.2. The energy of the laser must be concentrated at the joint in order to melt the polymer to form a weld. The laser passes through the upper workpiece to the joint. This melts a thin film of plastic on either side of the joint, resulting in a permanent weld when the joint has cooled [4].

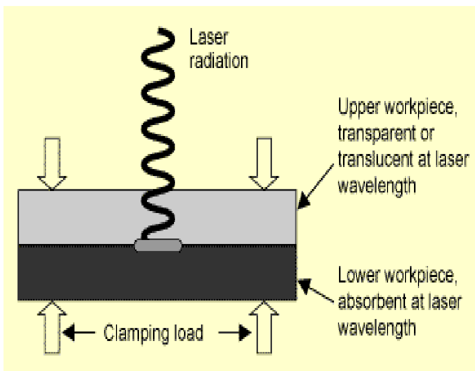

Fig.2. Through-transmission laser welding - cross-section through the welding process [4]

An important factor when using laser transmission welding is intimate contact between the surfaces to be joined. This ensures sufficient melt flow to produce a strong weld. To obtain intimate contact of the substrates at the weld interface, a certain amount of clamping pressure is required for most joints (the notable exception being an interference fit, as clamping may not be necessary). The amount of pressure depends upon the materials being joined, the specific joint design chosen, the quality of the surface conditions at the weld interface, and the final strength requirements. Surfaces typically have irregularities (bumps, valleys, etc.) which prevent close contact. As the surfaces heat and expand, the clamping pressure helps to flatten the surface, which removes entrapped air to impart even contact along the interface. This facilitates diffusion of the polymers necessary to create a strong weld [5].

III. Tensile test

The tensile strength of a material is the maximum amount of tensile stress it can be subjected to before failure. The definition of failure can vary according to the material type and design methodology. There are three typical definitions of tensile strength.

- Yield strength: the stress at which material strain changes from elastic deformation to plastic deformation causing it to deform permanently.
- Ultimate strength: the maximum stress a material can withstand.
- Breaking strength: the stress coordinate on the stress-strain curve at the point of rapture.

A lap shear join was used for the polymers samples to examine the strength of the welded area, figure 3 shows an example of lap shear joint.

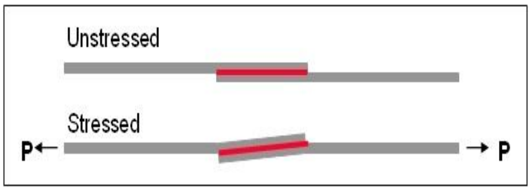

Figure 3: Schematic illustration (side view) of single lap joint before and after application of tensile stress [6].

IV. Experimental setup

Laser CNC machine:

A three dimensional Diode laser CNC machine was used and adapted to satisfy the welding process, as it was shown in fig. no.4. The diode laser parameters are 5W maximum power, CW mode at 1064 nm wavelength.

Clamping Pressure Device:

It was added to the laser CNC machine to adopt the machine for the laser polymer welding process.

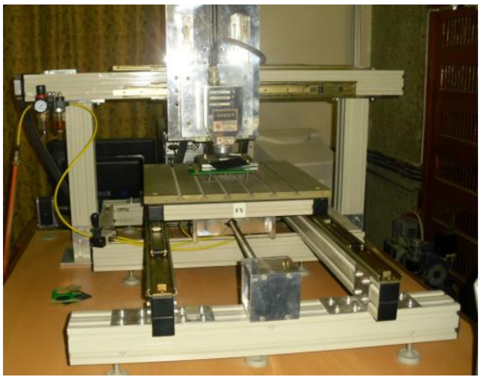

Fig. no.4: Laser CNC machine

Materials:

Three colours of 2.5 mm thickness PMMA (Polymethylmethacrylate) specimens were used, as shown in fig. 5, 6 & 7.

Fig. no.5: Red specimen

Fig. no.6: Blue specimen

Fig. no.7: Blue specimen

V. Absorption Spectrum:

One of the most important factor that must be considered in through transmission laser welding was the absorption of the used materials, fig. no. 8 , 9 & 10, shows the absorption spectrums of the three specimens.

