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RESEARCH ARTICLE - ENGINEERING

An Investigation of Joining Polyamide (PA) to Stainless Steel AISI 316L by Hot Press Process

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Abstract

A hot press process was used as a technique to pound a polyamide type of polymer of a thickness (2mm) to stainless steel AISI 316L of the thickness (1mm). A hybrid joint of dissimilar material was accomplished by a hot press bonding process. During the joining process, three different parameters of process were used: processing temperature of 175, 170 and 165°C, processing pressure of 3, 6 and 9 bar and time of 1.5, 3 and 4.5 min. The surface of stainless steel was prepared and treated by a mechanical treatment (surface grinding) to improve the wettability to increase the shear strength. A shear tensile, scanning electron microscope (SEM) and energy dispersive spectrometry (EDS) tests were used to investigate and examine the joint (bounding) specimens. The Minitab program was used to analyze the effect of the parameters of the joining process on the joint properties. The maximum and minimum values of shear force are exhibited at a processing temperature of 165°C, applied pressure of 6 bars and processing time of 1.5 minutes; the minimum shear force was found to be 675 N, while the maximum shear force was 2182 N at a processing temperature of 175°C, applied pressure of 6 bars and processing time of 3 minutes. The tested joints failed by an interfacial shear and necking in the polymer side with a ductile fracture. The joining process occurred through a mechanical interlocking between the molten polymer and the treated surface of the steel specimen. The average thickness of the joining line for the tested specimens was 8µm.

Publisher : Middle Technical University

Keywords: Hot Press Process; Polyamide; AISI 316L.

1. Introduction

This research discusses the quick technological progress; indeed, no single material contains extraordinary properties, such as high conductivity, high strength, toughness, corrosion resistance and lightweight [1]. In engineering structures, the processes of joining dissimilar materials between polymeric and metallic, on the other hand, are essential [2]. This type of joining is called hybrid joint, and the engineering applications for it biological and medical industry, automobile, and aerospace are constructed from hybrid components of dissimilar lightweight materials, such as copper, stainless steel, aluminium, or magnesium alloys and polyamide, polyvinyl chloride, polyethene and fibre reinforced polymers [3]. Hybrid joints are given combines the ductility and strength of metals with the resistance of physicochemical and polymers' high specific stiffness in these parts, which are hybrid welded [4]. Many processes of hybrid joints for bonding metal to a polymer, such as the hot press bonding method [5]. Friction spot welding [6]. Laser direct joining [7]. Due to the dissimilarities in physical and mechanical characteristics of the metal and polymer, the jointing of metal to polymer is complex [8]. Hybrid joints are lightweight, using dissimilar materials processes for joining, especially in manufacturing the polymers and metals progressively used, which were becoming essential hybrid joint parts for engineering applications [9]. A novel laser beam method has bonded aluminium to polyamide hybrid joints.

The metal surface pretreatment takes place by electrochemical, scratch (mechanical treatment) or laser, which has a particular influence on the shear strength of the joint [10]. The mechanism of joining between polymers and metals is by interlock in the joined mechanically and adhesives in the chemically bonded. To improve joint strength, surface roughness is significant to take into account due to the density and size of the surface roughness and the depth and size of the pores at the metal surface [11]. Joining a Magnesium alloy and carbon fibre-reinforced plastic (CFRP) is carried out through a hot press bonding method, so two bunches of samples are utilized; the first was received, and the second was annealed; the oxide layer of the metal was farmed into the CFRP close the interface of joint [12]. Carried out aluminium alloy (AA5754) to carbon fibre reinforced polymer (CFRP) joining by the ultrasonic metal welding process so that both mechanical interlocking and adhesive bonding are outset in the welding zone [13].

Nomenclature & Symbols			
AISI	American Iron and Steel Institute	SEM	Scanning Electron Microscope
EDS	Energy Dispersive Spectrometry	CFRP	Carbon Fibre Reinforced Polymer
AA	Aluminium Alloy	PET	Polyethene Terephthalate
PA	Polyamide	Tm	Melting Point

A metal and plastic joint which are welded by direct laser joining examined to join a polyethene terephthalate (PET) polymer overlapped onto stainless steel Type (AISI 304) [14]. Near contact between the polymer and metal was acquired by mechanical interlocking, chemical bonding and physical happening at the interface. By using a hot press process to join a hybrid form of aluminium alloy AA6061-T6 together with polyamide, the aluminium sample was pre-holed with a 5 mm diameter of two holes [15, 16].

