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Through Transmission Laser Spot Welding for PMMA

[I]Ahmed R. Al-Hamaoy, [II]Hussein A. Jawad
[I]Ph.D., College of Engineering, Al-Nahrain University, Baghdad, Iraq
[II]Assist. Prof., Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

Abstract
A CNC laser machine provided by 1064 nm diode laser was used to weldPolymethyl methacrylate (PMMA) (as a thermoplastic) with different (laser welding time, and specimens clamping pressure) with laser intensity of 558.53 W/cm2.
Two thicknesses (2.50 and 6.00) mm were used in this experiment. Tensile strength test for each welding point was examined. It is observed that the welding strength increased with increasing laser time and the clamping pressure till (5sec, 5 bar) respectively. The best condition for laser welding time and clamping pressure was (4 sec and 5 bar) respectively, for 2.50mm thickness. While the best conditions were (5 sec and 5 bar) respectively for 6.00mm thickness.

Keywords
TTLW, PMMA, Laser welding, spot welding.

Introduction

The laser welding process is one of the most advanced manufacturing technologies owing to its high speed and penetration[1].Laser welding of thermoplastic polymers is a technology already used for industrial batch production in several sectors like automotive, telecommunication, and medical. Several different approaches are being developed for laser welding of plastics [2].
Through- Transmission Laser Welding is a type of welding that may be applied for joining of the various plastics and in the rigid to rigid, flexible to rigid, and flexible to flexible design combinations, Fig. (1).This technique has become an important joining process offering unique technical and economical assembly methods for many industrial applications [3-6].
The basic advantages of through-transmission laser welding are absence of vibration of the parts in the welding process, seam quality and flash (particles) free, design freedom, processing freedom, easy to automate, low cost tooling, high mechanical performance of welded joints, rapid welding speeds, and welding pre-assembled plastic components with the parts in the same orientation and position [7-9].
This paper studies the effect of laser exposure time and clamping pressure on the welding strength.

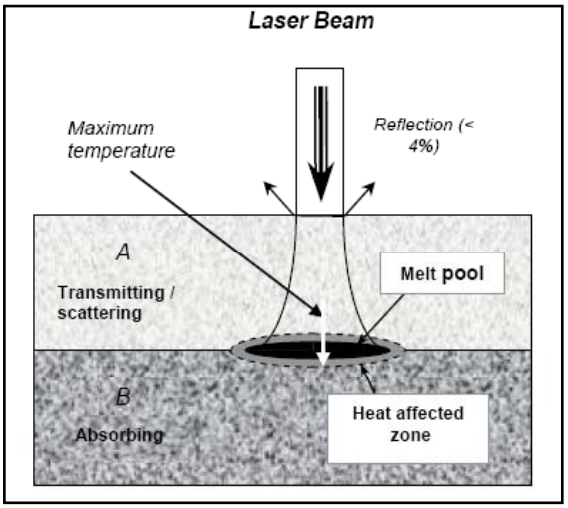

Fig. (1): Principles of the butt joint and the formation of the melt pool within the heat affected zone for traditional through-transmission laser welding. Legend: A is laser transmissible plastic; B is a thermoplastic that absorbs the transmitted light at the interfacial region [7].

Materials and methods

PMMA specimens with 100 x 20 mm^2 dimensions and(2.5 and 6) mm thicknesses were weld using laser CNC machine provided by a CW 1064 nm diode laser, with (3.29)W output power was used. The laser beam has an elliptical shape with (1.0x0.75) mm in diameters, and 100mm focal length. A manual controlled pneumatic clamper system with pressure range 0-10 bar is placed at the CNC machine table.
A computerized universal testing machine was used to calculate the tensile tests for the welded specimen, and a microscopic system with CCD camera was used to examine the welded area.
The transparent specimen was placed over the black one, then clamped and pressed under the pneumatic clamped system. Assist transparent and black parts were placed to ensure homogenous pressure distribution at the whole specimen, Fig.(2). The minimum spot diameter is placed at the specimens interfacing layer.

