

Experimental design investigation of through-transmission laser welding of dissimilar polymers

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Abstract. In the present study, the laser weldability of several types of dissimilar polymers couples are investigated using the experimental design method. This experimental strategy allowed to quantify the influence of the operating parameters on the failure force of the welded specimens. Some preliminary tests were used in order to find the initial conditions for the design of the experimental matrices. Based on the conclusions drawn from these preliminary tests, exploratory experimental designs were used to advance towards the optimum for each couple of polymeric materials. The polymeric materials considered were: ABS and PA11 with different pigments and thickness. One could note that the laser power used is the most important parameter on the mechanical resistance and the weldability is assured in a narrow interval of power laser. An important clamping pressure and two laser passages are useful to improve the performances of the weld strength.

1. Introduction

Widely used in automotive and medical applications, laser welding of polymers is a technique with acknowledged advantages as high welding speed, low residual stresses and excellent weld appearance.

The so called through-transmission laser welding configuration requires a transparent material to the laser wavelength and an absorbent one in the near-IR spectrum. The heat will be generated by absorption at the interface and transmitted to the transparent component by conduction. The bonding between the two components occurs by the interpenetration of the molecular chains in this area. Since this phenomenon is very active in a "fluid" state of matter, the temperature at interface has to be between the temperature of solid-liquid transition and the initial temperature of degradation of the thermoplastic materials [1].

Since the laser beam has to pass through the transparent component, the efficiency of this welding method is strongly dependent on the material's optical properties. Generally, the polymers contain different types of fillers, pigments, composites reinforcements with a big influence on the laser beam attenuation and its energy distribution at the interface. For determining laser weldability, there are different approaches based on simulating laser beam scattering by different methods (Monte Carlo method, radiative transfer etc). Since the trial and error method is still widely used in determining the optimal process parameters, the experimental methods based on experimental design remains a reliable and effective method to determine the weldability of involved polymeric materials [2-5].



2. Experimental set-ups

Since the laser weldability of polymeric materials strongly depends on their optical properties, several experimental set-ups have been created in order to accomplish the necessary tasks: characterize the optical properties of the materials, respect the principle of through-transmission laser welding and characterize the mechanical properties of the welded joint.

2.1. Experimental set-up for optical characterization of polymers

The experimental set-up for measuring the transmission coefficient for different thickness plates is depicted in Figure 1.

Two measurements are made. First, the defocused laser beam is directed into the measuring cell of the power meter (COHERENT LABMASTER). The second measurement is made by placing 1mm polymeric plate over the measuring cell. The transmission coefficient is obtained by the ratio of the two measured values $P_{\text{incident}}/P_{\text{transmitted}}$. The transparent polymers with a transmission coefficient greater than 90% were blue and natural PA11 and black ABS. The carbon black pigmented ABS absorbed more than 90% of laser radiation and degraded quickly.

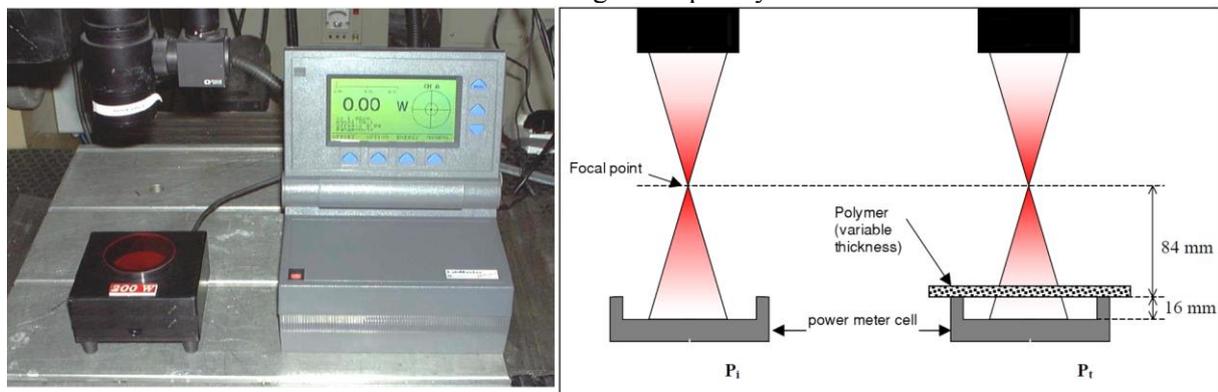


Figure 1. Experimental set-up for measuring the transmission coefficient

2.2. Experimental set-up for through-transmission laser welding

The two polymeric plates are fixed in a “T” configuration, depicted in Figure 2. The horizontal plate is transparent to the laser wavelength, and the vertical one is absorbent.

