Journal of
Polymer & Composites
https://journals.stmjournals.com/jopc
ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Issue 2, 2026
DOI (Journal): 10.37591/JoPC
Research JoPC

An Experimental Investigation on the Characterization of Al6061-Polymer Adhesive Joint by Design of Experiment

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Abstract

Aluminium alloys and polymers are the light-weight materials extensively used in structural, aerospace, automobile and marine applications. Al6061 alloy and nylon 6 were joined through the adhesive bond and their characteristics were analyzed. However, joining of these dissimilar materials for the evolution of hybrid engineering structures were complex because of their difference in physical, chemical and mechanical behaviours. The Taguchi's, Design of Experiment were conducted on the various mixture of adhesives and surface treatments. The two adhesives, Araldite and MC-bond and the three surface treatments viz, mechanical, chemical and sand blasting methods were combined together for L18 orthogonal array, according to the Design of Experiment. The B2-M2 part number with MC bond, processed mechanically of bonding thickness, 0.5 mm and the corresponding tensile strength of 70.77 MPa revealed the ideal trial in Design of Experiment. The MC-bond adhesive was observed to be the efficient joint, possessed the highest means value of 60 when compared with other combinations, being trialed. The mechanical surface treatment was found to be superior in the achievement of required surface structure which have great means value of 60 than the sand blasting means value of 25 and chemical surface treatment means value of 30. The mechanical strength of joints were assessed which revealed about the domination of mechanical surface treated joints when compared with the other joints. The main aim of this work is to estimate and understand the performance of Al6061-nylon 6 joints under dynamic loads.

Keywords Metal, polymer, adhesive joint, design of experiment and composites

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Received Date: March 16, 2026
Accepted Date: March 24, 2026
Published Date: April 03, 2026

Citation: Ravikumar K., Arunnath A., Nirmal Kannan V., Rajadurai Narayanamurthy, Rathinasabapathi G., Dinesh Kumar S. Autonomous Agentic AI for Adaptive Cure Optimization and Defect Prevention in Thermoset Polymer Composite Manufacturing. Journal of Polymer & Composites. 2026; 14(2): 206–219p.

INTRODUCTION

Metals and composites must be light weight, efficient, high thermal stability, great stiffness and joining of these materials has serious issue in aerospace structures. Adhesive bond is one of the most proficient and resilient bond in the assemblage of metallic parts into composite parts [1]. The adhesive bond possess enhanced flexibility in design and saving of time in the joining of dissimilar materials because of great joint strength, decline of stress concentrations and fewer surface groundwork. The adhesive types, surface groundwork and substrate behaviours, load types and temperature conditions have great impact on the strength of joint [2]. The assemblage of primary carbon fibers in innovative polymeric composite materials led to the mass reduction upto 65% which plays a vital role in the fuel economy and the emission control in automobile applications. The traditional method of mechanical fastening is reasonable but not perfect due to more structural irregularities, high stress concentration and fiber damage which straightaway weaken the performance and efficiency of the structures [3]. Adhesive joints were generally utilized in aerospace, automotive, ship-building industries and wind-turbine production applications due to its ability of joining similar and dissimilar materials, fine stress distribution, weight economizing, enhanced fatigue and corrosion resistance [4]. The primary structural integrity disputes in micro-electronic, photonic and optical assemblies were, their consistent performance under thermal loads. The various expansion rates led to the enhancement of thermally induced stresses and strains which allowed the uneven bending, delamination and finally, the failure of joined assemblies [5]. Flexibility in Design, great stress distribution and enhanced fatigue property were the unique features of adhesive joining when compared with the other joining methods [6]. Adhesive type of bond were widely used in automotive, aerospace, maritime and railway industries due to its low manufacturing cost, even stress distribution, joining of dissimilar materials and great fatigue resistance [7]. The engineering components like rotor blades were subjected to cyclic and impact loads and so, fatigue design is mandatory in safe working and low maintenance environment [8]. Design for disassembly leads to resource preservation, reduction of waste and promotes the concept of sustainability in several industries [9]. Adhesives were significantly tougher at shear loads than the peel loads and hence, they were preferably designed mainly to resist the shear type of loads [10]. Adhesive joint method is a novel technique and substitute other joining process like, fastening, welding, riveting and soldering [11]. The failure reaction of single lap joint possess substantial effect in structural engineering, especially in aerospace technology and light-weight resources [12]. The joining of dissimilar metal substrates find wide applications in automotive, aerospace, marine and civil sectors which led to the evolution of adhesive joint with greater strength [13]. The composite materials find wide usage in engineering and non engineering applications because of the significant behaviours of adhesives and fibres [14]. The traditional joining methods were limited to least thickness of materials to evade damages but adhesives were used for any thickness, avoid drilling and welding which reduced the effect of stress concentration [15]. Metal-metal and metal–polymer bonding were vital in the structural applications and adhesive joining is generally employed for the assembly. Al6061, light weight alloy when combined with tough polymer like nylon 6, resulted in a great shear strength of 20 MPa, under optimized environment. Further, the mixture of Al6061 and nylon 6 materials led to the weight reduction without any compromise in the structural integrity. Since, the polymeric structures were subjected to dynamic loads, it is mandatory to study about the reaction of those joints. The different surface treatments including, sand blasting, mechanical and chemical techniques were implemented on Al6061 alloy and nylon 6 surfaces for active adhesion. Araldite and MC-bond were selected for the experiments to study about the strength of bond.