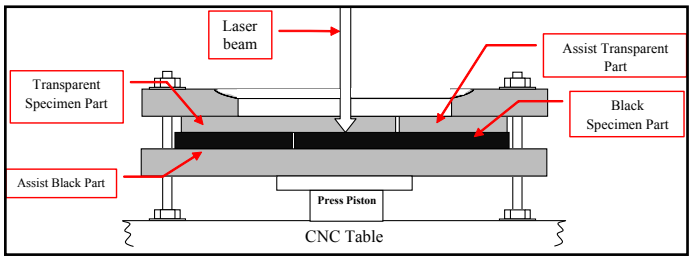

Fig (2): The Specimen Clamping Method (Cross Section View).

Specimens were divided into two groups; in group (A) 2.50 mm thick for eachsamplewas used, while the sample thickness was 6.0mm in group (B).
The clamper pressures used were (1, 3 and 5) bar, while the laser exposure times were (1, 2, 3, 4 and 5) sec, each case was repeated twice.
Then a tensile test characterization was done for every welded specimens and the maximum shear stress is calculated.

Results and Discussion

1. Group A

The shear stress as a function of clamping pressure for different welding time is illustrated in Fig.(3).
The maximum shear stress was recorded as 69.022 N/mm^2 at (5 sec, 5 bar) exposure time and clamping pressure respectivly.

While the minimum shear stress is 38.053 N/mm² at (2 sec, 1 bar) exposure time, and clamping pressure respectivly.
In general the shear stress increases as clamping pressure increases for all used welding time. This behavior is expected due to decreasing in air cavity between the two speciemens with preassure increased, which incraeses the heat conduction between these specimens.
Similar behavior was observed when the shear stress is plotted as a function of laser welding time, as shown in Fig.(4).
In other hand during the stress analysis an internal fracture were appeared in the transparent part of group A, as shown in Fig.(5), because the welding strength were higher than the PMMA shear strength which is equal to:

$$\tau_{Shear} = 625\frac{kg}{cm^2} = 61.291875\frac{N}{mm^2} \approx 61.3\frac{N}{mm^2}$$

While the specimens (4 sec, 5 bar), (5 sec, 1, 3, 5 bar) were undergo more than 61.3 N/mm², so an internal fracture appeared.

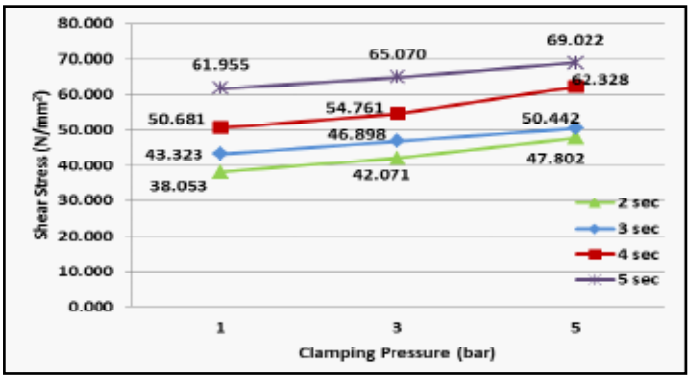

Fig (3): Shear Stress Vs Clamping Pressure at constant Laser Welding Time (PMMA 2.5 mm).

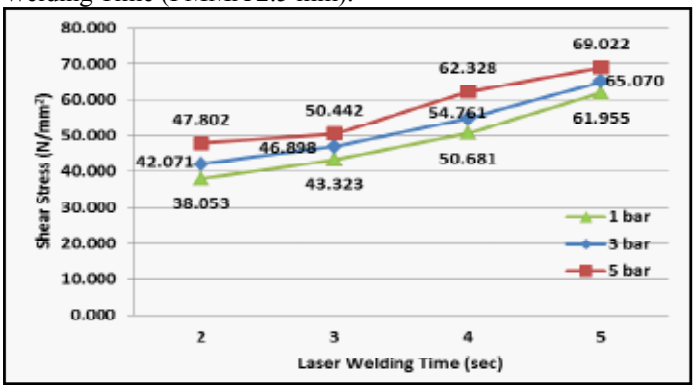

Fig. (4): Shear Stress Vs Laser Welding Time at constant Clamping Pressure (PMMA 2.5 mm).