In order to assure a good contact between the two plates, a specially designed clamping device has been used. The “T” welding configuration was identical for all polymer couples and materials thicknesses.

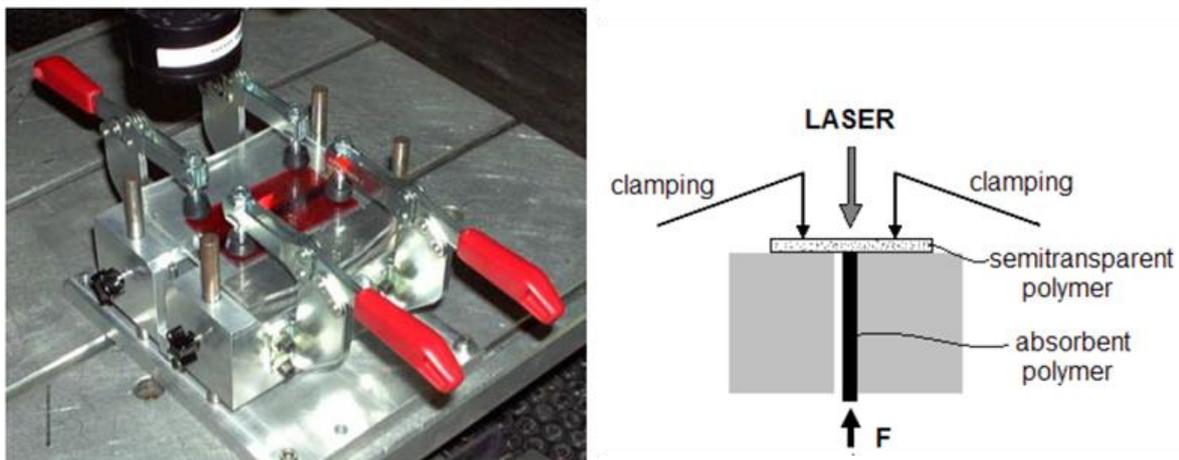


Figure 2. Experimental set-up for through-transmission laser welding

2.3. Experimental set-up for mechanical characterization of the welded joint

The weld failure force was determined with an MTS machine presented in Figure 3 with a special fixture for the T-geometry. The traction speed was set to 5 [mm/min].

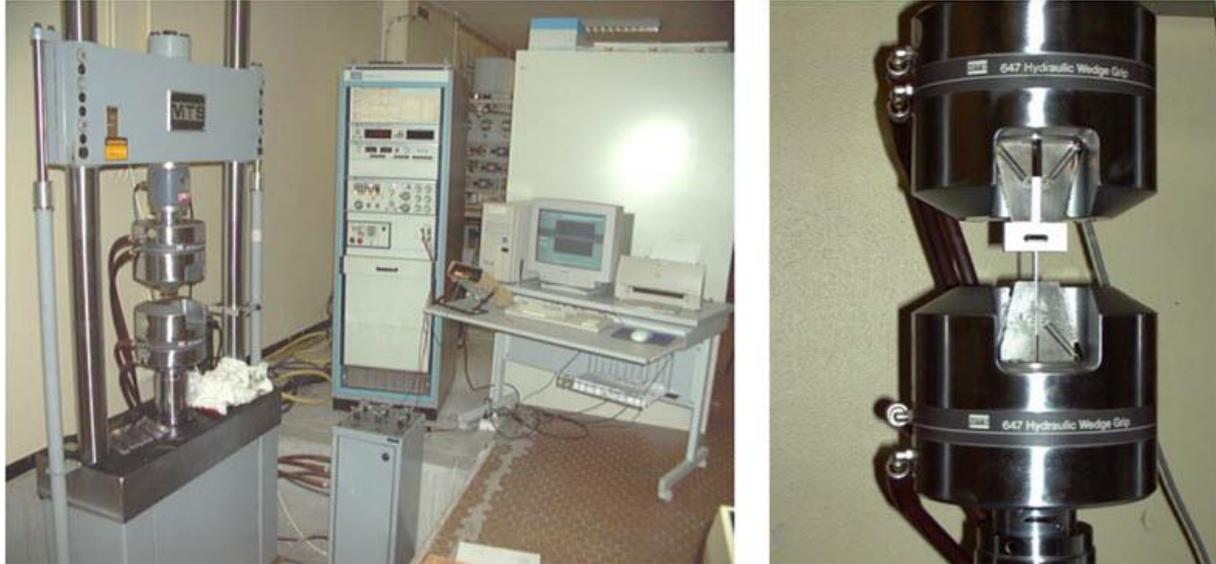


Figure 3. Experimental set-up for weld failure force

3. Experimental results

The polymeric materials were coupled according to industrial requests: black transparent ABS-carbon black pigmented ABS and natural PA11 with blue pigmented PA11. The first couple is very suitable for through-transmission laser welding, having a good absorbent component. In the second couple, both PA11 plates are transparent, thus an infrared absorber was used at their interface.

