Engineering and Technology Journal Vol. 38, Part A (2020), No. 05, Pages 761-768

Engineering and Technology Journal
Journal homepage: engtechjournal.org

Effect of Different Laser Welding Parameter on Welding Strength in Polymer Transmission Welding Using Semiconductor

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Submitted: 23/06/2019 Accepted: 14/08/2019 Published: 25/05/2020

K E Y W O R D S

Polymer, Laser Transmission Welding, Taguchi Technique, Weld Width. Weld Strength

A B S T R A C T

In this work, the diode laser (810μm wavelength) was used for laser transmission welding application on PMMA (polymethylmethacrylate). The welding was done between opaqueness and transparent with thickness 2 mm and 2.57 mm, respectively. The effects of different process parameters, laser speed, spot size and force with different values (5, 15, 20 mm/min), (2, 2.5, 3mm) and (2, 6, 10 N) respectively were used to study their effect on weld width and strength. L9 Taguchi orthogonal array has been used to design the experiments and optimize the result. The result of the signal to noise ratio shows that, the width of welding decrease with increasing both the welding speed and the spot size while it was increased with increasing the force on the sample. The narrower width observed at speed (20mm/min), spot size (3mm), and force (2N). Also, the best strength was found at speed (15 mm/min), spot size (2.5mm), and force (10N).

How to cite this article: F. M. Shaker, M. M. AL-Khafaji and K. A. Hubeatir, ,"Effect of different laser welding parameter on welding strength in polymer transmission welding using semiconductor laser,," Engineering and Technology Journal, Vol. 38, Part A, No. 05, pp. 761-768, 2020.
DOI: https://doi.org/10.30684/etj.v38i5A.368

1. Introduction

Polymers have turned into the most significant material in numerous field and application. They are lightweight, some have outstanding optical, thermal, and electrical properties, and in general, they are simpler and more affordable to make and to process into the last item [1]. Polymers are separated into three classes: thermoplastic, thermostats, elastomers. Thermoplastic can be arranged by their structure into to classes of amorphous and semi-crystalline polymers. They used in several applications in the medical, aerospace, automotive, and electronics industrial [2]. Recently, the use of laser has become important in the treatment of problems and the use of it has increased significant

There is a wide range of ways for joining plastics, with the chose procedure being needy upon such factors as a kind of plastic, area of application, and assembly requirements. These ways include Adhesive bonding, welding, and Mechanical fastening [3].

Transmission welding includes restricted heat the two specimens' surface of the polymer to the be weld to make potent, hermetically sealed joint. Transmission laser welding can be utilized for flexible or solid material, large and small parts [2]. Various experiments were conducted to study the effect of the parameter process on welding quality, with different plastic materials and different application. S.Singare et al utilized Nd: YAG (1064 nm wavelength) at 40W in the LTW procedure. They utilized an alternate speed to consider their impact on the weld width and quality. Their outcome has been demonstrated that slow speed causes more prominent weld width and the quality of the wild ascent and increments with the welding speed until it achieves the greatest and the started to decay [4]. B Acherjee et al utilized diode laser to weld PMMA to ABS polymer. They examined the impact of the speed, the pressure, the power, and the spot size on the weld width and quality. They found that the most strength welding was at the least speed and the biggest width is the point at which the most elevated power is entered and less speed [5]. Rana M. Taha utilized polymethylmethacrylate polymer (PMMA) and CW diode laser (1064nm wavelength) for contemplating the effect of the speed and the weight on the weld width and quality. From their outcome, the welding quality expanded with the expansion of weight and the welding width diminishes with expanded weight and expanded speed [6]. S.Singare et al, utilized distinctive thickness of polycarbonate polymer (PC), and by Nd: YAG laser (1064nm wavelength), tests was welded. A few factors were likewise used to think about their impact on the width and quality of the weld. The outcome demonstrates that, as the speed expands, the welding width diminishes and that the most grounded welding was found at the least speed [4].

Taguchi technique is a statistical way and is a widely applied method in various applications used to improve the selected laser parameters specified in laser transmission welding [7-10].