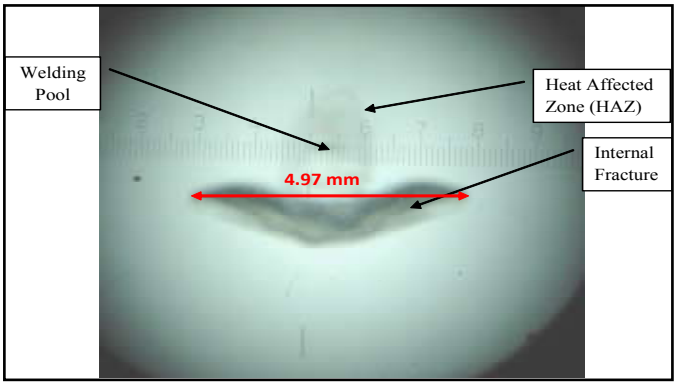

Fig. (5): The Internal Fracture in Group (A) specimen (29) (2.50 mm PMMA).

2. Group B

Similar process was done for 6.00 mm thick. It is clear that the shear stress decreases to be 63.166 N/mm² as a maximum value. While the minimum value shear stress approximately not varied, as shown in Fig.(6).
The behavior was observed similarly when the shear stress is plotted as a function of laser welding time, as shown in Fig.(7).

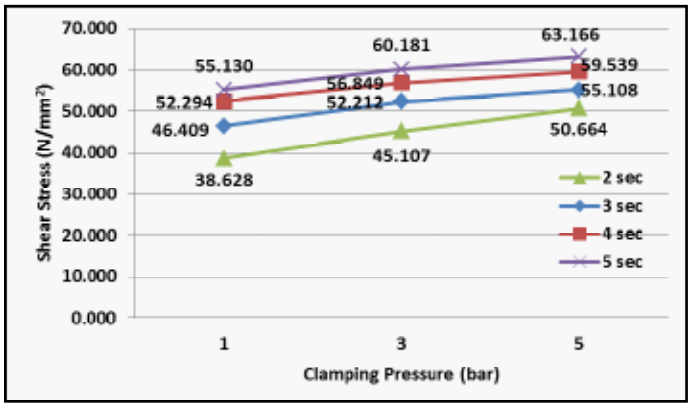

Fig. (6): Shear Stress Vs Clamping Pressure at constant Laser Welding Time (PMMA 6.0 mm).

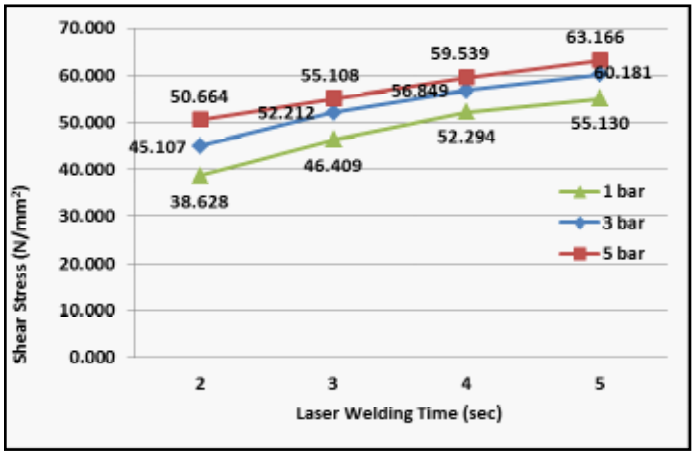

Fig. (7) : Shear Stress Vs Laser Welding Time at constant Clamping Pressure (PMMA 6.0 mm).

Generally a weak welding point appears for the one second of laser exposure time, and this was expected result due to the low laser intensity.
The shear stress increased proportionally with clamper pressure at constant laser exposure time, due to decreasing in air cavities between specimen parts which means increasing in heat conductivity, and the best pressure were 5 bar, as shown in Figs. (3 and 6).
Also the shear stress increased proportionally with laser exposure time (till 5 sec) at constant pressure, as shown in Figs.(4 and 7), due to increasing in transferred energy with time increasing.
On other hand drilling appears at laser exposure time longer than 5 sec, while no difference seen in results at clamping pressure higher than 5 bars.

Conclusion

The best laser welding time was 5 sec, while no welding appears during 1 sec laser exposure time, for the 3.29 W. The welding process for PMMA groups show that the welding strength increased with increasing laser time and clamping pressure till 5sec and 5 bar respectively. For 2.50 mm thick the best condition

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for laser welding time and clamping pressure was (4 sec, and 5 bar) respectively. While for 6.00 mm thick the best condition for laser welding time and clamping pressure was (5 sec, and 5 bar) respectively.

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