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The effect of laser beam transmission on the thermoplastic composite joint formation

Simonas Mindaugas Jankus[1], Regita Bendikienė[1]

[1]Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Department of Production Engineering, Studentų str. 56, Kaunas, Lithuania

simonas.jankus@ktu.edu, regita.bendikiene@ktu.lt

Abstract. The goal of this work was to analyse the influence of laser welding process parameters using different plastic transparency. To achieve this task the elemental composition of plastic PPAGF40 with 20 % and 30 % transparency parts were examined using EDS analysis and cross - sections were evaluated by using optical microscope. Burst pressure was performed to evaluate the strenght of welded joints produced with different laser welding process parameters. Studies showed that welded joints with 20 % of transparency possessed burn spots on the surface of samples. Cross - section analysis revealed tendency, that plastics with 30 % transparency led to higher temperatures in welding seam using the same process parameters used for 20 % transparency, which caused pores to form inside joint. Laser power of 390 W, scan - speed 1000/800 mm/s and 3000 N of clamping force used for 20 % transparency plastic parts are not suitable for 30 % transparency plastic parts. Welding process optimization achieved by using 1400/1200 mm/s scan - speed and 2700 - 3000N clamping force, which showed improved burst pressure values from 7.2 to 7.9 bar. Reduced welding cycle - time achieved from 2.2 to 2.3 s with 30 % transparency of polymer PPAG40 material.

1. Introduction

Laser welding of plastics is performed in the overlap process. Usually two plastics to be joined are used. The upper part is a laser transparent thermoplastic, selected according to the laser wavelength, which partially heats up on the passage of the laser beam [1]. For a weld seam to be produced, the second join part must absorb the laser radiation (figure 1). When lower substance absorbs energy it begins to fuse and transmits it‘s energy to the upper partner [2, 3]. The quality of welded parts is mainly influenced by interaction between concentrated laser radiation and plastic material. Polymer optical transparency is crutial for weld joint mechanical performance [4]. The degree of difficulty in laser-welding depends on the laser transparency of the upper and the laser absorption of the lower of the two join partners. The better the upper part transmits the laser energy and the better the housing absorbs energy from the laser beam [5, 6].

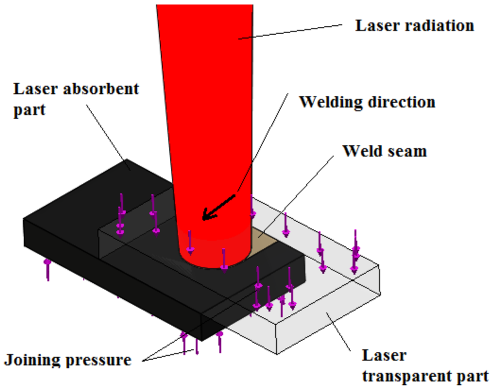

Figure 1. Basic representation of the laser transmission welding method [7].

In order to achieve absorption of laser radiation by the lower joining partner, carbon black is often used as an absorber [8]. Low upper part transparency, typically from 10 % to 20 %, is achieved by adding pigment additive black carbon 58 - 60 wt. % [9]. Studies have shown that higher transparency of upper part, obtained by reducing black carbon concentration to 50 - 55 wt. %, can led to higher temperatures and energy concentrations in the connection between cover and housing [10, 11]. This might lead to pores in the welding seam after welding process are reducing strenght of joint [12]. Therefore, it‘s important to understand what are the possibilities of the use of higher upper part transparency.

2. Materials and Methods

Two groups of samples were produced by using quasi-simultaneous laser welding method (LPKF InlineWeld 6600 welding equipment). For the first sample group, 20 % of transparency for the laser beam plastics were used (named sample 1). Second group of samples were welded using 30 % of transparency plastics (sample 2). Laser absorbent parts (sample 3) were used in both groups of samples. Polymer pairs sample 1 - sample 3 were welded using parameter set 1 and pairs sample 2 - sample 3 using all 5 welding process parameter sets (see Table 1). Laser source operates in cw (continuous-wave) mode, wavelengh λ = 980 nm with laser beam spot diameter in focus 2.5 mm. A total 72 mechanical parts were welded by using polyphthalamide PPAGF40 material. Dimensions of samples are 64.2 × 118.7 × 112.95 mm with a welding seam thickness of 1.4 ± 0.1 mm and width of welding seam 1.5 ± 0.1 mm. For determination of burst pressure 60 parts were used. Ten pairs of sample 1 - sample 3 using parameter set 1 and 50 pairs of sample 2 - sample 3 (10 of each process parameter set). For cross - section evaluation of weld seam 12 samples were used by using digital microscope Ash Technologies INSPEX II. Burst pressure was perfomed to evaluate strengh of joints using pressure measurement equipment from ZEUS (measured in bar). Upper part transparency of 32 samples the laser radiation measured by Softing LTW-1. Welding depth distance measured by Keyence GT2-H12. EDS analysis performed for determination of elemental composition using Bruker Quantax XFlash® 6|10. SEM micro-graph obtained by Carl Zeiss EVO MA10.