MATERIALS AND METHODOLOGY

Generally, the materials and methodology consists of chief materials associated with the research, experimental setup and fabrication processes. The selection of Al6061 alloy and its properties, selection of polymer and its properties, selection of adhesive and the different surface treatments provided to the specimens were discussed in this section.

Selection of Aluminium Alloy

Aluminium is one of the lightest metal which possess greater strength, corrosion resistance and flexibility. It can be combined with any other metals to form alloys and also a good conductor of electricity. The raw aluminium material can be processed into ultra-fine sheets, wires of 4 µm thickness and also ultra-thin foils can be fabricated. The properties of Al6061 alloy was displayed in Table 1.

Selection of Polymer

The characteristics, processing and uses of polymeric materials should be clearly understood by the engineers since, it find wide applications in construction materials, micro-electronics, etc. The elastic and plastic deformation of polymers were modified, regulated and additives were incorporated into polymers to refine the properties like stiffness, abrasion resistance, flammability resistance and thermal solidity. The smaller monomers were repeated and assembled together to form big organic compounds as polymers. Plastics, nylon and rubber were the best polymeric materials commonly used in varieties of engineering applications. Nylon is the generally used synthetic fiber in which its wear resistance is greater than the other fiber materials. Thousands of turns and twists can be applied in the nylon material without any breakage. Nylon 6 is the most popular polymeric material widely implemented in various fields of applications. Table 2, exposed about the properties of nylon 6 material.

Selection of Adhesive

The epoxy resin and hardener are the basic constituents in epoxy glue. The epoxy adhesives were available in one part and two part packages with respect to the type of curing method and the type of hardener used. Epoxy resin and hardener were the two part packages which are mixed together to form one element epoxy adhesive. Epoxy adhesives were commonly used in the assembly of electronics, automotive production, aero-space market and construction materials. When Araldite-klear and MC bond were mixed together, they respond faster to fabricate rigid and tough bond for composite, metal and other material surfaces that re-build and return to the service in a faster manner. The adhesive bond among high surface energy of Al6061 and low surface energy of nylon 6 was specified with curing time of 20 minutes at room temperature.

Surface Treatment of Specimens

The surface of Al6061 alloy was cleaned by ethanol in order to remove the organic wastes. The emery sheet of grit size 600 was rubbed against the Al6061 specimen to improve the surface roughness, treated mechanically. Then the specimens were chemically treated with sodium hydroxide solution for the time period of 30 to 60 minutes at room temperature to fabricate the micro-rough structure. The nylon 6 specimen surfaces were rubbed against the sand paper to enhance the initial adhesion. The plasma treatment was given to nylon 6 specimens in order to develop the surface energy and increase the shear strength.

Figure 1 specified about the display of various Al6061 and nylon 6 specimens with surface treatment through mechanical, chemical and sand blast process. According to ASTM D5868 standard, the sample dimensions were, lap length of 12.5 mm and width of 25 mm. ZwickRoell tensile testing machine is used to characterize the deformation behaviour and strength of materials, upto the failure. The universal testing machine has the maximum load of 30T capacity and the speed of 0 to 500 mm/min, applied on the samples for testing purpose.

