Mechanical performance of single lap polymeric joints welded by a portable diode laser

A.M. Visco[1*], G. Galtieri[1] , L. Torrisi [2] , C. Scolaro[2], A. Cannavò[2]

[1]*Dept. of Electronic Engineering, Chemistry and Industrial Engineering, University of Messina, C.da Di Dio, 98166 Messina*
[2]*Dept. of Physics and Earth Science, University of Messina, V.le F. S. D'Alcontres 31, 98166 Messina*
[*]*e-mail corresponding author: avisco@unime.it*

Abstract

The polymer laser welding can be successfully used to join two or more parts of plastic surfaces and it can be used in several fields, such as the biomaterials and microelectronics. Thermoplastic materials are welded by a localized energy input without the use of any organic solvents and formation of particulate.The employment of a portable diode laser can personalize the welding joint area and it let to draw the welding geometry, like a pen in a very easy and fast process.
In this research, we studied single lap joints made by biomedical grade polyethylene (UHMWPE) pure and filled with carbon nanomaterials, necessary to make the polymer laser absorbent, added in amount of 0,2% in weight.The joints were irradiated by a diode laser operating at 970 nm (fundamental harmonic), in repetition rate of 10Hz, with a maximum pulse energy of 200 mJ and a laser spot of ≈ 4 mm^2 (no focusing lens were employed). The portable laser was employed to realize four types of welding geometries (points, continuous and discontinuous lines, cross lines) in the overlapped area. The joints were characterized by mechanical shear tests and hardness Shore D test and observed by a morphological analysis (optical microscopy). The results suggested that the welding strength depends not only on the welded area, but also on the continuity of the welded geometry and on the stress direction. The points welding exhibits the worse mechanical performance, while is the cross lines welding the best one among these investigated.

Introduction

The traditional joining methods of the polymers are: bonding, hot plate welding, ultrasonic welding and vibration welding [1]. These methods have the following characteristics: the bonding process requires pretreatment of the surface and the use of organic solvents; the hot plate welding is a slow process and it is subject to wear; the ultrasonic welding or vibration welding processes expose the pieces to high mechanical stress.

The laser welding of polymers has great advantages compared to the above processes because [2] :

- it is a clean process, precise, and has a high degree of automation;
- it does not use solvents;
- it does not generate micro particles;
- it do not take place particular distortions of the material for fusion;
- no components must be pre-treated before welding.

Single lap polymeric joints can be obtained using laser welding overlapping two polymeric sheets, one laser transparent and the other laser adsorbent [3].

In this process, the laser beam is projected onto a region of the polymeric sheets where the sealing is to be performed [4]. The laser beam passes through an upper transparent layer and then it arrives to the lower absorbent partner where the melting occurs. After cooling down a bond is created. Fillers must added to the polymer for the absorption of the laser energy in the IR or visible range [5].

In this paper we have employed carbon nano materials (NC), in amount of 0.2% in weight, as filler to enhance the absorption of polyethylene (UHMWPE type). The NC have a crystalline structure that exhibits a high adsorption power to the laser light at the used wavelength [6]. We employed a portable diode laser in order to perform simply welded geometries on the two overlapped polymeric sheets. The great advantage with respect other lasers, such as the Nd:Yag one [3], consists on the fact that it is a portable laser easy to hand and that the welding process is fast and customizable according to the geometry to be welded.

We tested four welding geometries and compared their mechanical performances under a shear load. We investigated the hardness change and their morphology before and after the mechanical stress in order to quantify the welded area and to observe the type of tear.

Materials and methods

-*Ultra High Molecular Weight Poly Ethylene* (UHMWPE resin, Ticona-GUR 1020 ρ= 930 kg/m^3, $M_w \approx 3\times10^6$ g/mol), referred as "UH".

-Powder of *carbon nano materials* (referred as Nano-Carbon or "NC"), supplied by Good Fellow particle size of 50-100 nm order, were employed as filler.

