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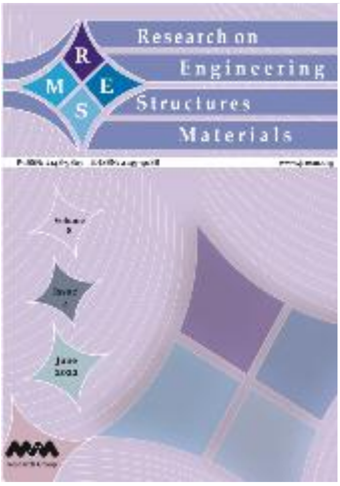

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Research Article

The effect of mechanical surface roughness for polyvinyl chloride (PVC) and aluminum joining

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Abstract

In this study, the joining technique of two different materials such as polyvinyl chloride (PVC) and aluminum that can replace steel insertion in the PVC profile industry was investigated. The aim was to improve the interface structure for joining PVC and aluminum with different geometries on the aluminum surface. The effects of mechanical surface roughness were studied for the joining performance. Aluminum samples with mechanically deformed surfaces were prepared and joined with PVC strips. Lap-shear, interlaminar shear strength (ILSS), 3-Point (3P) bending, and coefficient of linear thermal expansion (CTE) tests were performed. Microstructural investigations were conducted with an optical microscope and scanning electron microscope. According to the results obtained, mechanical surface roughness on the aluminum improved the joining interface between PVC and aluminum. The side-punched and perforated samples achieved the best results in terms of geometrical variations on the aluminum surface. Improvement in surface roughness resulted in a 2-fold increase in lap-shear shear strength and 45% reduction in 3-point bending test results. Optical microscopy was performed on the interface layer, the cavity structures were examined. In the samples with good adhesion results, it was observed that the desired locking mechanism was formed in joined structures as a result of the abrasion on the metal surface and the filling of holes with PVC.

1. Introduction

The construction industry plays an important role in the development of human history. Building materials can be divided into structural materials, decorative materials, and special materials. [1].

Aluminum and its alloys have many outstanding attributes that lead to a wide range of applications, including good corrosion and oxidation resistance, high electrical and thermal conductivities, low density, high reflectivity, high ductility and reasonably high strength, and relatively low cost [2]. Extruded aluminum profiles are used to make ladders, doors, windows, showers, and scaffolding, among other industrial applications. Roofs, facades, panels, components, awnings, cladding gutters & downpipes, ceilings, and many more structures in the building and construction business use our coated and uncoated building goods [3].

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PVC is one of the most widely used plastic compounds in the world, with a wide range of applications. UPVC has piqued the construction industry's attention as low-maintenance material [4].

PVC is widely employed in the construction sector for a variety of purposes, including pipelines, windows, flooring, roofing, and lighter constructions. The building industry consumes 67% of global PVC production [5]. Windows are available in a variety of frame materials in the construction industry, including aluminum, PVC, timber, and aluminum cover of PVC on timber, joined, composite, and fiberglass. Some observations concerning these building materials are relevant to an understanding of the PVC requirements [6].

The idea of having joined materials of PVC and aluminum is a solid product within an improved joining structure that can replace steel sheets. The current PVC window fabrication process includes additional labor costs for steel insertion and screwing. However, the modulus of elasticity of steel is approximately 3 times higher than aluminum, there is a positive reduction in deflection values in the moment of inertia for joined materials when used in multiple structures. For this reason, it was necessary to initiate a study with enhanced bonding properties at the PVC and aluminum interface.

Joining structure between interface layers can be improved with surface roughness, adhesive bonding, and plasma applications. Surface roughness is one of the important factors which influence the mechanical properties of the joints. Having surface roughness on aluminum material can be preferable in joining [7]. The importance of the surface and its favorable impact on bond strength was noted by the majority of the studies [8].

In this study, we used aluminum and PVC to create a new joined profile that overcomes the barriers for steel reinforcement in conventional PVC profiles. During the project evaluation phase, shear stress (lap-shear test) for adhesion strength, interlaminar shear stress for bending, and 3-point bending tests were performed. In addition, linear thermal expansion tests were performed on the samples prepared at different temperature ranges determined under laboratory conditions. With the use of an optical microscope, the interface layer and surface morphology between aluminum - PVC were investigated. After the results were minimized, the surface topography of the test sample showing the best adhesion was examined by Scanning Electron Microscope (SEM) analysis.