The study of the surface pretreatment of stainless steel AISI 316L to be welded to polyamide by the local process of the hot press bonding process is limited because it is independent of the standard specification and local process. And so, the electrochemical surface treatment is making it limited. Therefore, this work objective is to study; the grinded surface influence on the hot press bounding of AISI 304L to polyamide polymer, the influence of the grinding grains size of abrasive material on the joint quality between AISI 316L and polyamide bounding, investigate the result of the hot press bonding method parameters: applied processing time, applied pressure, and temperature on the shear strength of surface pretreatment of stainless steel to polyamide and study the effect of analysis the joint by Energy Dispersive Spectroscopy (EDS), with the assist of microstructure by using a scanning electron microscope (SEM).

2. Experimental Work

2.1. Materials

Use Two types of material in the hot press join; stainless steel 316L and polyamide (PA), melting point Tm=176°C. The chemical composition and mechanical properties of stainless steel alloy are offered in Tables 1 and 2, respectively.

Table 1. Chemical composition of AISI 316L [17]

Element / wt % / Material	C	Mn	Cr	Ni	P	S	Si	Mo	Fe
Standard %	0.03	2	16-18	10-14	0.045	0.03	1	2-3	Remainder
Actual %	0.025	1.3	16.9	11.4	0.025	0.015	0.501	2.4	Remainder

Table 2. Mechanical properties of AISI 316L [17]

Material		**Yield Strength YS, (MPa)**	**Tensile Strength UTS, (MPa)**	**Elongation EL, (%)**
AISI 316L	Nominal	170	450	40
	Actual	210	505	55

2.2. Specimens Preparation

The samples of stainless steel 316L are prepared from a thickness sheet (1 mm), while the polymer sheet specimens (PA) thickness is (2 mm). All samples are equipped with approval to the standard AWS spot welding specification (C1.1M/C1.1:2012) with measurements of dimensions (width = 25 mm, length =100 mm) as appeared in Fig. 1. The lap joint has its dimensions (25 x 25 mm^2) [18].

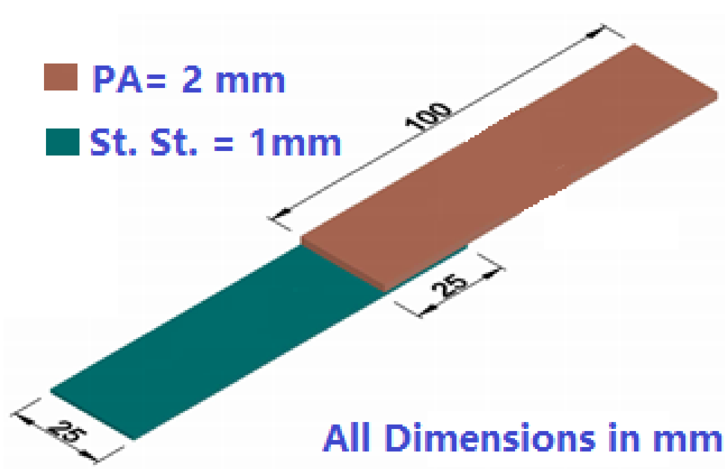

Fig. 1. Schematic lap joint of stainless steel/ polymer

2.3. The Mechanical Process

The surface of stainless steel was treated by a type of surface treatment; surface grinding. This treatment was utilized to build the surface roughness to improve the wet ability for good joining, which facilitates the joining process with the polymers. Surface granulating is a grinding operation that utilizes a rotating abrasive grinding wheel to remove material and objects that require high surface quality and high accuracy in shape and dimensions. The abrasive tools consist of fine particles emerging from abrasives with very high hardness and high thermal resistance. The layer of removed material from the surface by the grinding wheel becomes an accurate Reich during the wheel rotation at high speed. Therefore, the cooling fluid should be used when grinding the metal.

2.4. The Joint Process

The equipment function is to provide the necessary pressure to join the specimen of stainless steel with polymer by applying pressure and temperature over a time period.

