Laser heating of polypropylene – effects of interaction

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1. Introduction

Heating up to more than 70% of the melting or thermal degradation point can be met in the most processes that are applied to the polymers. Marking process requires temperatures below melting point, while welding require, generally, temperatures over the melting point. Such heating processes produce modifications of the polymers behavior during the exploitation and that was observed by any user of polymers [1-5]. The modifications can be evaluated by specific thermal and mechanical analysis. Differential Scanning Calorimetry (DSC) analysis can be applied to evaluate the modifications of the physical and mechanical properties of a polymer, due to the thermal cycle specific to the mentioned processes.

Henderson [2] analysed by thermal analysis the main influences brought by the polymer chain on the thermo-mechanical properties. Mano et. al [3] developed research on the shear and elongation flow fields and they concluded two aspects:

1. the flow fields modify the crystallization process via flow-induced crystallization;
2. the flow enhances the nucleation density by decades increasing the overall crystallization kinetics.

The paper presents several results of experimental program dedicated to the evaluation of the physical properties modifications of PP foils during the application of laser heating for welding process. Polypropylene (PP) is an often met polymer, in most of the industries, from domestic to aerospace. The use of polypropylene in the manufacturing of goods means the application of different processes, mainly as extrusion, plastic deformation, welding and marking. Having a plasticity appropriate to the destination, before the processing, PP proves an increasing of the rigidity after the application of the processing thermal cycle.

2. Experimental program

2.1. Laser heating system used for the experimental program

For the experimental program has been developed specific device dedicated to the laser processing of polymers (figure 1) consisting of:

1. Device to 2D travelling of the laser head,
2. Laser device based on laser-diode,
3. Temperature IR sensor,
4. Electronic device to feed the laser-diode.

The technical characteristics of the laser device are:

- Input voltage: U_{source} = 0-10 V DC
- Absorbed current (max): I = 110 mA
- Beam power (max): 1000 mW
- Air cooled
- Focusing lens.

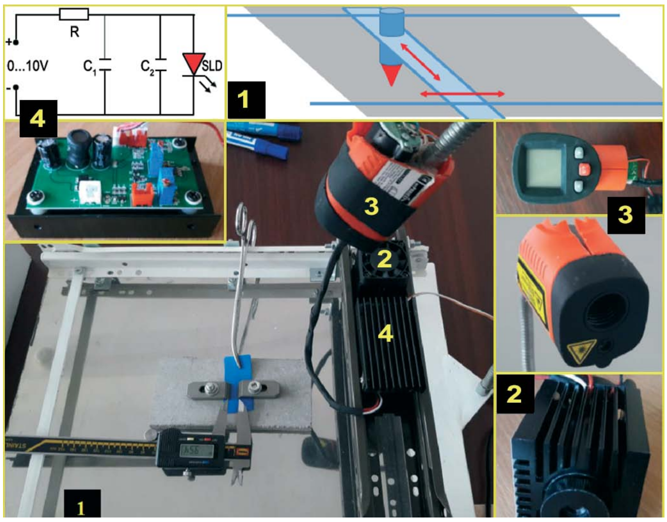

Figure 1. Laser heating system.

To prevent the damaging of the laser-diode, a maximum of 90 mA of the input current was considered.

The IR sensor was used for the continuous monitoring of the temperature during the heating process.

2.2. Base materials and specimens to weld

The specimens used for the experimental program were PP foils, having 0.15 mm thickness, in two versions: with high transparency and with low transparency (figure 2). The

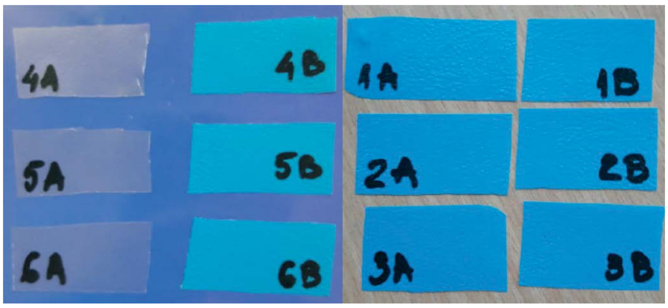

Figure 2. Specimens subjected to laser heating for welding.

specimens were subjected to laser heating for overlapped welding, in two versions: low transparency / low transparency and high transparency / low transparency. Before the heating process the base materials were cleaned by using isopropyl alcohol.