The experiment design was made in DOE using full factorial design techniques. DOE was created to deal with complex problems where more than one variable may influence response and two or more factors may interact [9]. DOE which is the dependent variables (responses) consist of the test results as lap-shear, 3-point bending, ILSS, and CTE performed as a result of the study. The independent variables (factor) were determined as aluminum surface roughness and process types. There are 6 levels for aluminum surface roughness and they are described as S1 to S6.

2. Material and Methods

2.1. Materials

2.1.1 PVC

PVC strips have been obtained from suspension u-PVC from Petkim S65. It has some properties which are 67±2 K-value, 0.55±005 g/cm3 bulk density, and 0.250 μm (Max 8%) and 0.063 μm (Min 90%) particle size. These materials were prepared from extruded u-PVC window profiles.

2.1.2 Aluminum

The alloy of 5052H18 which is the strongest temper produced through the action of only strain hardening decided to use for the preparation of aluminum strips in the study. It has some properties which are 2.7 g/cm3 density, 70 GPa Young Modulus, and 178 MPa Yield Strength.

Samples are prepared in the required dimensions from aluminum rolls.

2.2. Experimental Methods

2.2.1 Design of Experiments (DOE)

To analyze the effect of the design of the experimental parameters, the aluminum surface roughness and the process types were used for the improvement of two material joining. MINITAB 19 software Design of Experiment Full Factorial method was used to examine the main effect and interaction plots.

2.2.2 Preparation of PVC Samples

PVC profiles that are the origin of the samples were produced in the extrusion process. As the third step, the strips were prepared from extruded PVC profiles. The thickness of PVC samples was preferred as 3.2 mm.

2.2.3 Preparation of Aluminum Samples

To obtain the patterns on the aluminum surface, the modeling of different patterns was studied. During this study, the resistance to applied forces (such as lap-shear, 3P bending, ILSS, and linear thermal expansion) on the interface layer has been considered. Surfaced deformed, planned to apply on the aluminum surface, have been designed on CAD software. 3D modeling of patterns was created on a jig to have this effect on the aluminum surface. Having a patterned surface on an aluminum surface is included in the pressing process (Figure 1).

After the pressing process, surfaces of aluminum are prepared according to the pattern on these jigs. Six different types of roughness were applied to the aluminum surface. These are Flat, Perforated, Side Punched, Surface Deformed, Side Punched+Surface Deformed, and Side Punched+Perforated surfaces which are abbreviated as S1 to S6 (Table 1).

The thickness of the aluminum samples was 0.8 mm.

In the study, the aluminum surface type definitions will be expressed with the abbreviations explained in Table 1.

2.2.4 Preparation of Joined Samples as PVC Aluminum

The joined samples were prepared using a hot-pressing process is shown in Figure 1. In this method firstly, PVC and aluminum samples were preheated and joined in a hot press machine to obtain joined samples.

Hot-press equipment which provides 6 bar compression pressure is shown in Figure 2 includes two metal plates as horizontally on top and bottom with heating resistance.

180 °C, 190 °C, and 200 ºC temperatures have been studied for preheating rigid PVC samples to optimize the properties. The temperature (180 °C, 190 °C, 200 °C), pressure (6 bar), preheating time (10,15,20 minutes), and compression time (3, 4, 5 min) were varied to find the optimum joining properties.

The compression pressing conditions were optimized to 190 °C, 10 minutes for preheating, and 3 minutes for compression time. PVC and aluminum samples were placed on a customized tool and started tests as shown in Figure 3.

Table 1. Abbreviations of Aluminum Surface Types

#	Aluminum Surface Types	Sample Pictures	Codification
1	Flat		S1
2	Side Punched		S2
3	Perforated		S3
4	Perforated + Side Punched		S4
5	Surface Deformed		S5
6	Surface Deformed + Side Punched		S6