3.1. Experimental design

From preliminary experimental tests, the factors of influence selected were laser power, P [W] and welding speed, v [m/min]. Three levels were selected for each factor. An additional factor was taken into account, the number of laser beam passes, for which two levels were established. Based on the preliminary tests, the clamping pressure was set to 0.4 [MPa].

Table 1. The selected levels for influencing factors for ABS plates

	2mm ABS/2mm ABS			3 mm ABS/ 2 mm ABS		
	P [W]	v [mm/min]	No.pass	P [W]	v [mm/min]	No.pass
Level 1	21	500	1	24	500	1
Level 2	23	550	2	26	550	2
Level 3	25	600		28	600	

The experimental designs for each materials couple contains 16 experimental trials, with 4 replicas for every parameter's combinations. The dependent variables were the mean breaking force and the percentage of the welded area resulted from a visual inspection.

Table 2. The selected levels for influencing factors for PA11 plates

3mm natural PA11/ 2mm blue PA11			
	P [W]	V [mm/min]	No. pass.
Level 1	50	500	1
Level 2	60	700	2
Level 3	70	900	

3.2. Experimental results for ABS plates

The best results, based on fracture strength and standard deviation, are obtained with trials 2, 6, 8, 10, 11, 12, 13, 14 (Figure 4 a). The mean breaking force value is between 2000 and 3000 N. The optimal values are obtained for laser power between 22 and 24 [W] and welding speed between 500 and 570 [mm/min] (Figure 4 c). Two passes of laser beam increase the strength of the welded joint (Figure 4 d).