The pressure was controlled by the hydraulic press controller, while the temperature regulator controlled the temperature. This equipment contains a heater Tmax. (400°C), a hydraulic press (15ton capacity), and a dying fixture for the samples. The heating instrument includes the source of heat and lower and upper plates. Use a thermocouple (K-type) to degree the temperature. It was sited in the centre of the bottom surface in the lap joint of the stainless steel. An opportune die is designed comprising of two parts; the first part was stainless steel, and the second part was a particular type of wood to acquire a joint of the centre line for each specimen. The polymer samples were placed on the stainless steel sample over the die slot. The conductivity transfers heat from the heater to the stainless steel sample during the stainless steel part in this die. The polymer sample was squeezed on the surface, which was grinded by the stainless steel specimen.

The main parameters in the hot press process are; temperature, pressure, and time. The pressure was determined to be 3, 6 and 9 bar. However, the temperature is diverse between three values, 165, 170 & 175°C, while the pressing time were 1.5, 3 and 4.5 minutes. Applying the Taguchi method as the design of experiments method (DOE) to determine the number of samples to be prepared to study the effect of different welding parameters, as indicated in Table 3. Fig. 2 illustrates the joint specimens.

Table 3. The joining samples information (Welding parameters)

No.	Tem.(°C)	Pressure (bar)	time(min.)
1	175	3	1.5
2	175	6	3.0
3	175	9	4.5
4	170	3	3.0
5	170	6	4.5
6	170	9	1.5
7	165	3	4.5
8	165	6	1.5
9	165	9	3.0

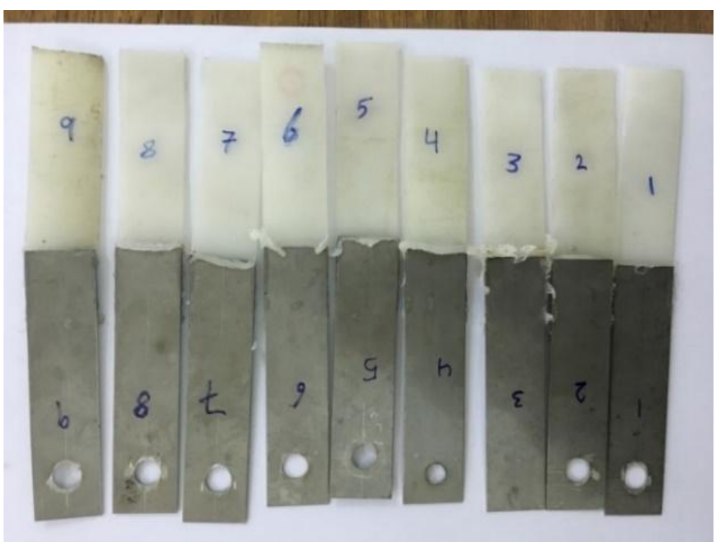

Fig. 2. The specimens of the experimental joint

2.5. Experimental Tests

The joint specimens were examined by the shear test, the scanning electron microscope (SEM) test and the energy dispersive spectrometry (EDS) test. The "AWS spot welding standard C1.1M/C1.1:2012" was embraced to prepare the shear test samples. So as to forestall the bending and slip amid the shear test, a shim is set at closes to the ends of every sample on the contrary sides, as shown in Fig. 3. The speed of the crosshead at the shear test is 10 mm/minute. In the microstructure test, the sample grinding is executed by utilizing SIC papers with different ASTM grits (400, 800, 1200 & 2000). The processes of polishing are done by the various particle size of alumina. A utilized special cloth at 250 RPM. The mirror was obtained by washing it with water and alcohol. To investigate the components of microstructure and appraisal of the elemental distribution percentage through (EDS) analysis.

Fig. 3. Shear test equipment

3. Results and Discussion

3.1. Shear Test

The whole samples were effectively jointed and tested under shear force. As appears in Fig. 4, the maximum and minimum values of shear force are observed. At a temperature of 165°C, applied pressure of 6 bar and time of 1.5 minutes, the minimum force was found to be 675 N, while the maximum force was 2182 N at a temperature of 175°C, applied pressure of 6 bar and time of 3 minutes. The diminished shear force was observed due to the amount of all or one of the joining parameters are not enough to give a complete penetration of the molten (PA) into the surface, which is grinded of stainless steel and vice versa, while the appropriate applying parameters of joining give a good penetration of the molten (PA) blasted on stainless steel.