In this work, an order was made to examine a few parts of laser welding and transmission of PMMA polymer. Different values were used for what was used in the previous search, the values of the pressure forces, and the size of the laser spot. Emphasis was placed on distinguishing between the effect of parameters of important information, a stand-off distance, welding speed, and the clamping pressure on quality (weld quality) and welding width. The Taguchi technique is used to transfer the soldering strength and the weld width.

2. Laser Transmission Welding Process

Laser transmission welding(LTW) is a helpful and fast way that utilized to weld the fixings thermoplastic with a strong and vigorous bond[11,12]Laser transmission welding as shown in Figure 1 includes inspecting pressure, transparent- laser part, and laser absorbent part. The laser beam goes into the laser transparent part and is absorbed in the absorbent part. The heat will at that point be created in the welding interface and moved to the laser-transmitting part by conduction. A little division of a thin layer of tests has been broken down and the weld is produced after hardening. This procedure is utilized in the welding of plastic materials in the bundling business with a high artfulness and efficiency, which is relying upon the thermal parameters, light absorption, and light dissipating.

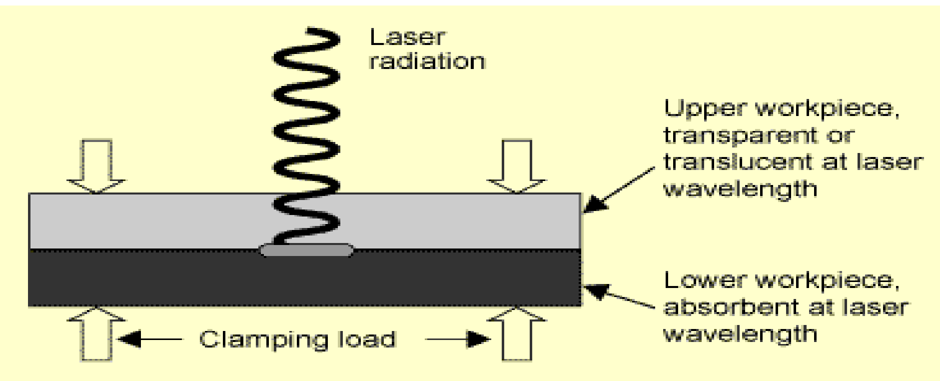


Figure 1: Through-Transmission Laser Welding - Cross-Section through the Welding Process [10]

One of the most important factors, when laser welding, is the intimate contact between the surfaces to be combined. These guarantees adequate liquefy inflow to produce potent welding. To ensure strong welding in the welding interface, a specific measure of clamping pressure is desired for more joints. The nature of the surface conditions in the welding interface, materials that are welded, the latest quality imperatives, the most important factors on which it is based pressure measurement. The surfaces usually have aberration (protrusions, valleys, etc.) which prevents close contact. When the surface is heated and extended, the clamping pressure presses the surface, releasing the twisted air to give it even contact with the side of the façade. This promotes the dispersion of important polymers for the manufacture of solid welding.

3. Material and Methods

I. Polymethalmethacrelate (PMMA)

Two different thicknesses of PMMA of transparent type (2mm) and one type of absorbent type(2.57mm) and with dimensions were used as shown in the Figures 2&3. This material was appropriate for laser transmission welding for its numerous applications like Low cost, Low weight, the relative densities of most plastic materials range from 0.9-1.4, as compared to 2.7 for aluminum and 7.8 for steel, Low frictional resistance, good corrosion resistance, and good insulation properties. The polymer used in this work is a pre-prepared material, and the samples were cut within measurements in the resistance laboratory in the Materials Engineering Department at the University of Technology. The dimensions of each sample are the same and as shown in Figure 3.

Figure 2: Opaque PMMA Specimen

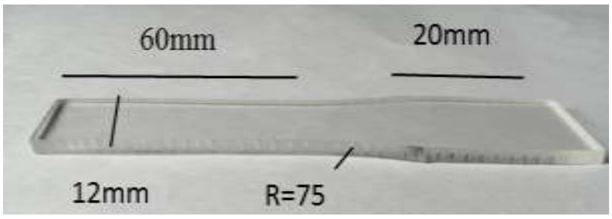


Figure 3: Transparent PMMA Specimen

II. Clamping Pressure Tool

A polymer mold holed from its 4 sides. It's made of two parts, the first part contains the samples and the second one contains the load cell. We can control the pressure by fastening and unfastening the screws of the mold, as shown in Figure 4.