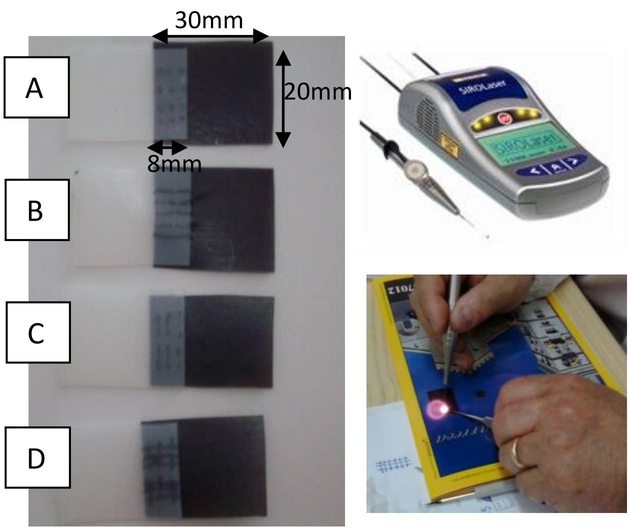

Fig.1- The four types of laser welded polymeric joints (sx), a picture of the diode laser used and its employments (dx).

-*Nanocomposites,* were made by mixing UHMWPE with 0.2% in weight of NC with pure ethanol (Fluka) and are referred as "UH-NC02". The mixing was kept in ultrasonic bath at room temperature for two hours. Then, the solvent was separated under stirring in a heated plate. The polymeric sheets (60mm×60mm, 0.5mm thick) were

moulded in a hot press at 200°C for 20 min, P=20MPa. The UH sheets had a semitransparent appearance while the nanocomposite UH-NC02 was black.
The joints were irradiated by a diode laser operating at 970 nm (fundamental harmonic), in repetition rate of 10Hz, with a maximum pulse energy of 200 mJ and a laser spot of ≈ 4 mm^2 (no focusing lens were employed) (fig.1). The pressure among the two polymeric sheets during the irradiation was of about 10N and it was performed by metallic clips. The irradiation occurred within the overlapped area, that was of 160 mm^2 (see fig.1).
The four geometries of welding were made by points (A type), continuous lines (B type), discontinuous lines (C type), cross lines (D type), are showed in fig.1 and visualized with respect to the mechanical load direction in fig.2. The shear test was carried out on the joints at 25°C by a LLOYD LR 10K universal testing machine with a crosshead speed of 5 mm/min (fig.2). The specimens had a rectangular geometry, 20mm x 30 mm, 0.5 mm thick (fig.1). For each kind of joint, 5 specimens were tested in order to give the average value.

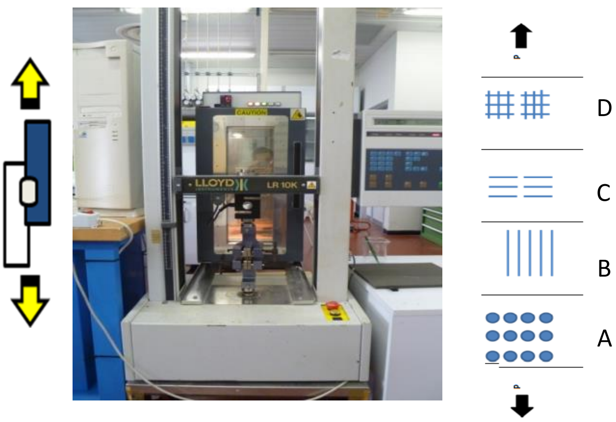

Fig.2- The shear load test machine (sx) of the four types of laser welded polymeric joints (dx).

SHORE D hardness mechanical tests were performed by means of a PCE-HT 210, according to the ASTM D 2240 international protocol. The resolution is of 0.1 degrees of hardness and precision of ±1 degrees, in scale range from 0 to 100 (fig.3).

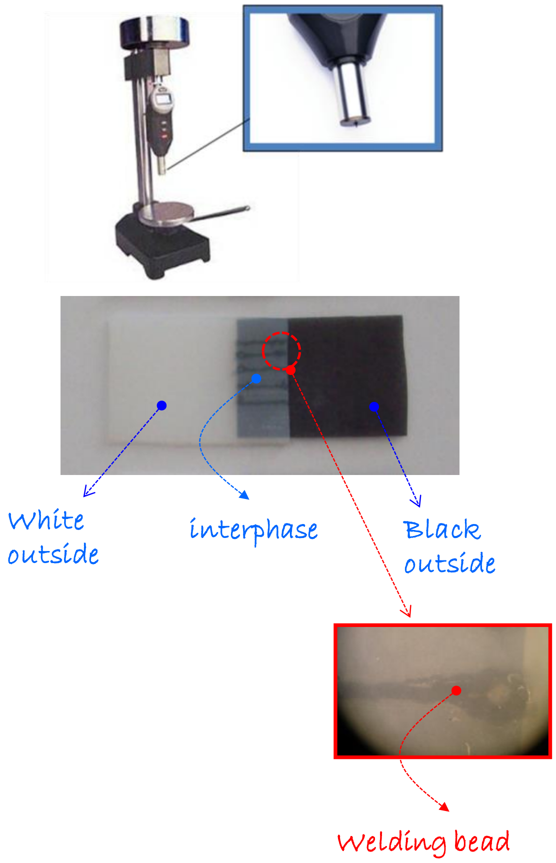

Fig.3- The hardness tester (top) and the zones measured in the laser welded polymeric joint (bottom)

Morphologic observations were performed by means of an optical microscope Mod. ZEISS Stemi 2000 C.