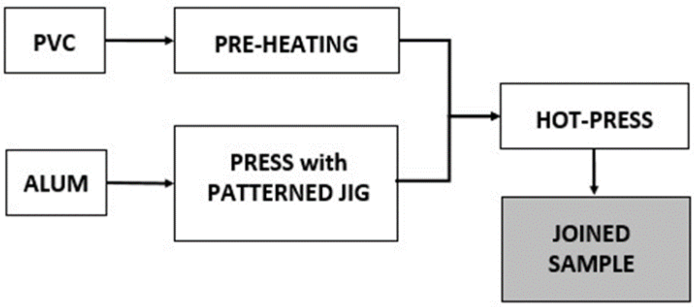

Fig. 1 A schematic picture of the sample preparation process

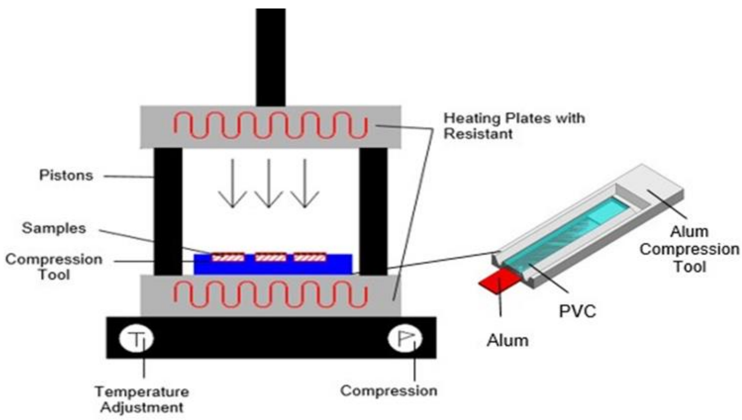

Fig. 2 Schematic representative of hot press equipment

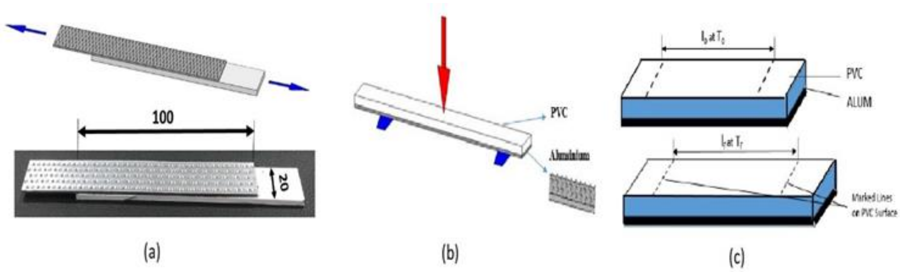

Fig. 3 Sample preparation and tests (a) Lap-Shear, (b) 3P Bending, (c) CTE

2.3. Characterization

2.3.1 Mechanical Testing

2.3.1.1 Lap-Shear Test

The lap-shear tests were conducted on a Zwick mechanical tensile testing equipment with a load cell of 20 kN. During the tensile/shear testing, the displacement control mode with a rate of 1 mm/min was utilized. After the peak loads were recorded, the experiments were terminated.

The test specimen in the lap-shear arrangement is formed by two rectangular pieces with an overlapping area large enough to cause failure. The subsequent tensile testing determines the lap-shear strength, which is given by:

$$\sigma = \frac{P}{b.L} \tag{1}$$

where,

P – Maximum load (N),

b- Joint width (mm),

L- Joint length (mm),

▯ - Stress (N/mm2)

Lap-shear properties of composite materials were measured with Zwick Roell 20 kN. Samples dimensions were 20x100 mm. The measurements were done at 23 ± 2 °C and relative humidity %45 ± 10.

2.3.2 3-Point Bending

A flexural strength test imposes tensile stress in the convex side of the specimen and compressive stress in the concave side. Test has been performed with 30 kN.

2.3.3 Inter Laminar Shear Strength (ILSS)

The short beam strength test of high modulus reinforced composite materials is determined in ASTM D 2344. The samples have dimensions of 4x24x8 mm. The ILSS values were evaluated from the short beam shear test according to the following relation:

$$ILSS = 0.75\ x\ Pb\ /\ (b\ x\ d) \tag{2}$$

Where Pb = breaking load (N), b = width (mm) and d = thickness (mm) of the specimen.

2.3.4 Thermal Tests

2.3.4.1 Coefficient of Linear Thermal Expansion (CTE)

Different substances expand by different amounts. Over small temperature ranges, the linear thermal expansion of uniform objects is proportional to temperature change.