2.3. Heating parameters

It were used 3 regimes for the laser beam, from the feeding of the laser-diode point of view: 30 mA, 60 mA and 90 mA, for an open-gate voltage of 1.2V. The distance from the lens to the first base material was set to 50 mm, for all the regimes mentioned above. Table 1 presents the main parameters of the heating process.

3. Results and discussions

Using the data presented above the specimens were welded in overlapped joints. Figure 3 presents examples of welded joints, for the 6 regimes of Table 1.

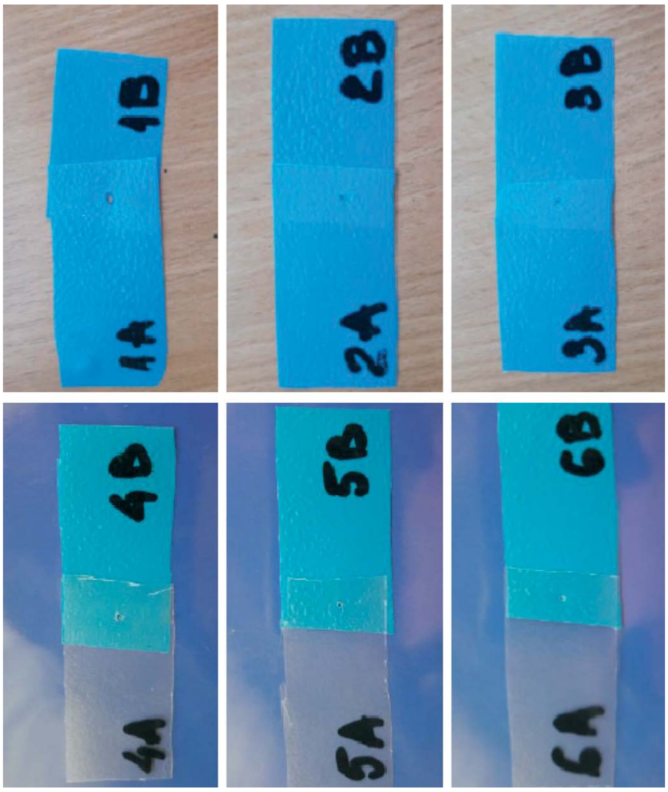

Figure 3. Welded specimens.

When welded low transparency with high transparency PP specimens, the high transparency specimen was positioned above the low transparency one. In that manner, the laser beam has crossed the transparent polymer and heated the second polymer and the contact between the two.

For each of the 6 regimes the parameters were appropriate considered and welds were created.

Figure 4 shows the thermal field when used 90 mA current for the feeding of the laser-diode. It can be seen that the evolution of the thermal field is almost radial from the laser spot and the light energy absorbed by the PP [6] foil has been turned into thermal energy which gives range of temperatures from the ambient temperature to around 500^{o}C.

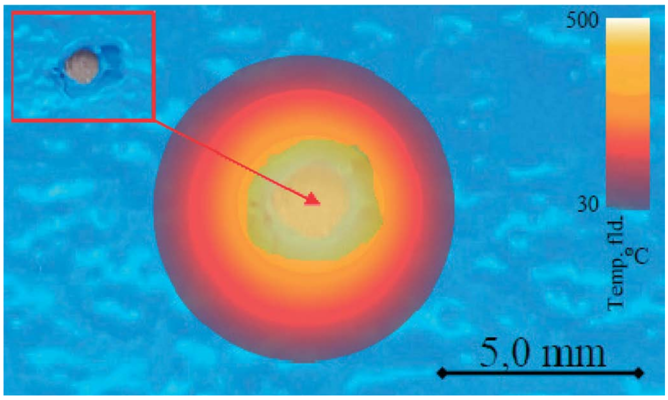

Figure 4. Thermal field evaluation.