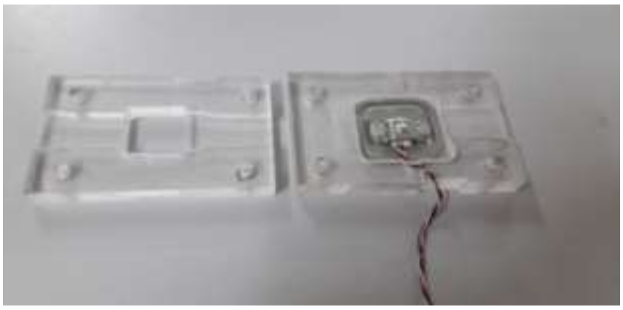


Figure 4: The Clamping Pressure Mold

A CNC machine was utilized, and adjusted to fulfill the welding process. Diode laser was used; the diode laser parameter was 0.684W maximum power, CW mode 810nm wavelength. PMMA specimens (transparent and absorbed) were welded, as shown in Figure 5.

Figure 5: Laser Welded Samples

A universal testing machine was utilized to compute the tensile tests for the welded example. The machine is shown in Figure 6, with limited ranges to 200kN force. The machine gives computerized output data. The tensile tests can be utilized to find out a few mechanical properties of materials that are significantly in structure. There are three ordinary meanings of tensile strength :

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

The specimens are mounted by its ends into the holding grips of the testing apertures as shown in Figure 6. A specimen is disfigured, for the most part, to crack, with slowly expanding tensile test that is connected uniaxial along with the long axis of a specimen.

Figure 6: Tensile Specimens

4. Taguchi Method

It is a statistical way for production or process design that focuses on limiting variety and/or sensitivity to noise. Taguchi method gives a powerful and efficacious technique for structuring products that work consistently and ideally over a diversity of conditions[11]. The Taguchi strategy utilizes a specific design of orthogonal arrays for studying the whole procedure parameter space with just a few numbers of experiments. In Taguchi's technique, all variables influencing the procedure quality can be partitioned into two kinds: control factors and noise factors, Control factors variables are those set by the manufacturer and are effectively customizable. These variables are most significant in deciding the nature of item attributes. In data analysis, the signal-to-noise (S/N) ratios are utilized to permit the control of the response as well as to decrease the variability about the response[12]. The S/N ratio was calculated from the Eq1,2 [13]. Three levels for each parameter used to weld the samples listed in Table 1.

$$S/N = -10\ \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$ The smaller y is better (1)

$$S/N = -10\ \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]$$ The greater y is better (2)

Where:

y Is the result of the response, n is the number of measurement data.

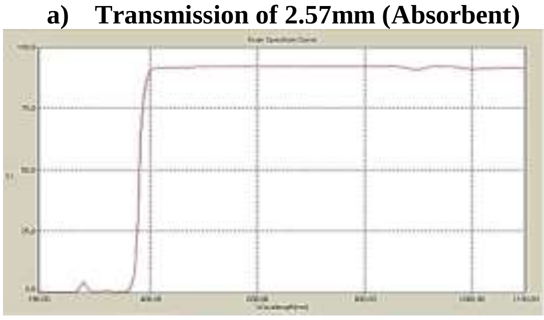
Table 1: The Level Values of Process Parameter for PMMA

Parameter	Level 1	Level 2	Level 3
Welding speed(mm/min)	5	15	20
Stand-off distance(mm)	2	2.5	3
Force(N)	2	6	10

5. Results and Discussion

One of the important and influential factors in the through transmission laser welding process was the transmission or absorption of the used materials, Figure 7 shows the transmission spectrums of the three samples by using UV-visible spectrometer.

a) Transmission of 2.57mm (Absorbent)



b) Transmission of 2mm (Transparent)