Table 1. Properties of Al6061 alloy.

S.N.	Properties	Units
1	Young’s modulus	68.9 GPa
2	Poisons ratio	0.33
3	Tensile strength	270 Mpa
4	Ultimate tensile strength	310 Mpa
5	Shear strength	207 MPa
6	Melting point	620˚C

Table 2. Properties of Nylon 6.

S.N.	Properties	Units
1	Young’s modulus	4 GPa
2	Poisons ratio	0.43
3	Tensile strength	71 Mpa
4	Ultimate tensile strength	90 Mpa
5	Shear strength	40 MPa
6	Melting point	215˚C

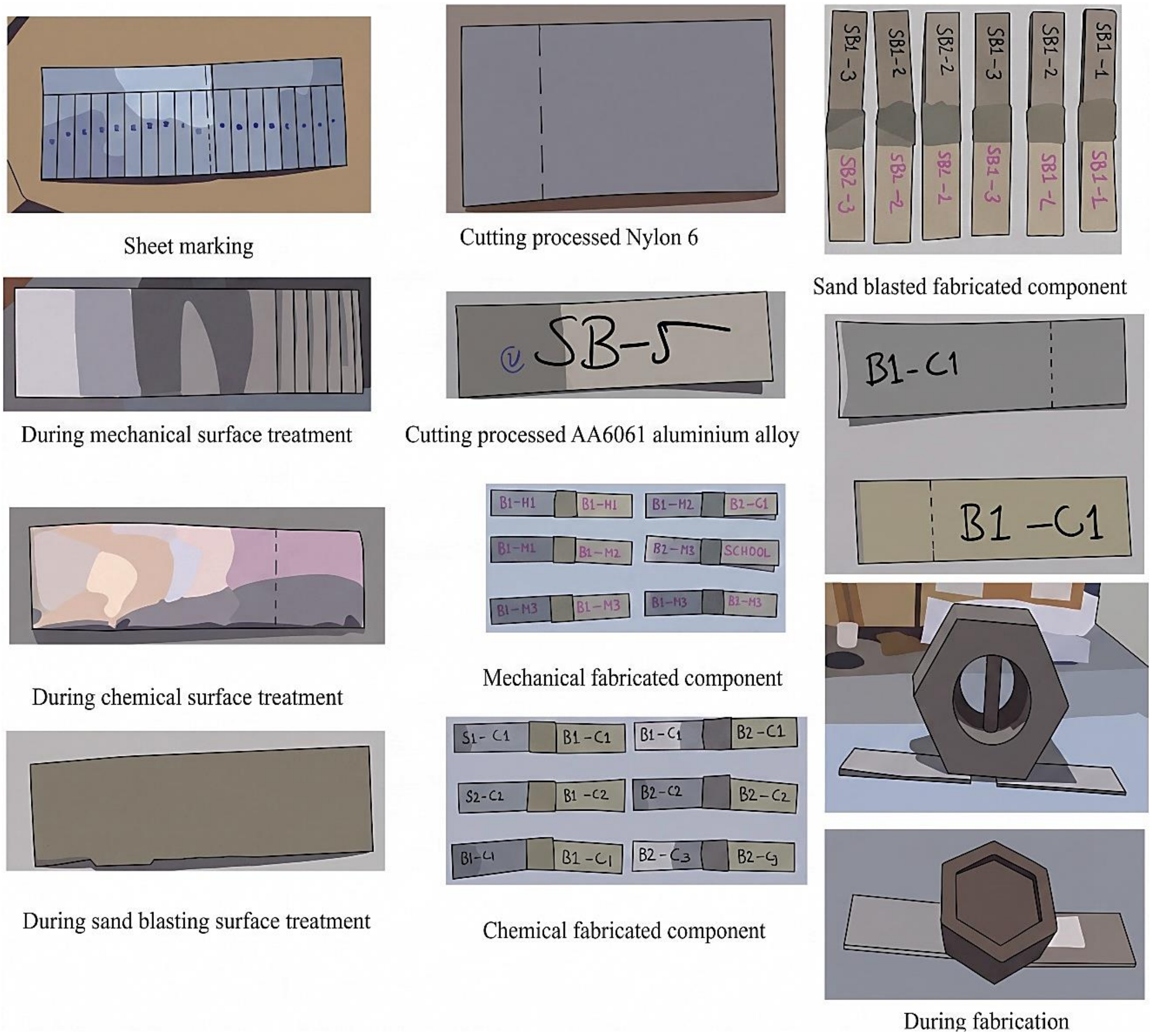

Figure 1. Display of mechanically, chemically and sand blasted surface treated specimens.