The test specimens were marked as lo at To, after the test, lf has been recorded at temperature Tf . By measuring the length at room temperature, the expansion, and the temperature difference, the α value can be calculated as the formulation given below.

$$(l_f - l_0) / l_0 = \alpha 1 \, x \, (Tf - T0) \quad (3)$$

$$\Delta l / l_0 = \alpha 1 \, x \, \Delta T \quad => \alpha 1 = 1/l(dl/dT) \quad (4)$$

where l0 and lf represent, respectively, where l_0 and l_f represent, respectively, the original and final lengths with the temperature change from T_0 to T_f. The parameter α1 has units of reciprocal temperature (K^{-1}) such as μm/mK or 10^{-6}/K.

The length of the marked sample is measured at room temperature, and again when it has been heated up. The test has been performed in a Nuve heating oven at 20 °C (T_o) to 70 °C with 10 °C increasing temperature intervals.

2.3.5 Microscopic Analysis

2.3.5.1 Optical Microscope

The interface layer of sections of joined samples were analyzed in the Optical Microscope

of Eclipse LV100ND model in Nikon. The section of joined samples were prepared to have 100X magnifications.

According to tests explained in this study, overview of test performed samples as shown in Figure 4.

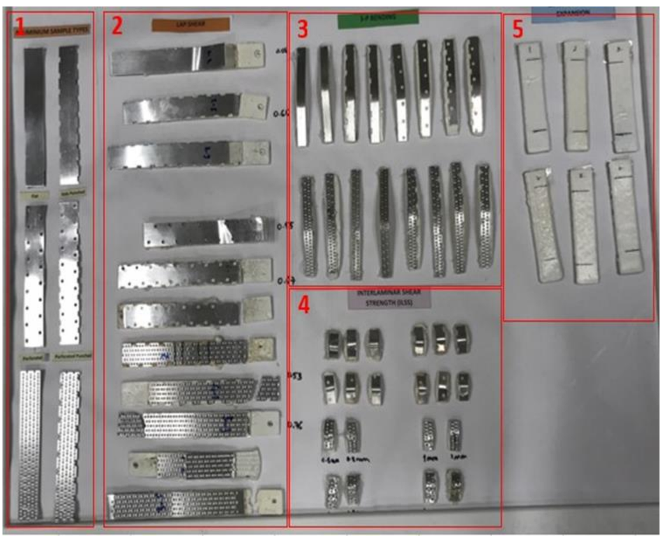

Fig. 4 Overview of test samples

3. Results and Discussion

3.1. Design of Experiment (DOE)

MINITAB software was used to examine the main effect and interaction plots.

Main effect plots provide information about which is the most influencing factor and the classic relationship between availability, performance, and quality rate [10].

DOE which is shown in Figure 5; the dependent variables (responses) consist of the test results as lap-shear, 3-point bending, ILSS, and CTE performed as a result of the study. The independent variables (factors) were determined as aluminum surface roughness and process types. The determined independent variables are classified as levels and described in Minitab software. There are 6 levels for aluminum surface roughness and they are described as S1 to S6.

In the study of Rafidah et al. (2014) on "Comparison Design of Experiment (DOE): Taguchi Method and Full Factorial Design in Surface Roughness", they compared the effectiveness of Taguchi and full factorial design methods on surface roughness using both Taguchi and full factorial design techniques [11]. According to the obtained results in their paper, the full factorial design looks better DOE technique than the Taguchi method, since the mean square error is lower, the parameter design of the full factorial design provides a simple, systematic, and efficient methodology for optimizing process parameters. When the available techniques in DOE analysis were evaluated, full factorial design has been decided to use in the current study.

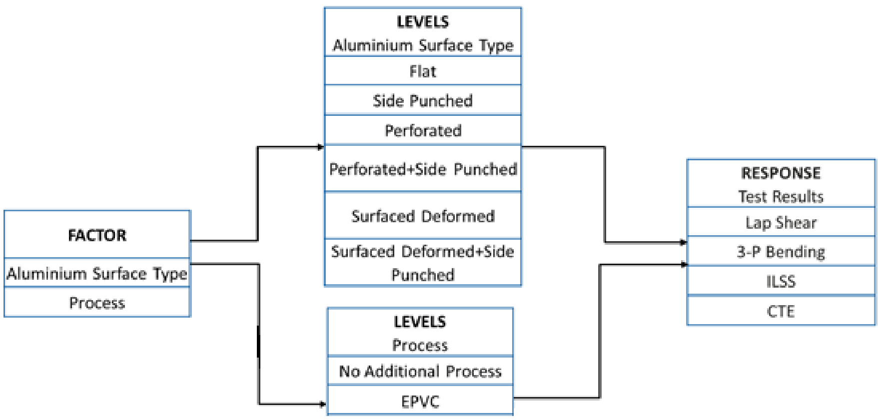

Fig. 5 DOE analysis in the study (factors, levels and responses)