Figure 7: The transmission of the specimens

I. The weld Width Test

It's observed from the Figures 8&9 the increase in welding speed, reduces the welding width. This means that welding speed has a negative impact on the welding width. At the point when the speed is slower, the heat created increments and the temperature between the two specimens raises profoundly and that reason the beginning of the deterioration of the material and obviously the slower the speed the bigger the melting pool and the hole formation. Also, the irradiation time lessens and less heat, are provided a subsequent decrease in the volume of the molten material described by a thin and feeble weld. Among the parameters that affect the width of the weld are the stand-off distance, in our work, a smaller welding width at larger spot size, Despite the fact that the expansion of stand- off separation decreases the power density at a consistent laser power it at the same time increases the region of interaction due to the defocused beam. Because of this, the laser power spreads onto a wide spot at the weld interface. In this manner, a wide territory of the base metal is softened prompting an expansion in weld width or the other way around. During the welding process, the clamping pressure assumes a significant role in the process notwithstanding the laser and material parameters and properties. It ought to be shown that in all cover arrangements a clamping pressure is expected to guarantee the greatest contact between the welded parts generally the nature of the welding will not be productive. It should also be noted that regardless of pressure, there is still an air gap between the two parts that prevent the heat from spreading evenly on both sides. In this work, The practical results indicated that the more pressure on the two samples, the less distance between them and increased the spread of heat and more cohesion between the two samples and thus increase the width of the welding[5]. The result of the welding width was listed in Table 2.

Table 2: S/N ratio value for L9 Taguchi design of experiments

Welding speed (mm/min)	Spot size(mm)	Force (N)	Weld width(mm)	S/N ratio
5	2	2	2.3558	-7.4427
5	2.5	6	2.0477	-6.8765
5	3	10	2.0571	-6.6821
15	2	6	2.0605	-6.5849
15	2.5	10	1.8916	-6.3945
15	3	2	1.3262	-5.9397
20	2	10	1.7987	-5.8291
20	2.5	2	1.4516	-5.5780
20	3	6	1.3998	-5.0340

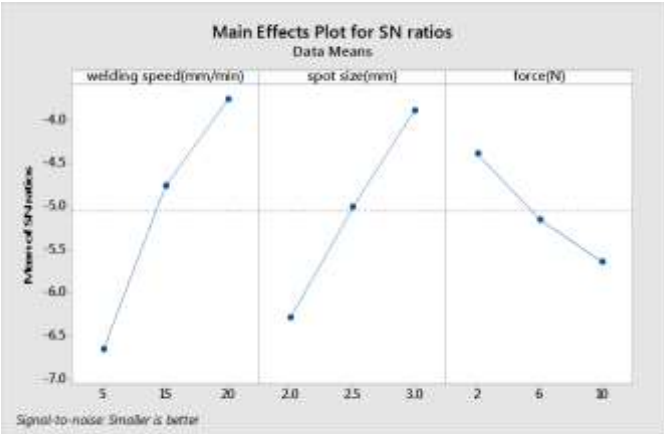


Figure 8: Main Effects Plot for S/N Ratios

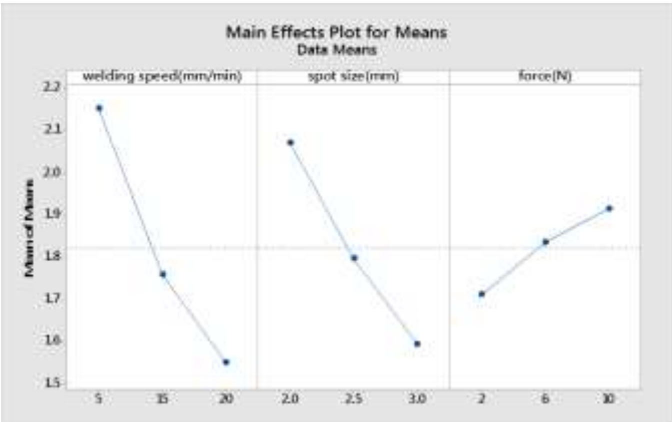


Figure 9: Main Effects Plot for Means

II. The Tensile Test

Quality testing was a significant part of weld ability think about in laser welding, and among all tests. The rigidity test was the most well-known research facility test used to decide the quality of the weld because of its effortlessness. The basic impact plot for the S / N ratios, as in Figures 10&11 delineates the impacts of individual process parameters on the strength of the weld. Figure 10 pointing to, welding strength increases with welding speed of up to 15 mm / min and then began to decline. The irradiation time and laser power density are the significant variables that rely upon them the energy deposition and the heat diffusion into the material. Higher irradiation time was generated at low speeds, resulting in a higher material temperature and degradation and a much lower joint strength. After that, with the speed increase above 15 mm/min, cause the reduction of irradiation time, etc., low heat input and non-penetration, which reduces the strength of the joint.