Table 1. Parameter sets used for cover - housing pairs sample 1 - sample 3 and sample 2 - sample 3 laser welding tests.

Process parameter sets	Laser power [W]	Scanning speed [mm/s]	Joint cooling time [s]	Clamping force [N]	Welding depth [mm]
Set 1	390	1000/800	3.5	3000	0.3
Set 2	390	1400/1200	3.5	2700	0.3
Set 3	390	1400/1200	3.5	3000	0.3
Set 4	380	1400/1200	3.5	3000	0.3
Set 5	420	1000/800	3.5	3000	0.3

3. Results and Discussion

3.1. Plastic material PPAGF40 transparency for the laser beam measurement

For thermoplastics optical transparency for laser beam is determined by transparency measurements. Purpose of these measurements is to determine how much light in % can pass through sample 1 and sample 2 polymer PPAGF40 material. Sample 1 covers transparency for laser light 20.85 - 21.97 %, sample 2 covers transparency varying from 31.34 to 33.60 %.

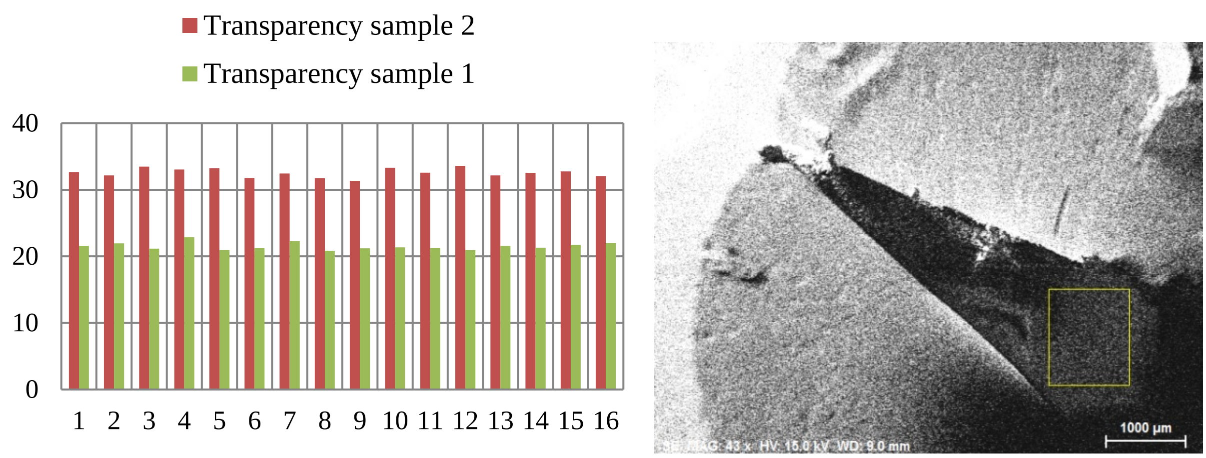

Figure 2. Sample 1 and sample 2 cover tansparency for the laser beam measurements on the left and SEM micro-graph of PPAGF40 sample on the right.

3.2. EDS chemical analysis of PPAGF40

The chemical elements of sample 1, sample 2, sample 3 were examined by usig EDS analysis. Depth of elemental measure 1 µm. Lowest amount of carbon 55.88 wt. % was found in covers sample 2 which has highest transparency of 30 %. In comparison to sample 2, sample 1 covers due to lower transparency has 56.53 wt. % of carbon. Laser light absorbing part 3 carbon concentration 58.07 wt. %.

Table 2. EDS elemental analysis of composition of the transparent covers sample 1, sample 2 and absorbing housing sample 3 [wt. %].