The brief contents of the results from the DOE results are as follows:

The lap-shear tests were performed on the modified samples which have the effect of surface roughness and adhesions. The results show that increasing sanding time as higher surface roughness, was improving mechanical locking. But, after having maximum shear strength, the surface roughness degraded the bond strength of the adhesive which means reducing in shear strength at higher roughness. The results of the lap-shear relationship between the different samples were explained in the first main effect plot. These plots show the mean value of that parameter based on different roughness and process types.

The other purpose was to describe how different surface roughness classes affected flexural performance. In the current study, the flexural strength of the surface roughness has increased. The 3-point bending test results showed that the fracture surfaces in the samples with surface roughness were filled with plastic material, enhancing the interface and contributing to the study's findings of a decrease in deflection. The detected deflection on test samples is explained by a 3P bending main effect plot.

ILSS was measured as a function of surface roughness. Roughness and surface energy variations effectively improve laminate bonding strength. In our study, the measured ILSS results were higher for the specimens which having pretreated processes on surfaces. Roughness has improved the results identically for the samples S4, S5, and S6 (perforated, punched, and deformed surfaces).

The measured results for CTE show that the roughness on the aluminum surface affects expansion property. The lowest values in the S range, which are identical to the joined structure were obtained in S2, S4, and S5 samples.

According to the plots of the main effect in DOE studies, the surface roughness examined on the aluminum surface contributes positively to the joining interface. Additional processes also resulted positively when they are compared to the untreated process. DOE study results show that S2, S4, and S5 specimens achieved better results among all samples.

3.1.1 Main Effect Plots

Main effect plots provide information about which is the most influencing factor and the classic relationship between availability, performance, and quality rate [10].

In this study, main effect plots describe the relations of levels between aluminum surface roughness and process types. The mean values of test results were shown on main effect plots. Therefore, these plots provide a good overview of the data.

Lap-shear, ILSS, and 3P bending tests were examined to focus on mechanical properties deviation. CTE test was set to see how enhancing the joining affects the thermal expansion behavior.

3.1.1.1 Main Effect Plot of Lap-shear

Kwon et. al researched “Comparison of interfacial adhesion of joined materials of aluminum/ carbon fiber reinforced epoxy composites with different surface roughness” in 2019. They have modified the surface of aluminum using some sanding processes. The lap-shear tests were performed on the modified samples which have the effect of surface roughness and adhesions. The results show that increasing sanding time as higher surface roughness, was improving mechanical locking. In other words, the increased energy of the surface results in improved mechanical adhesion with higher lap-shear values [12].

Similar to these results, the different roughness types have improved the results positively in our study. Because of the locking mechanism, PVC material filled the deformations on the aluminum surface, the results were obtained identically higher than the S1-flat surface.

Hamdi et. al (1995) studied “Improving the adhesion strength of polymers: effect of surface treatments” on PVC, ABS, and EPDM materials. According to their outputs on graphs for lap-shear tests, PU application on PVC surface has a lower effect than other adhesives selected as silicone and modified silane. On the other hand, the samples which were treated had better results [13]. Pretreatment had also a similar influence on the outcomes of the present study specimens. The samples which were premiered as a pre-treatment on the aluminum surface have higher values on lap-shear tests.

The surface treatment of effect on aluminum was studied by Boutar et.al (2016) for automotive applications. They determined the effect of surface roughness and wettability on the strength of single lap joints on three abraded surfaces. The results indicate that shear strength appears to increase from not abraded to a polishes surface with abrasive paper that provides 0.6 μm surface roughness. But, after having maximum shear strength, the surface roughness degraded the bond strength of the adhesive which means reducing in shear strength at higher roughness. They have summarized that joint durability cannot be provided by higher surface roughness, it also depends on the characterization of the interphase and its formation mechanism [14].

In the present study, the customized tool has been designed to deform and increase the surface area like roughness. While the values were expected to go up, the results were worse than expected, because of air in the gap remained closed, it had a negative impact on the outcomes. Equivalent to their study, the depth of roughness must be optimized. Otherwise, the roughness can have a negative effect on the results.