LITERATURE SURVEY

Literature surveys were normally conducted for the investigation of aim, objective, research gap and the methodology. Here, Literature survey on various classifications of surface treatment, fatigue/dynamic and type of adhesives were described in this session.

Surface Treatment Studies

The influence of surface treatment on damping and stiffness properties of metal and composite materials through adhesive joint were investigated. The chemical etching and anodizing process led to the formation of porous layer which increased the surface area thereby, enhanced the bond among the metal and adhesive. The peel ply removal, dressed the composite and the micro roughness produced by the chemical etching treatment, improved the inter-locking among the composite and adhesive surfaces. The anodizing process fabricated a porous layer over the scraped surface and enhanced the joint strength to the great heights when compared with the mechanical treatment of metal and composite materials. The stiffness property of metal-metal joints were great at the temperature of 35°C due to the tight package of adhesive polymeric chains, huge cross-link among the composites and adhesives and remarkable thermo-mechanical behaviours of the joints [1]. The characteristics of mild steel and aluminium joint, treated chemically and mechanically by UDM processed titanium oxide was analysed. The lap shear strength of aluminium and adhesive strength of mild steel, considerably depends on the adhesive bond-line thickness. The bond-line thickness of nano composite is comparatively greater than the neat adhesive, during the load of 4.2 N. The lap shear strength of mild steel and aluminium joint were improved considerably due to the chemical treatment rather than the substrates, mechanical treatment. The lap shear strength was retained through the addition of 10 wt% of TiO_2 Nano filler, even at higher temperature of 150˚C. The ductility behaviour of the lap joint was substantially declined at higher temperature, regardless of any situation [13].

Fatigue/Dynamic Studies

The joining of aluminium and CFRP materials for automotive applications were studied under impact and quasi static conditions, at low and high temperatures. The single lap joint by Al substrates were failed due to huge peel stresses produced by the plastic deformation whereas in the CFRP substrates, failure occurred at low and room temperatures and the adhesive became less resilient and more elastic, at high temperature. In the combined Al 5754-H22 + CFRP (Al 1.5 +CFRP) substrates, fatigue took place either by the delamination of CFRP or by the total failure of the Al substrate, at low temperature. SLJs through CFRP substrates, displayed greater failure load when compared with the AL substrates because of the dependence of failure on the mechanical behaviour of the substrates [2]. The fracture property of adhesive joint produced with the composite adherends, bonded through epoxy based adhesive for wind turbine application were examined. Several double cantilever beam samples with various crack length has to be characterised for the calculation of compliance magnitudes since, the crack proliferation route is unstable. The presence of T-stress confirmed through the in-situ method is the primary reason for the choice of crack kinking theory. The crack was proliferated along original path at the negative value of T-stress whereas it was projected on vertical route, during the positive value of T-stress. The mis-match in thermal expansion among the adhesive and adherends and the pre-crack cutting, confirmed about the presence of residual stresses at the tip of crack [4].