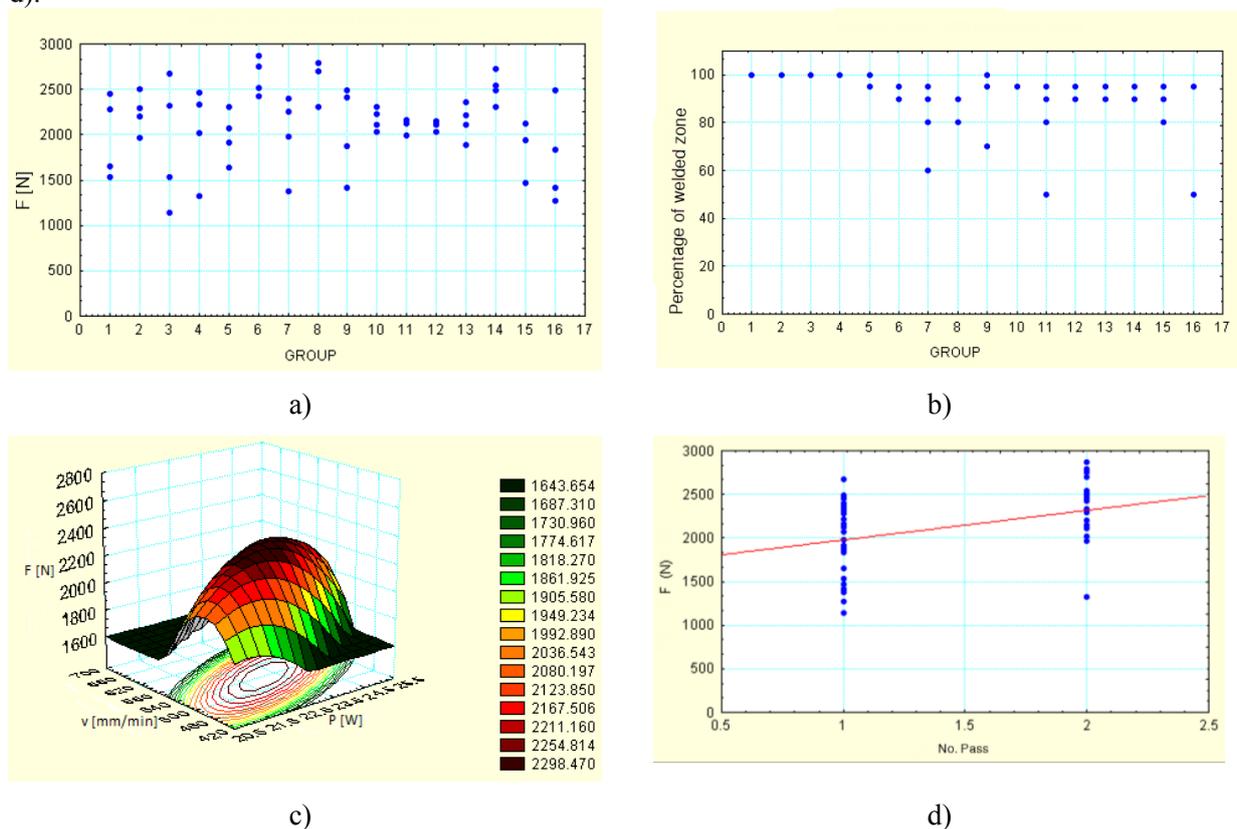


Figure 4. Experimental results for ABS plates 2mm/2mm

For 3mm transparent black ABS and 2 mm carbon black pigmented ABS the best results are obtained in 1, 2, 6, 8, 10, 12, 14 experimental trials. The mean breaking force value is between 2800 and 3600 [N] and the optimal values are obtained for 28[W] laser power and 550[mm/min] welding speed.