The results of the lap-shear relationship between the different samples were explained in the first main effect plot. These plots show the mean value of that parameter based on different roughness and process types. According to the given results, the addition of roughness and process types have positive effects on the results. While S1 (untreated flat surfaces) have the lowest value, the additional processes and mechanical operations on the surface have an impact on the values as variations. The main effect plots for lap-shear test results were summarized that S2, S3 and S4 samples in surface types have resulted as higher than 2 MPa which was 1.08 MPa without any roughness.

3.1.1.2 Main Effect Plot of 3P Bending

Lee et al. (2016) studied carbon fiber-reinforced plastic/Al5052 joined samples. When the flexural stress of the composite was measured about the surface roughness, it was found that if the specimen surface was treated with sandblasting, the flexural stress remained relatively constant regardless of the surface roughness; nevertheless, it was lower when the specimen surface was not treated. This shows that surface treatment improved the flexural strength of the material. The specimen had a flexural stress of 480–500 MPa after sandblasting, whereas it was only 220 MPa in the absence of surface treatment [15].

In the present study, the roughness on the surface has increased in flexural strength. The 3-point bending test results showed that in the samples with surface roughness, the fracture surfaces were filled with plastic material, thus improving the interface, which also led to a positive decrease in the deflection results in this study.

Zal et al. (2016) studied the effect of the surface roughness of aluminum on fiber metal laminates (FML) which include fiberglass, PVC film (0.2 mm), and aluminum. Four different surface treatments (pickled with HCI, cold rolled, holes, grinding, and mechanically roughened) were applied on three-point bending samples to measure flexural strength. The least flexural strength has been measured in the etched aluminum layered sample, because of pickling removed contaminant substances from the aluminum surface and tend to form a chemical bond. In this case, PVC polymer tolerates delaminating shear stress which also provides an improvement in flexural strength. The overview of the results showed that mechanical treatment and roughening of the aluminum surface was found to be a good treatment method to obtain a high-strength PVC matrix/aluminum layer interface bonding in the produced FMLs [16] some processes as surface treatment and having some holes similar to S2 and S3 specimens look close to principally. The created holes improved the interlock mechanism in both studies were resulted in higher values. Piercing on aluminum allowed the PVC filling which is similar to S2-side punched and S3-perforated specimens, resulting in better outcomes.

The "Effects of surface roughness and bond enhancing techniques on flexural performance of CFRP/concrete composites" subject has been studied by Ariyachandra et al (2017). The surface preparation and bonding alternative techniques on joined performance were performed with the three-point bending test method. The purpose was to define the effects of dissimilar surface roughness classes on flexural performance. Polymer anchorages' effect for delaying the end debonding was studied. The surface roughness of concrete substrates has significant effects on the bond strength of CFRP-concrete composites. Samples with shorter leg – anchorages results were not big improvements, which means longer leg-anchorage geometry provided better outputs in three-point bending results [17].

Interface assessment has been studied by Karakaya (2020) They have investigated an alternative joining method on the over-molding of thermoplastics on thermoset composites. The peel ply treated over-molding on the surface indicates better adhesion performance. The tests reveal that the peel-ply application increases the roughness by providing a good effect on flexural strength and modulus. This effect was more evident in the sample which was prepared with 80 oC temperature mold [18].

In that study higher temperatures provided the softening phase for polymers to improve the joining. Similarly to that, the temperature in the hot press was 190 °C in the current study, which allowed the softened PVC higher than the Vicat temperature. The roughness on the aluminum surface was filled with a soft polymer that enabled good adhesion. 3P bending main effect plot explains the measured deflection on test samples. The highest deflection value was measured in S1, which decreased roughly from 2.5 mm to lower than 1.0 mm with surface roughness and adding extra treatments. The results indicated that the pretreatment on the aluminum surface with primer provided a lower displacement. The main effect plots for 3P bending indicated that decrease in the deflection after surface modifications and treatments. S4, S5, and S6 in surface types have lower deflection with the result of good joining properties.