Chemical element	sample 1	sample 2	sample 3
C	56.53	55.88	58.07
N	19.73	22.55	23.22
O	22.53	20.29	17.46
Al	0.86	1.19	0.71
Si	0.03	0.06	0.49
Na	0.06	0.03	0.04
Ca	0.26	-	0.01

3.3. Effect of transparency for the laser beam on the plastic join formation

Cross - section studies of weld seam have been conducted to determine the structure of joint after laser beam welding. Polymer PPAGF40 pairs sample 1 - sample 3 and sample 2 - sample 3 with different cover transparency were used. First welding test was performed using 390 W laser power and 1000/800 mm/s scan - speed with sample 1 cover and sample 3 housing pair. Burn marks due to low transparency observed at the plastic surface, which is caused by 56.53 wt. % carbon concentration (figure 3 a). Higher

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temperature concentration due to higher transparency caused partial plastic evaporation and formation of pores inside collapsed cover and housing using sample 2 covers with process parameter set 1 and set 2 [8]. Pores covered around 50 % (figure 3 b) and 35 % of welding seam (figure 3 c).

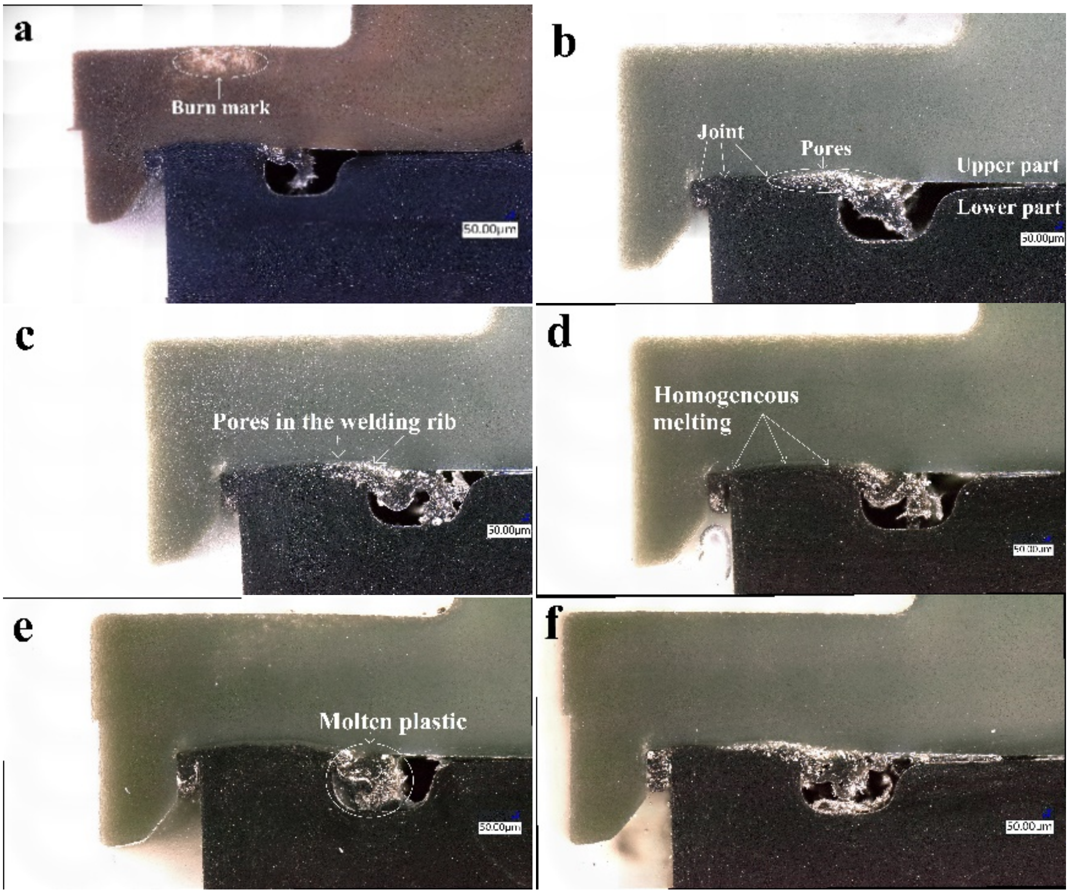

Figure 3. Weld seam cross - section view: a - sample 1 and b - sample 2 covers with parameter set 1; c - sample 2 covers with set 2 and d - sample 2 set 3; e and f - sample 2 set 4 and set 5.