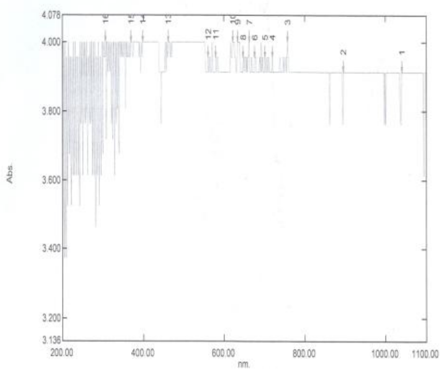

Fig. No.8: Absorbance of Black specimen

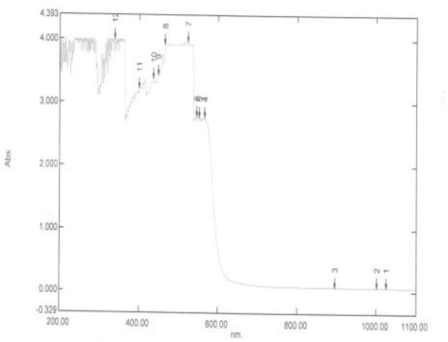

Fig. No.9: Absorbance of Red specimen

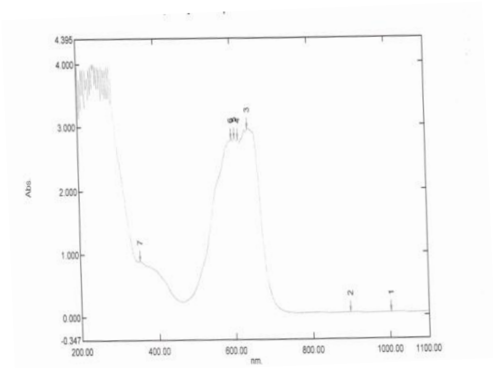

Fig. No.10 : Absorbance of Blue specimen

From fig. no.8, we observed that the black specimen has a high absorbance at 1064 nm wavelength which reaches to 3.9, while for the red and blue specimens, the absorbance reaches to 0.065 and 0.048 respectively.

VI. The Procedure

A two sets of PMMA specimens (Red with Black and Blue with Black) were welded, , fig. no. 11 & 12 shows the two welded sets.

Fig. no.11: 1st set of welded specimens

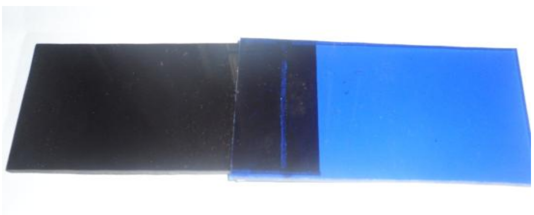

Fig. no.12: 2nd set of welded specimens

VII. Shear test:

Strength testing was an important aspect of a weldability study in laser welding, and among all tests, static tensile-shear testing was the most common laboratory test used in the determination of weld strength because of its simplicity in which the average forces were calculated to each couples of specimens then the shear stress were calculated using the following equation:

$$\tau_{sh} = \frac{P}{A} \quad (N/mm^2)$$

Where; P=Failure Force (N)

A= Spot Area = πab (mm^2)

a, b= Spot Radii (where the spot have an ellipse shape)

Fig. no. 13 and 14 shows the shear strength versus the clamping pressure for two sets of specimens.

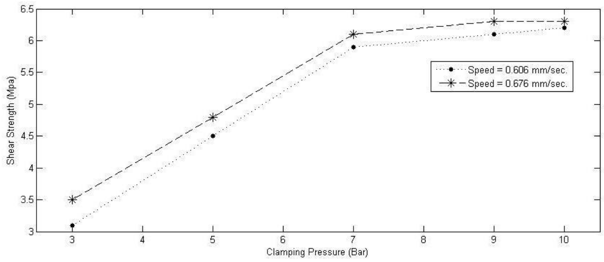

Fig. No.13: Shear strength (Mpa) versus Clamping pressure (Bar) of the 1st set

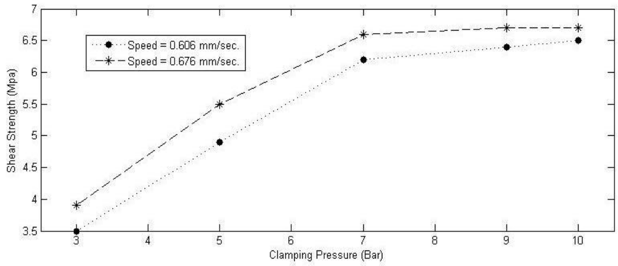

Fig. No.14: Shear strength (Mpa) versus Clamping pressure (Bar) of the 2nd set

From fig. no.13 & 14, we noticed that the shear strength was increased with an increasing of the clamping pressure and from that figures we noticed that the maximum increasing in the shear strength occurs in clamping pressure between 5 to 7 bar also we can noticed that the values of the shear strength of the second set (blue with black) have a larger values than that of the first set (Red with Black) and this is because the red specimen have a larger value of absorbance than that of blue specimen.

Fig. No. 15 & 16, shows the upper depth of the two sets of specimens.

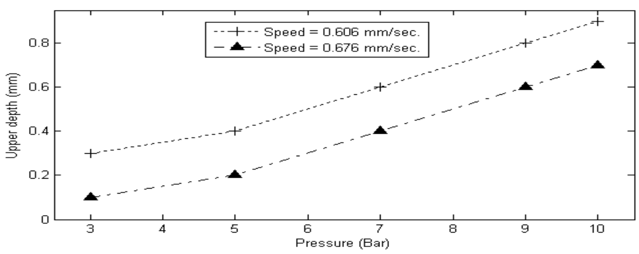

Fig. No.15: Upper depth (mm) versus Clamping pressure (Bar) of 1st set

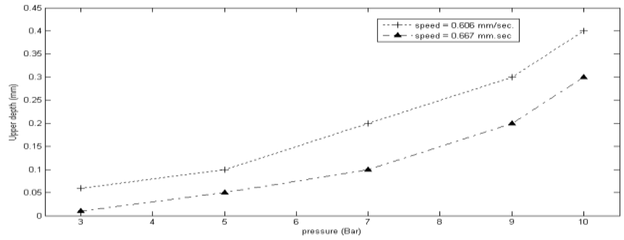

Fig. No.16: Upper depth (mm) versus Clamping pressure (Bar) of 2nd set

From fig. no. 15 &16, we noticed that the upper depth was increased with an increasing in the clamping pressure also it was affected by an increasing in welding speed where it was inversely proportional with it, also the second set have a relatively lower values for upper depth than that of the first set.