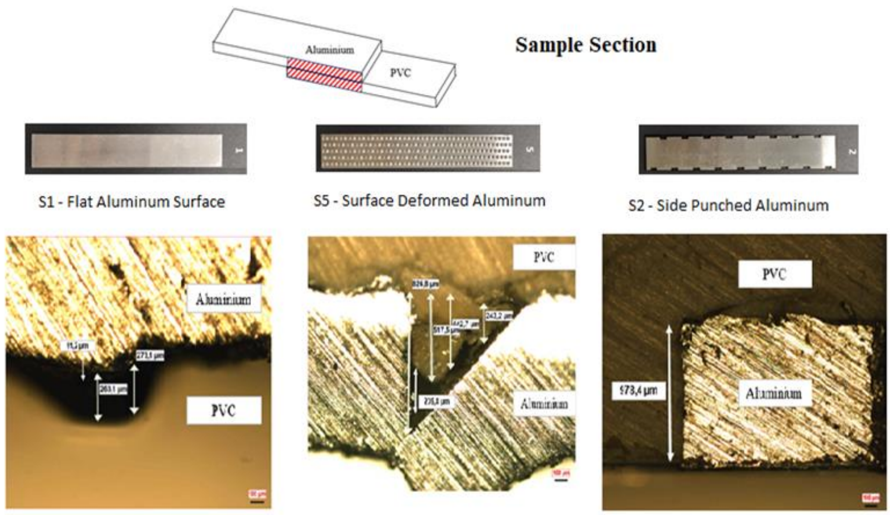

Fig. 6 Optical microscope result of interface on S1, S5 and S2

3.1.1.3 Main Effect Plot of ILSS

Choi et al (2010), investigated the interface of a metal sheet–prepreg. The studies were carried out on aluminum sheets with different roughness levels of surface textures (sanding and nylon-pad abrasion) and chemical etches systematically changing the surface morphology. ILSS was measured as a function of surface roughness. Roughness and surface energy variations effectively improve laminate bonding strength [19].

In our study, similar to their outputs, the measured ILSS results were higher for the specimens which having pretreated processes on surfaces. Roughness has improved the results identically for the samples S4, S5, and S6 (perforated, punched, and deformed surfaces).

Wu et al.2014, studied the impacts of various surface treatments on fiber metal laminate ILSS. For the surface treatment of aluminum, they utilized solvent degreasing, mechanical abrasion, alkaline cleaning, and plasma treatment. Sandpaper and alkaline cleaning with NaOH had the greatest ILSS among the various surface treatments. The reason for the greater ILSS value is that when metal is abraded with a lower-grit sandpaper, it achieves a higher roughness than when metal is abraded with a higher-grit sandpaper. With alkaline washing, an interface layer was created, causing a bridging effect between aluminum and composite, resulting in greater adhesion. As the concentration of NaOH rises, the thickness of this interface layer increases [20].

As lower grit sandpaper provided higher roughness in their study, ILSS measurements of S5 surface deformed samples have resulted more than others, which is identical to outcomes of higher roughness. The results of the ILSS test indicated that the surface roughness on the Aluminum surface has an effect in a positive direction on the values. From aluminum surface types, S4 and S5 have higher values in their range. Small sizes of ILSS specimen needs to prepare the sampling more sensitively. It is the one reason for these deviations in the results. If the location of the roughness was not centered correctly on the specimen, it creates some deviations in unexpected direction.

3.1.1.4 Main Effect Plot of CTE

The main effect plot for CTE results has been indicated. The measured results for CTE show that the roughness on the aluminum surface affects expansion property. The lowest values in the S range, which are identical to the joined structure were obtained in S2, S4, and S5 samples. The main effect plot was created for CTE which is critical for the products that need to be exposed to outside weathering conditions. Therefore, the thermal expansion of each material for the joined structure must be examined if the value is a limitation at certain temperature differences. The results revealed that S2, S4, and S5 have lower coefficients than other types.

According to the plots of the main effect in DOE studies, the surface roughness examined on the aluminum surface contributes positively to the joining interface. Additional processes also resulted positively when they are compared to the untreated process. DOE study results show that S2, S4, and S5 specimens achieved better results among all samples. Main Effect plots for Lap Shear, Deflection, Short Beam Strength, and CTE results were given in Figure 7.

3.2. Microscopic Analysis

3.2.1 Optical Microscope

S1- Flat Aluminum surface;

On flat samples, Figure 6 illustrates the gaps between the PVC and aluminum interface regions. In some local areas of the interface, there is a gap of nearly 263 µm, which has a significant impact on the result of the sample, which has no surface roughness.