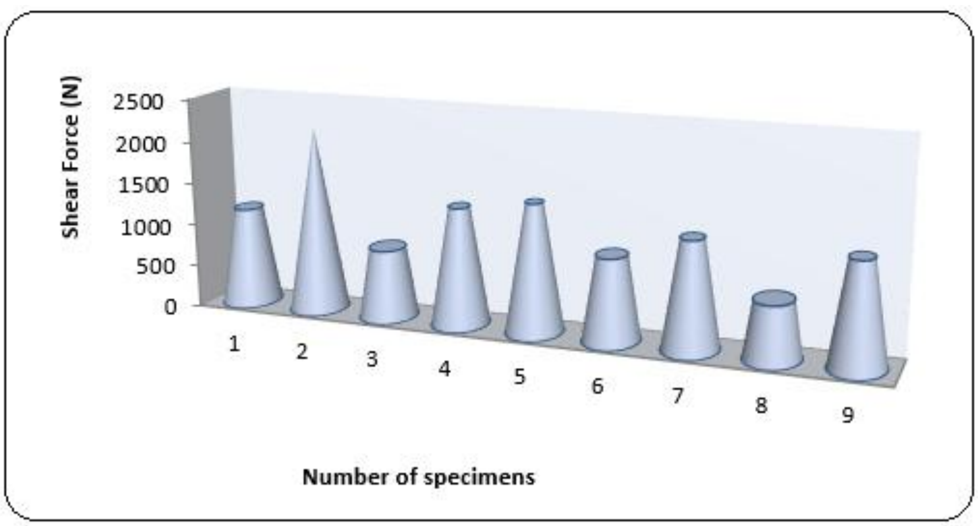

Fig. 4. Shear force of specimen

3.2. DOE analysis

The joining parameters effect from DOE was exhibited in Fig. 5 with the guide of utilizing the MINITAB program. The main effect plot shows that shear force increments with temperature, pressure until 6 bar, and joining time until 3 minutes, while the shear force diminishes slowly with an increase of the pressure and time until reaching its minimum value at a pressure = 9 bar & time = 4.5 minutes.

From the examination of the MINITAB program, the Pareto chart was acquired utilizing the confidence level (α =0.05); this chart shows that the joining temperature has the highest effect on the shear force of the lap joint as compared to other parameters, as shown in Fig. 6.

By using the MINITAB program, the interaction plot was drawn to analyze shear test results. This plot studies the effect of each two joining parameters separately on the shear force, as shown in Fig. 7.

1- The temperature with pressure has an irregular effect, but the temperature (175°C)at pressure 6 bar gives the maximum shear force.
2- The temperature with time has an alternating effect, but the temperature (175°C) at a time of 3 minutes gives the maximum shear force.
3- The pressure with time has an alternating effect, but the pressure (9 bar) at a time of 3 minutes gives the maximum shear force.

The results of the shear force for all the specimens joints were analyzed by the design of experiments method using the MINITAB program to estimate the effect of each joint parameter on the shear force and then access the optimal parameters that give the best value of the shear force. It was at a temperature of 175°C, applied pressure of 3 bar and time of 4.5 minutes, the force (2535 N) which is expected to be obtained; when these conditions were performed, and the shear test was performed, the shear force was equal to 2418 N. This means that the error ratio of the result was 0.05.

Fig. 8 presents the fracture surface of specimens; the interfacial failure occurred in some specimens that have a lower shear force. A ductile failure with an extension and necking at the polymer region is observed in other specimens that have higher shear force has acquired force maximum = 2182N.

The lower shear force resulted from the penetrated melted (PA) into the lines of the grinding stainless steel surface incomplete, which gave partial adhesion, while the higher penetration area of PA in the grinding surface of the stainless steel specimens performed to the higher shear force.

3.3. Scanning Electron Microscope (SEM) Test

This test was performed on the optimal sample; the better depth of the plastic zone inline joint should have approximately 15µm [19]; such value was acquired from the SEM test as appeared in Fig. 9. At the joint interface, the interlocking has happened by methods for filling melted polymer cavities because of heat, time, and pressure. The melted part of the polymer was completely filled in the grinded surface of the Stainless steel with the aid of the applied temperature, time and pressure. As a result, a good mechanical interlock between two materials was obtained [19, 20].