The effect of bristle and grit blasting treatments on the fracture energy and fatigue property of adhesive joints, at various loads were investigated. Except the ratio of 56.6˚, R_a and R_t values were higher for grit blasting whereas these values were 22% and 12% greater in bristle blasting which represented about larger bonding area that resulted in the advanced fracture energies. The crack was propagated towards sideway at the phase angles of 56˚, 61.7˚ and 86.9˚ in bristle blasting method which delayed the speed of propagation. The difference in initial stiffness values were due to the poor adhesion which reduced the load transfer among joined surfaces. The fracture energies were affected by the change of failure mechanism from mid of the crack to near the interface, revealed through the fracture envelop [6]. The effect of geometry of joint, type of materials, loading conditions and environmental factors on the fatigue property of attached joints were reviewed. The overlap configuration, overlap length and the thickness of adhesive has considerable effect on the enhancement of fatigue behaviour of the joint. The multiple arrangement of unidirectional layers in a stacking system with the composite adherend for attached joints, improved the strength of failure. The shift of adhesive interface layer from 0˚ to 45˚, influence the growth of crack and the type of failure. The diffusion of multi-walled carbon Nano tubes and grapheme Nano platelets, considerably develop the fatigue behaviour of attached joints when compared with Al_2O_3, SiO_2 and TiO_2 particles. The failure strength of attached joints with polymeric-composite substrates were increased by the abrasion followed by laser, plasma and grit blasting type of surface treatments. The life period of metal attached joints were enhanced through sand blasting and laser treatments [8].
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The assessment of fatigue life period of adhesive joints with respect to recovery of peel stresses were analysed by FE modeling. The type of failure was primarily cohesive and very near to the inter-face among the adhesive and adherend, observed through the characterization. The stiffness behaviour was consistent for 50% of the entire life period but the initiation of crack displayed the substantial portion of the total joint life. The peel stresses present in the solid elements were recovered by the addition of shell elements, along the visible faces. The bespoke failure factors were derived and the proposed methodology was validated through the total set of test outcomes [10]. The influence of CFRP stiffness on the fatigue strength, static behaviours of A2017 alloy and CFRP adhesive single lap joint were examined. The deformation under tensile load become solid due to the rise in bending stiffness among adherends which influenced the distribution of stress on the edge of A2017 aluminium alloy. Even though, the inter-laminar peeling of CFRP happened in CF2/8 with bottommost stiffness, the A2017-adhesive inter-facial fracture was prominent. During short life period of $N_f \leq 10^5$ cycles, the fatigue property was not influenced by the type of adherend whereas it was affected in the longer life period and the fatigue behaviour was inter-facial among A2017 aluminium alloy and the adhesive. The fatigue behaviour was enhanced considerably since, it become the cohesiveness type due to the anodization of A2017 adherend [16].

The fatigue property and joint strength of AA5052-H36 single lap joint, under adhesive bond were studied. The 7% wave mobile speed decline, illustrated about the condition of saturation resulted in great defect levels which was measured in the attached joints. There was 23% development in the ultimate resistance and 45% rise in the joints energy absorption due to silane abrasion, during tensile testing. The bond resistance to damage origination were declined by 30% in the condition of cataplasma degradation. The surfaces of pristine and untreated samples were cohesive in nature where the fatigue arise from the adhesive layer. The distribution of more number of dimples in the untreated samples than the pristine samples confirmed about the influence of surface treatment on the evolution of bonding. During the instance of failure fife and bond resistance to damage origination, the pristine single lap joints were more durable and resistant under complete cure and cataplasma degradation situation [17]. The development of strength in AlSi10Mg adhesively bonded single lap joint were studied. In conventional single lap joints, the mean of the fatigue load was observed as 5268.3 N whereas it was increased to 7865.6 N in the notched single lap joints since, the stresses were reduced due to the presence of notch on the overlap area. The conventional SLJ specimens failed rapidly, after the initiation of crack but the notched specimens can able to withstand great loads due to their high fracture strength. The failure and damage of the single lap joints were expected through simulation when compared with the real experiments which can be applied for the design and assembly of the future parts. The confined displacement particulars from the tensile test were obtained through digital image correlation method by which the stiffness of machine was eliminated from the outcomes that allowed for one by one comparison, among experiment and simulation [18].