It's seen from Figure 10 that the welding strength increments with the spot size up to 2.5mm after that it begins to decrease. In the welding interface, the diameter of the beam spot increases with the focal distance, which reduces the laser power density. We conclude that the strength of the weld depends heavily on energy density, resulting in material degradation and very low energy density in the absence of fusion [12].

The clamping pressure a significant job to upgrade the mechanical properties of the welded zone. The outcomes might be identified with the degrees of the decay of the polymer material inside the welding pool and identified with the hole formation which influenced the tensile strength and the estimation of the ideal clasping weight. According to the practical results, the higher the pressure on the two samples, the less the distance between the two samples and more match. The two samples become closer and cohesive. The welding strength increased by the clamping pressure, higher clamp pressure results in higher weld strength [14]. The result of welding strength was listed in Table 3.

Table 3 S/N ratio value for L9 Taguchi design of experiments

Welding speed (mm/min)	Spot size (mm)	Force(N)	Weld strength(N)	S/N ratio
5	2	2	182	-45.201
5	2.5	6	182	-45.2014
5	3	10	264	-46.036
15	2	6	180	-45.784
15	2.5	10	444	-46.549
15	3	2	50	-40.700
20	2	10	244	-41.229
20	2.5	2	192	-41.591
20	3	6	180	-41.867

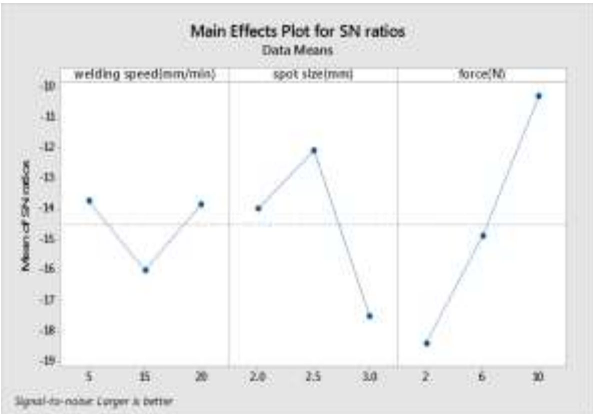


Figure 10: Main Effects Plot for S/N Ratio

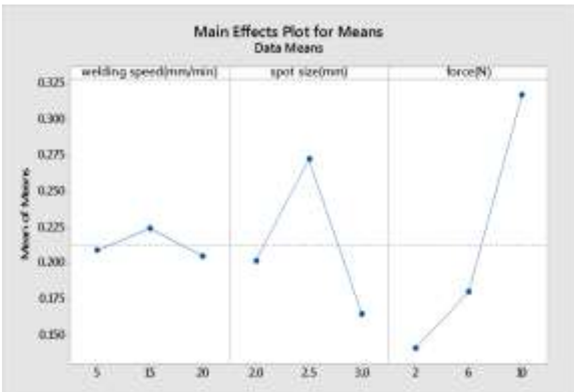


Figure 11: Main Effects Plot for S/N Means

6. Conclusions

Taguchi method was utilized to define the optimum process parameter for laser transmission welding of PMMA polymer. With orthogonal L9 range, a sum of 9 Experimental works, covering three major process Parameters at all three levels. Therefore, the welding width referred as ,"the- smaller-the-better," type and calculated from Eq (1), and the welding strength referred as ,"the- larger-the-better," type and calculated from Eq (2). Propose that Taguchi parameter design is respective means to limit the welding parameters for the welding width and the welding strength. From the result, we could conclude the following: All process parameters have serious consequences for welding width and the welding strength. The optimum welding process parameters are achieved with a minimum welding width with welding speed (20mm/min), spot size (3 mm), and the force (2N). The optimum welding process parameters are achieved with maximum welding strength with welding speed (15 mm / min), spot size (2.5 mm), and power (10N).The stress test confirms the strength of the weld joint, which also indicates the validity of the current improvement procedure using the Taguchi methodology.

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