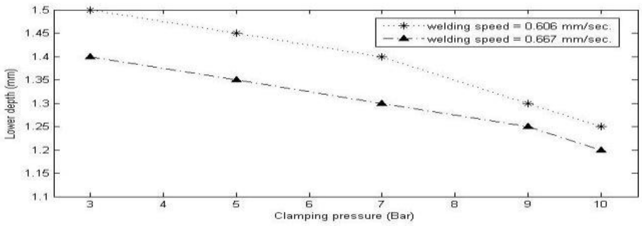

Fig. No.17: Lower depth (mm) versus Clamping pressure (Bar) of 1st set

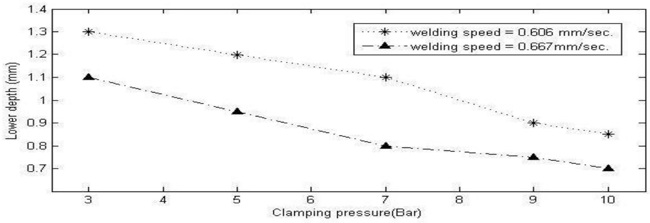

Fig. No.18: Lower depth (mm) versus Clamping pressure (Bar) of 2nd set

From fig. no. 17 & 18, we noticed that the lower depth was inversely proportional with an increasing in the clamping pressure and welding speed, and as in the upper depth the lower depth also have relatively a lower values than that of the first set of specimens.

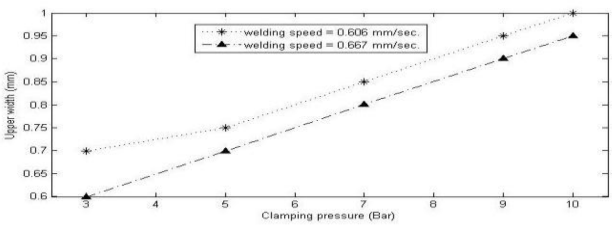

Fig. No.19: Upper Width (mm) versus Clamping pressure (Bar) of 1st set

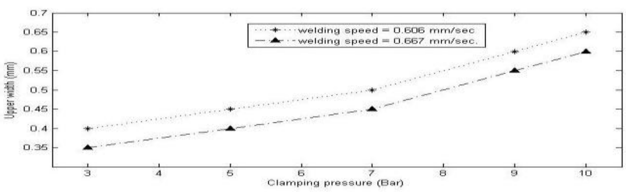

Fig. No.20 : Upper Width (mm) versus Clamping pressure (Bar) of 2nd set

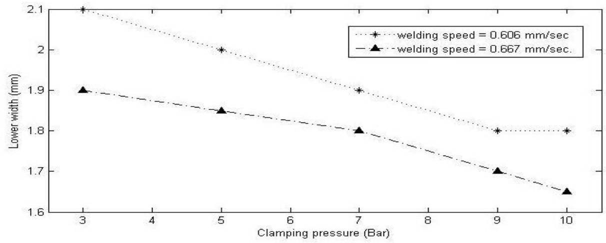

Fig. No.21 : Lower Width (mm) versus Clamping pressure (Bar) of 1st set

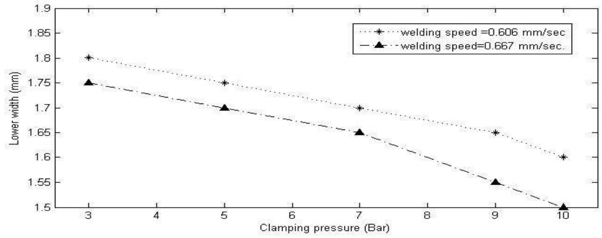

Fig. No.22 : Lower Width (mm) versus Clamping pressure (Bar) of 2nd set

From fig. no. 19, 20, 21 & 22, we noticed that the upper and lower width were also affected by increasing in clamping pressure and welding speed and they were taking the same platform of upper and lower depth.

VIII. Conclusion:

1- From fig. no. 13 & 14, we can conclude that:

* The clamping pressure must have a limit in increasing where when it reached to a certain value, the increasing in the shear strength becomes slightly.
* The second set of specimens (Blue with Black) have a better welding quality that the first one (Red with Black) .
* The best results for shear strength of two sets were achieved at clamping pressure between 5 to 7 bar and welding speed of 0.667 mm/sec.

2- From figures no.15 through 22, we can conclude the clamping pressure and welding speed play a very important role to enhance the mechanical properties of the welded zone.

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