No defects were observed in pair sample 2 - sample 3 cross - section area by using parameter sets 3 and 4 (see figure 3 d and e). Increased scanning speed of the laser beam in set 3 to 1400/1200 mm/s and reduced laser power by 10 W to 280 W in set 4 influenced lower energy input from radiation per time than compared to 1000/800 mm/s scan-speed 290 W laser power [11]. More homogeneous melting of the part is achieved. No burn marks, pores or vapours are generated inside welded joint after cooling process by using sample 2 covers with set 3 and set 4. Futhermore, increasing laser power up to 420 W it is observed in cross - section area that 70 - 75 % of welding seam is covered with pores (figure 3 f).

3.4. Welding process improvement by using sample 2 covers
Burst pressure test was performed for strength evaluation of polymer joints. It is observed that with welding process parameter sets 3 and 4 highest values of burst pressure were obtained from 7.2 to 7.9 bar (figure 4). Homogeneous weld seam with no defects formed (see figure 3 d and e). Lower heating time range 4.1 - 4.5 s using sample 2 covers achieved in comparison with 20 % transparency covers sample 1 from 5.4 s to 5.7 s. Joints with lowest heating time varying from 3 to 3.3 s possessed lowest burst pressure values, respectively 2.38 - 2.80 bar. Pores (figure 3 f) weakened welded plastic parts burst pressure.

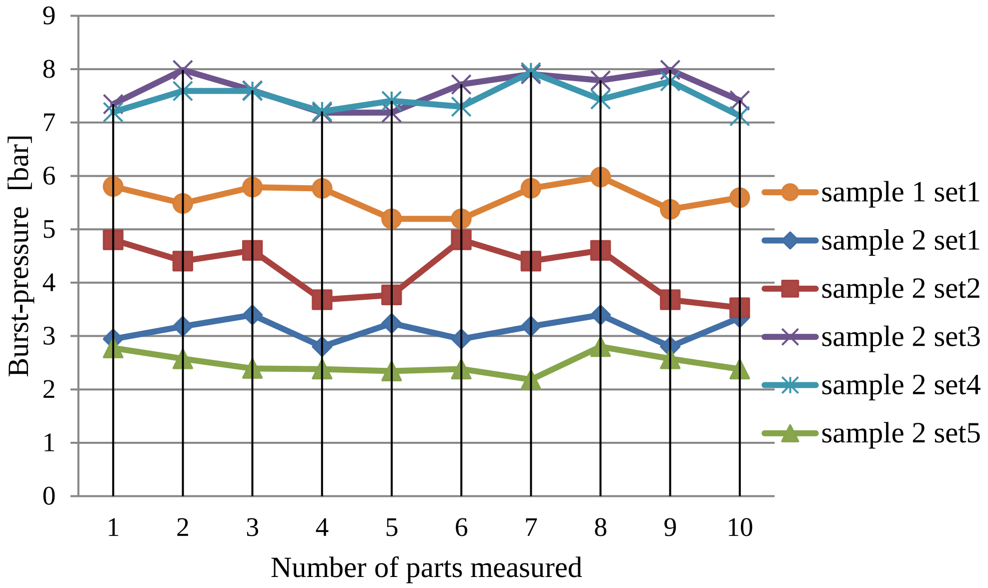

Figure 4. Polymer PPAGF40 burst pressure values using different transparency cover/housing pairss sample 1 - sample 3 and sample 2 - sample 3.

4. Summary

Transparency for the laser beam measurements performed for plastic parts. EDS elemental composition of samples used for welding trials was determined.

Increasing upper part transparency from 20 % to 30 % increases heat concentration on the welding seam locally. Welding parameters 390 W - 380 W of laser power and 1400/1200 mm/s scan - speed for 30 % transparency plastics were the most suitable. No defects were found in weld seam during cross - section analysis. Obtained burst pressure values are varying from 7.2 to 7.9 bar. Cross - section analysis revealed that using 420 W of laser power, 1000/800 mm/s scan - speed and 2700 N clamping force for 30 % transparency plastics, pores formed inside joint. As a result, burst pressure values are varying from 2.38 to 4.80 bar. Same laser welding process parameters can‘t be adapted for plastic parts, which have different transparency.

Welding operation time was reduced by 2.2 - 2.3 s with 30 % transparency plastics. Obtained research results of welding process optimisation are already applied in bulk production.

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