Adhesive Type Studies

The development of commercial Henkel and ethylene-diamine adhesives for the attachment of Al6061 and glass fiber reinforced polymer were studied. The static strength of 19.56 MPa of Henkel 5089+2.5% AEEA+4.0% 2,4-EMI are considerably better than the 8.04 MPa of Henkel 5089+4.0% AEEA+2.5% 2,4-EMI, cured at 100°C for 20 minutes which inferred that 2,4-EMI was much active to reduce the curing temperature of Henkel 5089 than the AEEA. The reformed adhesive decreased the curing temperature from 177°C to 100°C for 20 minutes in both Cf/PA6-Cf/PA6 and AA6061-Cf/PA6 joints due to the rapid curing response with the inclusion of 2,4-EMI and AEEA. The lap strength of entire joints of modified adhesive were slightly exaggerated for the thermal exposure at 82°, for 30 minutes [3]. The differential strains developed between poly methyl methacrylate and glass at low temperatures were investigated through digital image correlation system. The evolution of longitudinal strain value of -0.028 was observed, close to the bond-line, earlier to the launch of delamination. The different coefficient of thermal expansions led to the huge contraction of PMMA substrate when compared with glass and hence, positive strain value of 0.5 was found at the glass-silicone boundary whereas negative strain value of -0.045 was observed between PMMA-silicon border. The ultimate value of shear strain was found as 0.036, before failure. The transverse strain reached to the mean value of -0.02, at the mid-part of the assemblage. The good agreement between DIC results and FEA outcomes, designated about the high reliability of DIC technique for the checking of thermally encouraged strains, in joined assemblies [5].

The experimental and numerical analysis of aluminium type of adhesive joints with dual adhesive technology were examined. Araldite AV138, Araldite 2015 and Sikaforce type of adhesives were used for characterization. The ultimate difference was observed as 9% at 7752-AV-7752 dual adhesive joint in the mean pressure comparison, among experimental and numerical outcomes. The DAJ exposed substantial enhancements when compared with the single adhesive strength, during the estimation of strength of joint with respect to the overall length. SAJ represented high failure energy for smaller overall length but 7752-AV138-7752 DAJ, displayed 178.8% greater failure energy than SAJ for the larger overall length [7]. The variation of thermo-mechanical effects and the geometry of joint were studied on the single type of lap joint in EN AW6060 alloy substrates. The increase in over-lap area increase the same percentage of disassembly time period with 28% heat from the oven and 27% from the gun. The doubling of thickness of the substrate led to the rise in disassembly time period of 36% for the gun and 31% for the oven. Huge quantities of sample with different parameters like type of substrate material, type of substrate surface, type of joint, attached area and life cycle of the joint were characterized through the above methodology [9].

A semi- automated method, based on ultra-sonic pulse echo technique and machine learning algorithms were enhanced for the detection of inter-face defects, in the adhesive joints. The peak to peak amplitude, fall time of wave form, crest factor, maximum amplitude, frequency value at the maximum amplitude, variation coefficient and harmonic to noise ratio, features were recovered through entire sub-groups which have ultimate score for the classification of defects. The accuracy in classification is more than 90% for the train data and more than 87% for the single subset data. The maximum accuracy for the three depths viz, depth 1, depth 2 and depth 3 were found larger than 98% in the subsets. The subsets were classified accurately in greater than 96% of instances for depth 1, in larger than 62% of instances for depth 2 and in more than 91% of instances for depth 3 [11]. The great energy absorption and more strength, provided under quasi static compressive loading on the design of single lap joint were investigated. The maximum quantity of energy and the ultimate load were unaltered at larger displacement of load, carried by single lap joint. The energy absorption was developed to greater than 80% due to the rise in adherend thickness from 4 mm to 6 mm for the same overlap length which represented about the ductile characteristics of the single lap joint. The damage of adhesive layer, developed from the end towards the centre when the single lap joint was loaded at larger displacements, without any fatigue. The effect of peel stresses were reduced by the spacers at tensile loading and they are few favourable, during buckling situations [12].

The usage of AV138 brittle adhesives and Araldite-2015 ductile adhesives in aluminium and CFRP adherends and their characteristics were investigated. It was observed that the single Araldite-2015 adhesive joint exhibited great strength of bond when compared with the single AV138 adhesive joint. The strength of the dual adhesive joint was improved due to the presence of AV138 adhesive, at the bond centre with 20% bond length but the bond strength decreased with the rise in bond length. The experimental and numerical studies recommended about the implementation of dual adhesives in order to enhance the performance of structural components [14]. The optimization of strength of the adhesive joint among deck and hull of a boat, type of adhesives and geometric solutions for the enhancement of present configuration were investigated. The minimum peak stresses were observed in butt structure at shear loads, chamfer 1 structure at compressive and tensile loads and chamfer 2 structure, at bending loads. The AV138 possess maximum peak due to its stiffness and maximized the mean pressure for butt structure. The 7752 is the best choice for chamfer 1 structure and AV138 is the better solution for chamfer 2 structure. The 7752 used for chamfer 1 structure and AV138 implemented for chamfer 2 structure were the best configuration, irrespective of production time and costs due to the resistance capacity of normal and shear stresses [15].