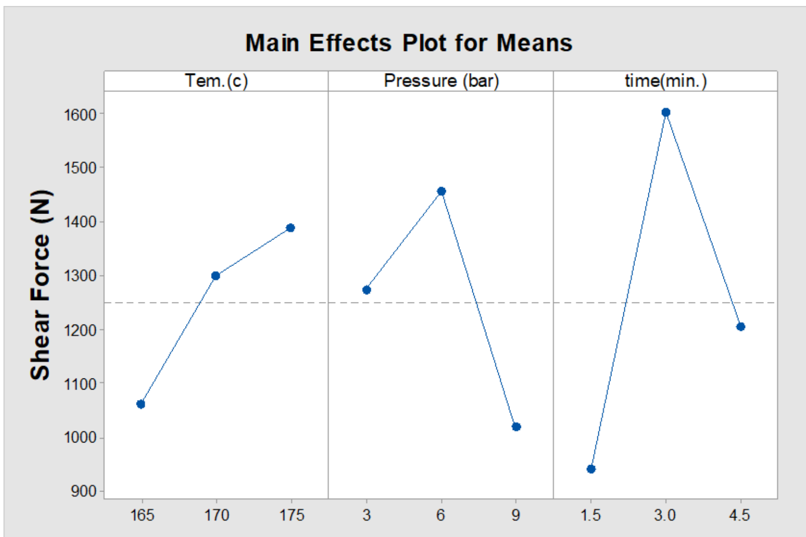

Fig. 5. Main effects plot for joining parameters

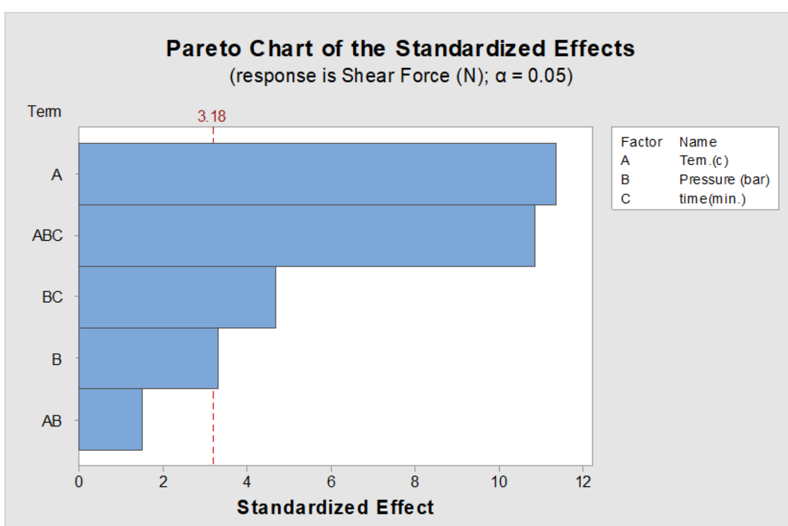

Fig. 6. Pareto chart for joining parameters

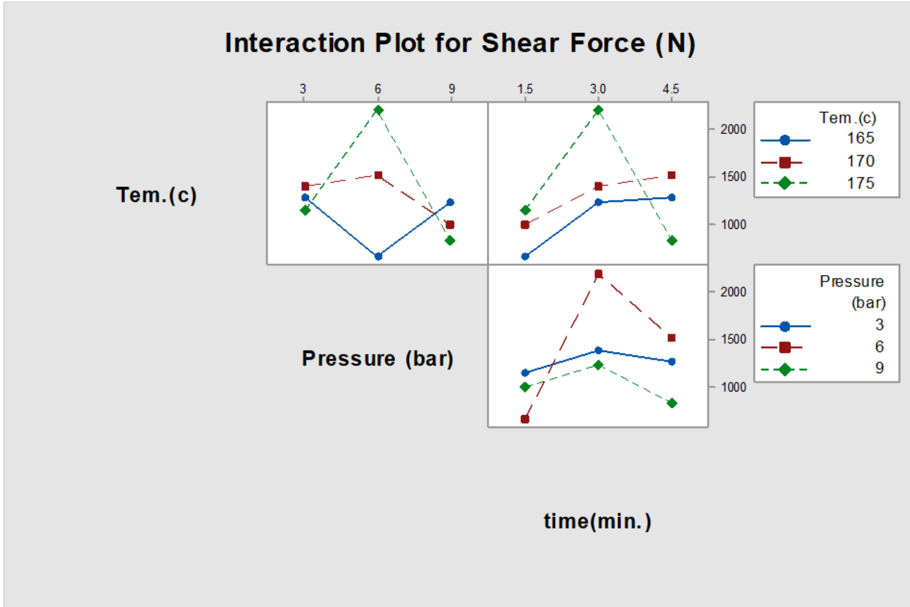

Fig. 7. Interaction Plot for joining parameters.