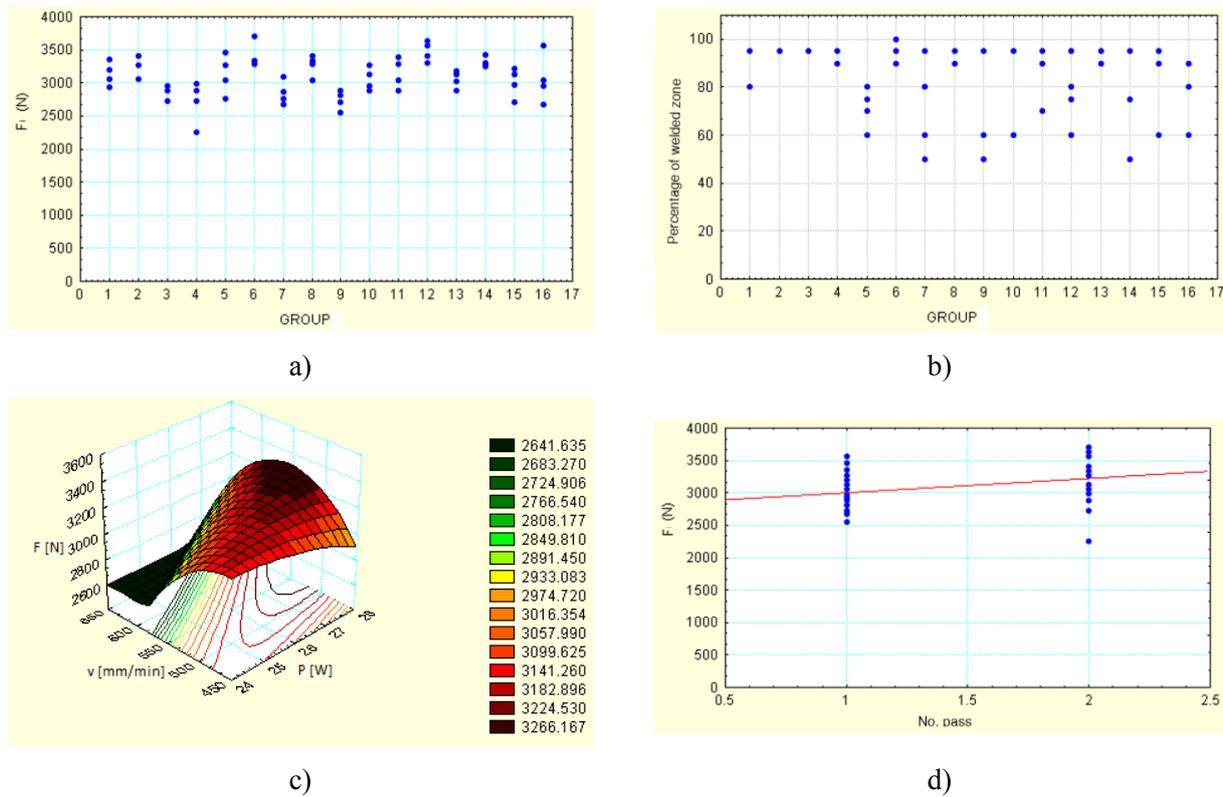


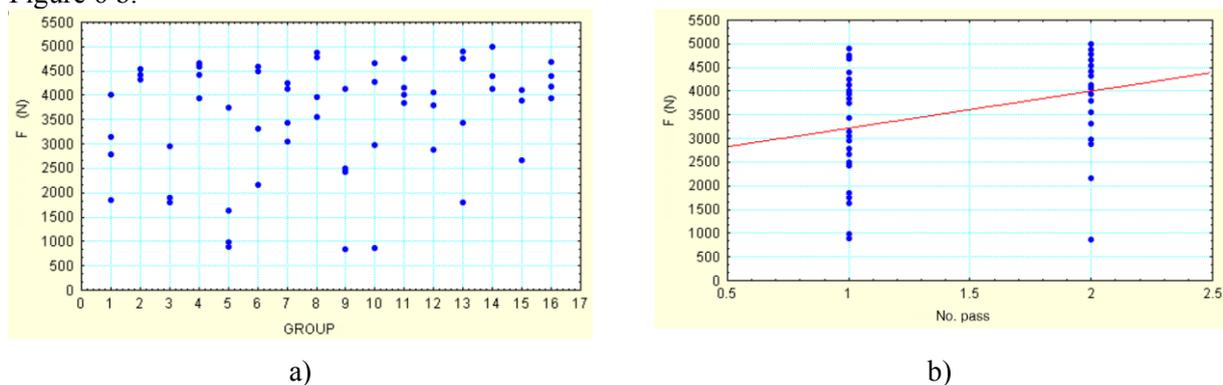
Figure 5. Experimental results for ABS plates 3mm/2mm

We note that 1 mm extra thickness requires an additional 5W of power, changing absorption conditions requires a 3W difference in one direction or the other for identical thicknesses, the addition of a transparent black pigment has no influence on the welded joint strength. After optimization, the parameters for welding the 'ABS/ ABS' couple are:

- $v = 550$ mm/min,
- pressure - 0.4 - 0.5 MPa,
- number of passes - 2,
- P - depending on the thickness and transparency of the ABS plates.

3.3. Experimental results for PA11 plates

The weldability of these polymeric plates is good. The mean breaking force is between 3500 and 5000 [N]. The best results are obtained with trials 2, 4, 8, 11, 14, 16 (see Figure 6 a). It is also noted that all groups selected (except 11) correspond to 2 passes, which is also confirmed by the trend presented in Figure 6 b.



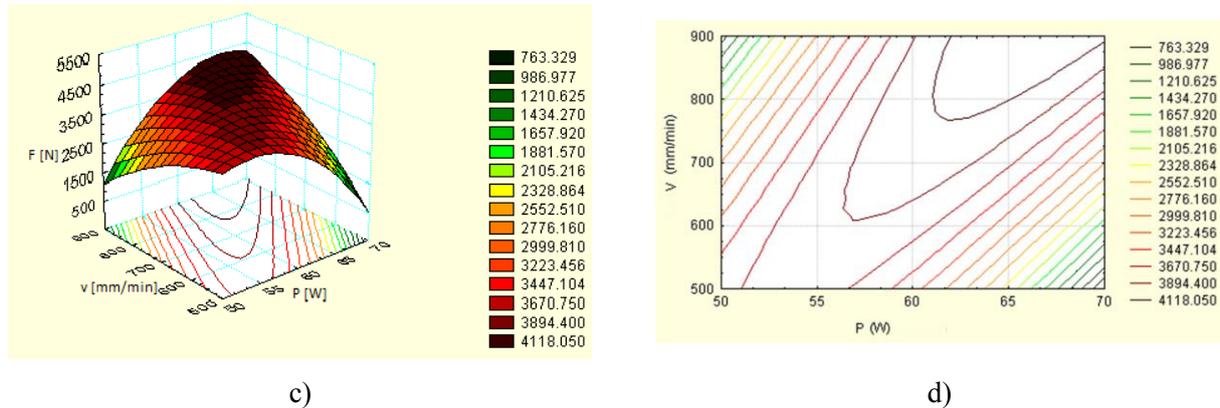


Figure 6. Experimental results for PA11 plates 3mm/2mm

The analysis of trends for mean breaking force and their standard deviations (see Figure 6 c, d) identifies two areas of optimal: $P \in (60;70)$ [W] and $v - 900$ [mm/min] if force is preferred to rupture (group 14) or $P - 50$ [W] and $v - 500$ [mm/min] if a significant 'force/standard deviation' ratio (group 2) is preferred.

4. Conclusions

The experimental strategy applied in this study, based on the experimental design's method, made it possible to find the optimal parameter combinations. One could note that the laser power used is the most important parameter on the mechanical resistance and the weldability is assured in a narrow interval of power laser. An important clamping pressure and two laser passages are useful to improve the performances of the weld strength.

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