Results

Mechanical shear test results of the four joints are shown in fig.4 and given in details in table 1. The graphs indicate an improvement of the maximum load in the order of the joint type:

A<C<B<D

since the load grows from 110 N up to 200 N, quite duplicating its value. Similarly, the deformation at break grows from 3.6 mm up to about 30 mm in the same order of the joint geometry, becoming about 10 times higher.

The welded area of each joint type was calculated by means of the optical images of fig.5 and an image elaboration program (Image J code).

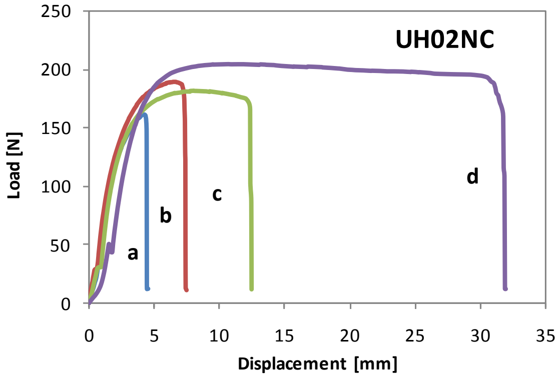

Fig.4- Load-displacement typical curves of the four types of laser welded polymeric joints.

The results show an improvement of the area involved in the welding from the 16 mm^2 (in the A type joint) up to the about 45 mm^2 (in D type joint). This time, the area improvement order of the joints was :

A<B<C<D

and this order was different than that found for the mechanical shear behavior.

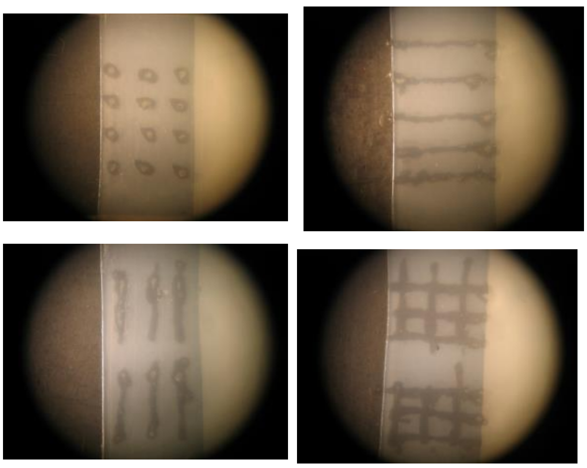

Fig.5- Optical images (15x) of the four joints before the mechanical stress.

Optical images of fig.6 were taken on the lowest mechanical resistant joint (A-type, points) and of the highest one (D-type, cross lines) at two magnifications (15x and 40x) in the joint detached after the shear load.

Both the images exhibit holes in the laser contact area surrounded by an area in which the polymer was torn, as evidenced by the presence of filaments. These areas are much more higher and evident in the cross lines welding geometry with respect to the point one.

Joint type		Area	Load Max	deform. at break
		[mm^2]	[N]	[mm]
A	*points*	16,40	110,86	3,57
B	*Lines Cont.*	21,88	172,96	8,73
C	*Lines Discont.*	24,49	157,75	7,77
D	*Cross lines*	44,99	200,56	29,70

Table 1- Mechanical parameters of laser welded polymeric joints and welded area.

The hardness values were measured in different areas of the welded joint, as schematized in fig.3 and plotted in fig.7.

In particular it was detected outside the white and the black sheet, and inside them, in the welding bead. Besides, it was detected among two welded lines (interphase).