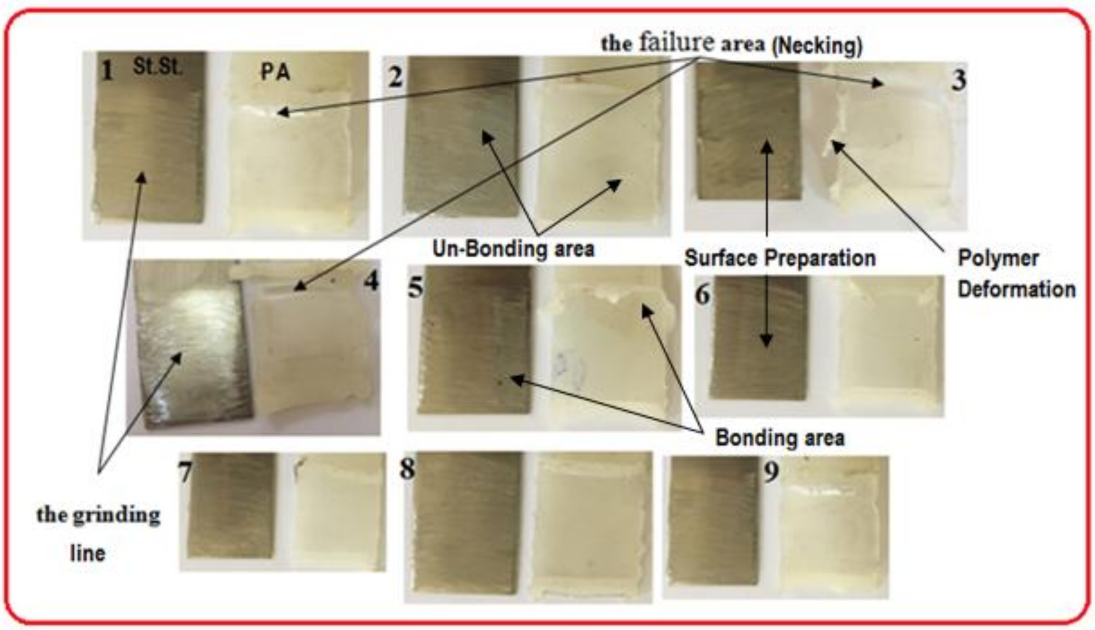

Fig. 9. The failure in shear test

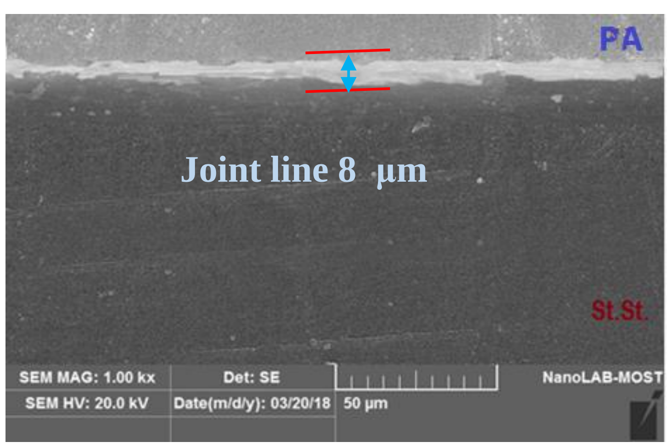

Fig. 9. SEM of the joint area for the optimum condition (50 µm)

3.4. Energy dispersive spectroscopy (EDS) analysis

Energy dispersive spectroscopy (EDS) line analysis was carried out to determine the distribution of the elements across the joint of the stainless steel to polymer bonding. Fig. 10 shows the EDS line scan across the base material and the bonding zone, which indicates the element of adhesive bonding at the interfaces of the two materials. It was observed that the EDS analysis showed three main elements, O, C and Fe. The presence of oxide film and the carbon atoms of polymers showed the chemical bonding and reaction between them, It is therefore believed find mechanical interlocking and Vander Waals force between metal and polymer.