The mechanical characteristics of the adhesive bond, among 3D printed onyx composite and CFRP were experimented. The AC adhesive demonstrated about ideal adhesion of polyamide onyx substrate, even without any surface treatment whereas it was poor at the interface of CFRP. The EP adhesive along with LPP treatment, illustrated about the robust inter-facial bond and great performance of the joint but failed, at the weaker substrate. The increase in tensile strength of the joint acts against the peeling because of mis-alignment of the substrates through the addition of mechanical inter-locks. Multilayer joints perform lesser than the single lap joints because of the structural restriction of onyx substrate that displayed early fatigue of decreased thickness in cross-sections. The various configuration of the joints of onyx substrate generally fails under stress, especially in thinner sections which can be overcome by increasing the section thickness [19]. The effect of cyclic ageing on the mechanical property of double cantilever beam between glass fibre reinforced polymer and aluminium substrates were investigated. The tensile strength of the adhesive was improved due to the desorption of moisture whereas it was reduced because of the absorption of moisture, during cyclic ageing. The influence of ageing cycles on the elastic modulus and tensile strength were reduced with the rise in cycle numbers. The cohesive traction and original stiffness were declined whereas the damage origination and critical active separation, increased with the rise in moisture. The load –displacement curves of adhesive joints were similar at un-aged situations and after 1st absorption because of the minimum diffusion of moisture content. A considerable amount of reduction in the DCB strength was observed at the 2nd and 4th moisture absorption cycles [20].

METHODOLOGY

Methodology comprises of literature survey, selection of Al6061 alloy, polymer, adhesives, optimal selection of surface treatment, model of DoE, evaluation of strength of joints and finally, drafting and documentation.

Figure. 2 displays about the flow chart of methodology which includes literature survey, selection of materials, selection of surface treatments, design of DoE, conclusions and documentation.

RESULTS AND DISCUSSIONS

Results and discussions mainly consists of the characterization of adhesive joints. The fracture strength, Orthogonal Array of DoE, ANOVA table, tensile strength, main effect plot for means and the interaction plot for means were explained in this section.

Fracture Strength of Joint

Figure 3 represents about the joint fracture of mechanical surface treated joint. The energies of fracture were varied by the failure mechanism alteration, from crack middle to the interface adjacent, exposed by the fracture envelop [6].

The adhesive strength by MC-bond revealed about significant improvements than the araldite adhesive joint during the calculation of joint strength, as per the given overall length [7]. The failure type was mainly cohesive and very close to the inter-face between the adherend and adhesive, found by experimentation [10]. The adhesive layer damage was advanced from the end towards the centre while the lap joint was loaded at greater displacements without any failure [10]. The influence of peel stresses were declined by the spacers during tensile loading and are less supported, at buckling conditions [12]. The lap shear strength of mild polymer and aluminium joint was enhanced significantly because of the mechanical surface treatment than the chemical and sand blasting treatments [13]. It was also found that the MC-bond adhesive joint revealed about huge strength of bond when compared with the araldite adhesive joint [14]. The B2-M2 part number with MC bond, treated mechanically of bonding thickness, 0.5 mm and the corresponding tensile strength of 70.77 MPa exhibited the optimal trial in DoE which was supported by the experimental calculations. The mechanical surface treatment was found to be dominant in the achievement of required surface structure when compared with the sand blasting and chemical surface treatment methods, based on the value of means.

Design of Experiment Approach

Doe technique has delivered effective outcome and declined the time duration. L18, orthogonal array is used for the calculation of required number of trials and factor levels for individual parameter. A common L18 orthogonal array comprised of experiments combination with 3 factors at 2 levels. The three factors were viz, mechanical, chemical and sand blasting surface treatments and the two levels are, araldite and MC bond.