S5 - Surface deformed Aluminum;

In Figure 6, the optical microscope result of the S5 joined sample is shown. OM picture indicates that PVC material penetrated through the cavity on the aluminum surface. The dimension of PVC penetration was measured as 517.5 μm which provides an advantage as interlocking on test results. But, there is still a void (239.8 μm) on this joining structure that PVC can't fill since it is a closed gap with air. Air in these gaps could not be replaced with PVC.

S2 - Side punched Aluminum surface;

The optical microscope output for side-punched aluminum samples is shown in Figure 6. OM result presents on the cross section that removed part of aluminum were filled by PVC material. The depth of penetrated PVC was measured to be 978.4 mm, which is the best interlocking mechanism among the other surface roughness.

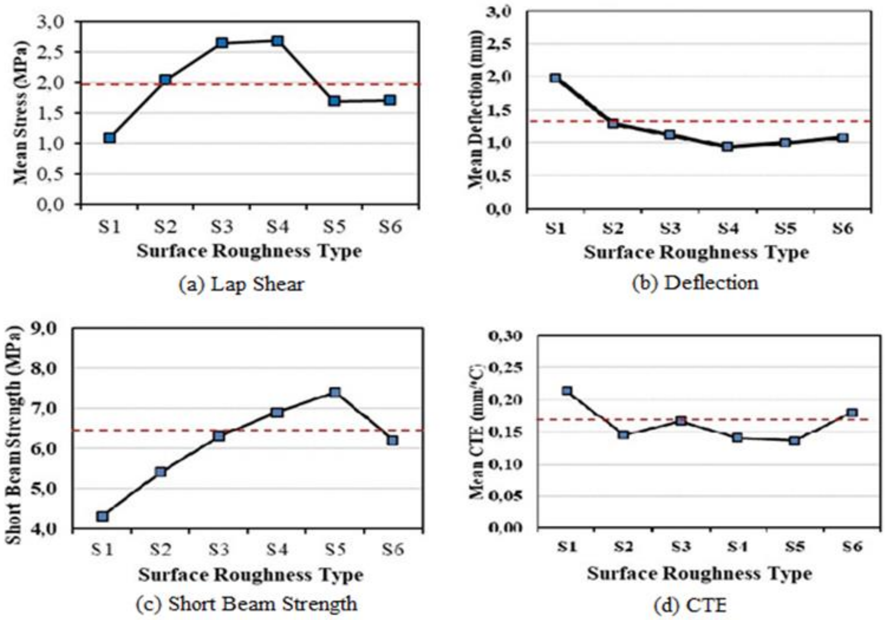

Fig. 7 Main Effect plots (a) Lap Shear (b) Deflection (c) Short Beam Strength (d) CTE-Based on Roughness

4. Conclusion

In this study, the idea of having joined PVC and aluminum a solid product within an improved joining structure that can replace the steel sheet. However, the modulus of elasticity of steel is approximately 3 times higher than aluminum. It has a positive reduction in the deflection values in the moment of inertia for joined materials when using aluminum in multiple structures. For this reason, it was necessary to initiate a study with enhanced bonding properties at the PVC and aluminum interface.

Before any experimental study, the design of the experiment methodology was exploited for all the parametric studies. In the study, which aims to strengthen the joining between PVC and aluminum, good results were obtained from the samples of the metal surface, with side punched and perforated aluminum surfaces with a positive increase of around 40%.

The specimens with side cuts and perforated holes with interlock mechanisms resulted in the expected direction, where shear forces appear to be difficult due to the plastic raw material filling the emptied space. This view was also supported by cross-sectional images taken with an optical microscope. In the side punched samples, it was observed that PVC and aluminum formed an interlocked structure which provides an advantage on joined structure. Contrary to expectations, in the surface deformed samples, the PVC material could not fill the deformed area on the surface, since the air is trapped inside.

Considering all of the parameters and findings of this study, it has been determined that surface roughness has a critical effect on joining structure and that mechanical and thermal results can be improved by adding additional processes to the specified surface.

When the findings of these studies are analyzed, new coupling techniques or parameter adjustments are still in discussion, and the potential implications of new applications on the results will be investigated further in the study's subsequent steps.

In further steps of this study, it is thought that the interface formation on the process-based parameters on aluminum surfaces has a positive effect on the bonding. For this reason, several processes such as emulsion PVC, adhesives, and plasma will be evaluated in further studies. This is an area where we scratched the surface and there are many studies to conduct in this area, we are also working on the adhesive type for the joining that has the optimized roughness.

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