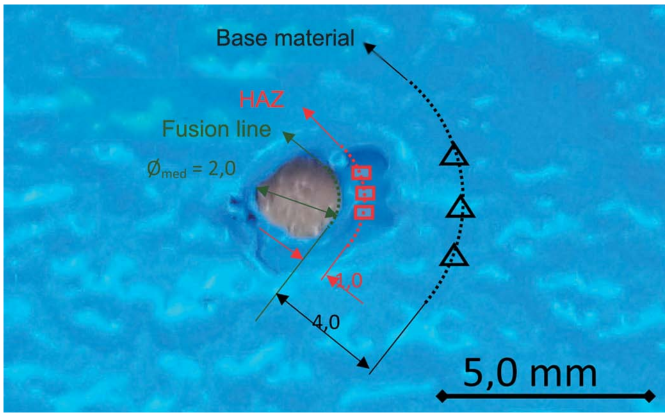

Figure 5. Locations to cut out samples for DSC.

The welds were subjected to thermal analysis. It was used the Differential Scanning Calorimetry (DSC) to evaluate the elongation viscosity and the relaxation modulus. Both characteristics give important information on the elasticity / plasticity of the polymer. Figure 5 shows the locations from which samples were taken. The first set of samples has been

Table 1. Heating parameters.

Test number	Transparency	Thickness [µm]	Laser-diode parameters		Distance to foil [mm]	Incidental angle α [°]
			Voltage U [V]	Current I [mA]		
1	High / Low	150	1,2	30	50	90
				60		
				90		
2	Low / Low	150	1,2	30	50	90
				60		
				90		

cut out from the material located 1 mm from the limit of the molten material of the weld. The second set of samples was taken from area positioned at 4 mm distance from the limit of the molten area.

Figure 6 presents the relaxation modulus and Figure 7 shows the evolution of the elongation viscosity of the welded PP.

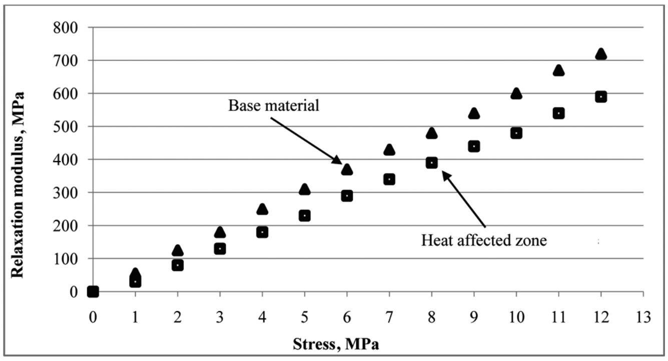

Figure 6. Relaxation modulus.

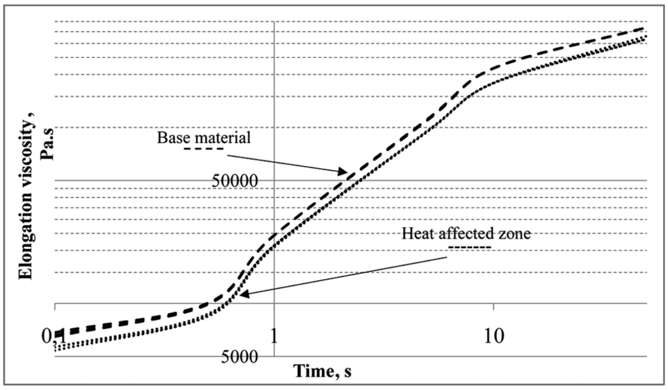

Figure 7. Recorded curve of the elongation viscosity.

It can be observed in Figure 6 an almost linear evolution of the relaxation modulus for the both the base material and the heat affected zone. The lower values obtained for the heat affected zone mean a decreasing of the PP's plasticity. The material becomes harder and stiffer. The loss in plasticity is confirmed by the elongation viscosity which is, also, lower in the case of the heat affected zone of the weld. Both areas have the same evolution of the elongation viscosity: lower increasing for the first second of heating, a faster increasing up to the second 10 and an important relaxation after 10 s. That means critical behaviour from the beginning of the heating until second 1, when, if stressed, the material could crack. When the relaxation modulus is increasing faster the cracking risk is lower.

4. Conclusions

When using high-transparency and low-transparency PP foils to join by welding, the superior transparency foil should be placed above to improve absorption of energy.

Laser-diode can be used to weld PP foils and all the used regimes (30 mA, 60 mA and 90 mA) proved to be appropriate to produce welds.

PP proves reaction during the interaction with the laser beam, in welding process. The reaction consisted in a loss of plasticity.

The loss of plasticity was confirmed by thermal analysis, a decreasing of the relaxation modulus and a decreasing of the elongation viscosity being recorded during the DSC analysis

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