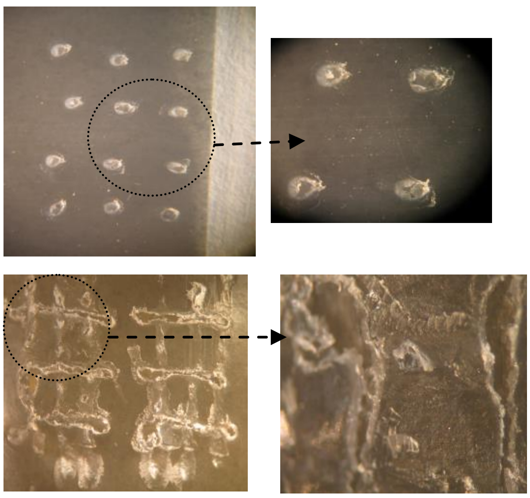

Fig.6- Optical images of the black sheet (15x and 40x) of the A type (top) and D type (bottom) joint after the mechanical load.

The experimental values were detected by the thin metallic points of the instrument and they changed in the different areas investigated. They decrease from ≈77 Shore D in the pure UH sheet (white) to ≈75 Shore D in the interphase and re-increases in the welded bead (≈76 shore D). Similarly, in the black sheet the value was of ≈79 Shore D and decreases to ≈77 shore D in the interphase and in the welded bead.

The higher hardness of the black sheet compared to the white one is probably due to the filler presence (NC) that improved the plastic consistence, although its small amount (0.4 % in weight).

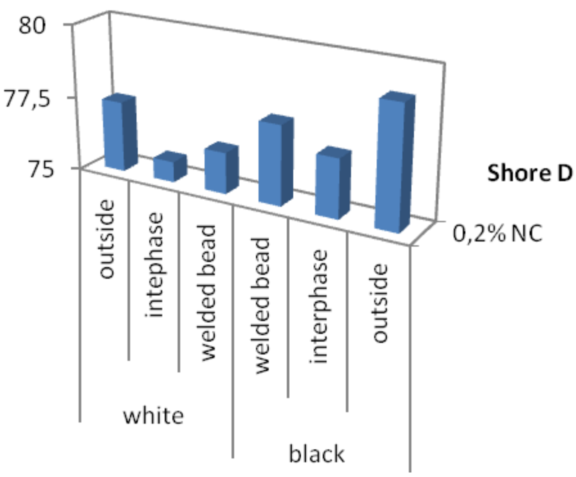

Fig.7- Shore D harness measured in different points of the joint both in the white as in the black polymeric sheet.

Discussion

Despite the welding area of the vertical lines in the C type joint is greater than that of B type, with horizontal lines, we get a lower shear load, probably due to the discontinuity of the welded lines. The horizontal lines, covering the entire width of the zone of overlap, ensure a greater adherence of the interface. So, the experimental results suggested us that not only it is important the welded area amount but also their continuity with respect to the load direction.

The welded occurs involving intimately the polymeric material and it modifies its structural order during the melting that occurs in the contact area. This is confirmed by the hardness change both in the welded bead and in the interphase, and visualized by the tears and plastic filaments presence, especially in the cross lines (D type) geometry.

Conclusions

The welding made by the portable diode laser is capable to perform different welding geometries in easily manner. The welding geometry is an important aspect to reach a good mechanical performance. The worst geometry was the points (A type) while the best one was the cross lines (D type) among the four tested. The D type reached the highest shear resistance with a load of about 200N and the deformability was of 30mm. The shear load duplicates and the deformability of the joint grow of 10 times with respect to the A type geometry. The D type joint involved the highest welding area with continuous lines in the overlapped laserated area. The lines were both perpendicular as transversal to the shear load direction. The diode laser process occurs by melting the polymer in the lines direction at the interface and it modified also the surrounding area. The quick melting induced by the laser process decreased the local hardness of the polymeric material suggesting that the laser absorption process modifies the polymeric structure.

References

[1] S.T. Amancio-Filho, J.F. dos Santos, Polymer Enginenering ad Science (2009) 1461-1476.

[2] http://www.leister.com/it-mc/leister-technologies/laser-plastic-welding/

[3] A.M.Visco,N.Campo, L.Torrisi,A.Borrielli, Radiation Effects and Defects in Solids (2010) 165: 6, 601 — 608

[4] G.Casalino,E.Ghorbel, J. Mater. Process. Technol. (2008), 207 (1–3), 63–71.

[5] L.Torrisi,A.M.Visco,N.Campo,F.Caridi, Nuclear Instruments and Methods in Physics Research B,(2010) 268, 3117–3121

[6] A. M. Visco, V. Brancato, L. Torrisi, and M. Cutroneo, International Journal of Polymer Anal. Charact., 19: 1–12, 2014