That the presence of carbon was observed in the polymer zone, while the appearance of FE indicates the AISI 316L and the O indicates the presence of oxide film, but the interface layer has observed the presence of the three elements. The bounded region is clearly observed in the approximate range (40 - 51µm) as in Fig. 10. The bonding layer depth, according to an EDS map analysis, is approximately (8µm).

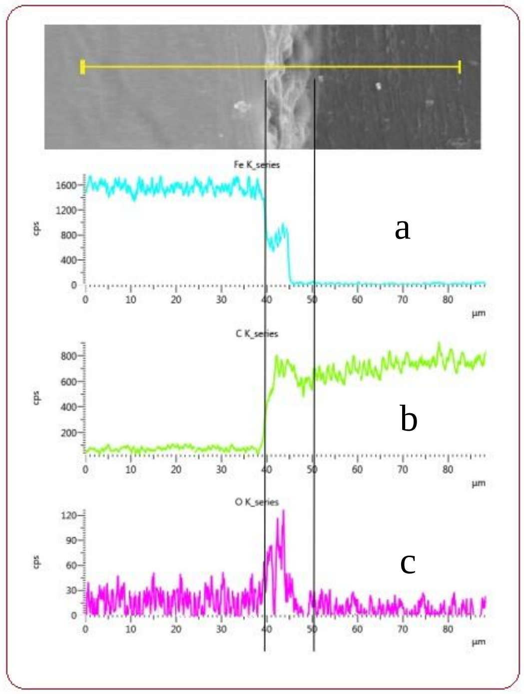

Fig. 10. EDS map line of PA and St.St. joint: (a) Stainless steel; (b) Carbon; (c) Oxygen

4. Conclusion

AISI 316L sheets were joined with polyamide (PA) utilizing a hot press method. The following conclusions were summarized:

The hot press process effectively joined dissimilar materials: AISI 316L with polyamide (PA). The SEM investigation of the joint cross signified that the joining technique between the metal and polyamide was accomplished by mechanical interlock between the molten polyamide and metal surface. the depth of the plastic zone inline joint had approximately 8µm. The EDS examination demonstrated that the interaction line between the two materials contained three elements: Fe, C and O. The shear test distinguished that all the tested specimens failed by shearing the polyamide layers at the lap joint. The applied temperature was the most elevated compelling parameter on the shear force of the joint (AISI 316L/ PA). The time was the most reduced compelling parameter on the shear force of joint AISI 316L/ PA. Increasing the applied temperature increased the shear force of joint AISI 316L/ PA.

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References

[1] Kadiyala, A. K., & Bijwe, J. (2018). Poly (ether ether ketone)-Silicon carbide composite adhesives for elevated temperature applications of stainless steel joints. Composites Science and technology, 155, 177-188, https://doi.org/10.1016/j.compscitech.2017.12.004.
[1] Wang, H., Yang, K., & Liu, L. (2018). The analysis of welding and riveting hybrid bonding joint of aluminum alloy and polyether-ether-ketone composites. Journal of Manufacturing Processes, 36, 301-308, https://doi.org/10.1016/j.jmapro.2018.10.031.
[2] Huang, Y., Meng, X., Xie, Y., Li, J., & Wan, L. (2019). New technique of friction-based filling stacking joining for metal and polymer. Composites Part B: Engineering, 163, 217-223, https://doi.org/10.1016/j.compositesb.2018.11.050.
[3] Bragança, I. M. F., Silva, C. M. A., Alves, L. M., & Martins, P. A. F. (2017). Lightweight joining of polymer and polymer-metal sheets by sheet-bulk forming. Journal of Cleaner Production, 145, 98-104, https://doi.org/10.1016/j.jclepro.2017.01.049.

[4] Hamzah, M. M., & Hussein, S. K. (2020, February). Effect of Surface Pretreatment on Hot Press Lap joining of High Density Polyethylene to Stainless Steel Alloy AISI 304L. In IOP Conference Series: Mterials Science and Engineering (Vol. 745, No. 1, p. 012058). IOP Publishing, https://doi.org/10.1088/1757-899X/745/1/012058 .
[5] Jiao, J., Xu, Z., Wang, Q., Sheng, L., & Zhang, W. (2018). CFRTP and stainless steel laser joining: Thermal defects analysis and joining parameters optimization. Optics & Laser Technology, 103, 170-176, https://doi.org/10.1016/j.optlastec.2018.01.023.
[6] Huang, Y., Meng, X., Xie, Y., Li, J., & Wan, L. (2018). Joining of carbon fiber reinforced thermoplastic and metal via friction stir welding with co-controlling shape and performance. Composites Part A: Applied Science and Manufacturing, 112, 328-336, https://doi.org/10.1016/j.compositesa.2018.06.027.
[7] Amancio-Filho, S. T., & Dos Santos, J. F. (2009). Joining of polymers and polymer–metal hybrid structures: recent developments and trends. Polymer engineering & science, 49(8), 1461-1476, https://doi.org/10.1002/pen.21424
[8] Kah, P., Suoranta, R., Martikainen, J., & Magnus, C. (2014). Techniques For Joining Dissimilar Materials: Metals And Polymers. Reviews on Advanced Materials Science, 36(2).
[9] Lamberti, C., Solchenbach, T., Plapper, P., & Possart, W. (2014). Laser assisted joining of hybrid polyamide-aluminum structures. Physics Procedia, 56, 845-853, https://doi.org/10.1016/j.phpro.2014.08.103.
[10] Kajihara, Y., Tamura, Y., Kimura, F., Suzuki, G., Nakura, N., & Yamaguchi, E. (2018). Joining strength dependence on molding conditions and surface textures in blast-assisted metal-polymer direct joining. CIRP Annals, 67(1), 591-594, https://doi.org/10.1016/j.cirp.2018.04.112.
[11] Arkhurst, B. M., Kim, J. H., & Lee, M. Y. (2019). Hot metal pressing joining of carbon fiber reinforced plastic to AZ31 Mg alloy and the effect of the oxide surface layer on joint strength. Applied Surface Science, 477, 241-256, https://doi.org/10.1016/j.apsusc.2017.10.009.
[12] Balle, F., Wagner, G., & Eifler, D. (2007). Ultrasonic spot welding of aluminum sheet/carbon fiber reinforced polymer–joints. Materialwissenschaft und Werkstofftechnik: Entwicklung, Fertigung, Prüfung, Eigenschaften und Anwendungen Technischer Werkstoffe, 38(11), 934-938, https://doi.org/10.1002/mawe.200700212
[13] Katayama, S., & Kawahito, Y. (2008). Laser direct joining of metal and plastic. Scripta materialia, 59(12), 1247-1250, https://doi.org/10.1016/j.scriptamat.2008.08.026.
[14] Abdullah, I. T. (2022). Friction Spot Joining of Aluminium Alloy AA 5052 To Pre-Holed Steel AISI 1006 By Extrusion Aluminium Into A Rivet Head Die. Journal of Techniques, 4(2), 10-20, https://doi.org/10.51173/jt.v4i2.492 .
[15] Barrak, O. S., Saad, M. L., Mezher, M. T., Hussein, S. K., & Hamzah, M. M. (2020, July). Joining of double pre-holed aluminum alloy AA6061-T6 to polyamide PA using hot press technique. In IOP Conference Series: Materials Science and Engineering (Vol. 881, No. 1, p. 012062). IOP Publishing, https://doi.org/10.1088/1757-899X/881/1/012062 .
[16] American Society for Metals (ASM), "Properties and Selection: Irons, Steels, and High Performance Alloys", ASM Handbook, Volume 1, 01 Sep. 2005.
[17] ANSI/AWS C1.1M/C1.1:2012, "Recommended Practices for Resistance Welding", American Welding Society.
[18] Hart-Smith, L. J. (1999). A peel-type durability test coupon to assess interfaces in bonded, co-bonded, and co-cured composite structures. International journal of adhesion and adhesives, 19(2-3), 181-191, https://doi.org/10.1016/S0143-7496(98)00033-5.
[19] Ratanathavorn, W. (2012). Hybrid joining of aluminium to thermoplastics with friction stir welding (FSW).
[20] M.S. thesis, Department of Materials Science and Engineering, KTH-Royal Institute of Technology, Stockholm, Sweden, 2012.