Table 3 shows about the L18 Orthogonal Array of DOE with the part numbers, types of bond, types of surface treatment and the corresponding tensile strength. Three different types of surface treatment and two altered varieties of adhesive were designated for the characterization of tensile strength. According to Taguchi's method of DOE, three factors and two levels were considered for individual trials. Araldite and MC-bond adhesives and mechanical, chemical and sand blasting type of surface treatments were executed, according to Taguchi's L18 array. The force/displacement measurement along with the tensile force system were combined together during tensile testing of the samples. The sample was drawn at a constant speed along the direction of force and a load cell was employed to determine the force along the direction of sample. The sample subjected to tensile load was determined by the force element and the tensile strain was calculated, after the processing of strain data in the integrated circuit through dynamic system. The mechanically processed aluminium alloy and MC bonded adhesives proved to be the effective joints when compared with other combinations, observed through experimental work. The B2-M2 part number with MC bond, treated mechanically of bonding thickness, 0.5 mm and the corresponding tensile strength of 70.77 MPa exhibited the optimal trial in DoE which was supported by the experimental calculations.

Review of existing literatures

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Selection of suitable aluminium alloy, polymer, & adhesives

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Selection of suitable surface preparation methods

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To design suitable experimental plan (doe) considering adhesive thickness, curing time, surface treatment method, and other variables

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To deterimine the strength of joints and to arrive at scientific conclusions

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Document and reporting

Figure 2. Flow chart of methodology.

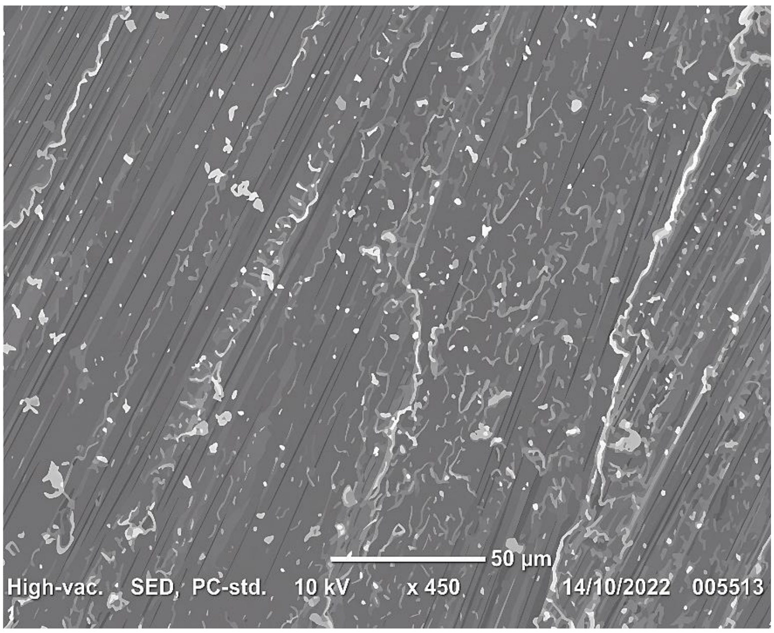

Figure 3. Joint fracture of mechanical surface treated joint.

Table 4 depicts about the anova table with tensile strength as response and the adhesives as the factors, fabricated through Minitab software. It reveals about the values of degrees of freedom as 1, adjusted sum of squares as 140.4, adjusted mean squares as 140.4, F as 0.56 and P as 0.467.

Table 5 shows about the anova table with tensile strength as response and the surface treatments as the factors, constructed by Minitab software. It exposes about the values of degrees of freedom as 2, adjusted sum of squares as 2239, adjusted mean squares as 1119.3, F as 8.63 and P as 0.003.

Figure.4 indicates about the graph between part number along X- axis and tensile strength along Y-axis. L18 orthogonal array were considered according to Taguchi's method of DoE in which the adhesives, Araldite & MC-bond and the surface treatments, mechanical, chemical and sand blasting methods were altered. The part number B2-M2 experienced better tensile strength which was joined through MC-bond and subjected to mechanical surface treatment when compared with the other part numbers.

Table 3. L18 Orthogonal array of DOE.

Experiment No.	Part number	Bond	Surface Treatment	Tensile Strength(MPa)
1	B1-M1	Araldite	Mechanical	66.49
2	B1-M2	Araldite	Mechanical	24.47
3	B1-M3	Araldite	Mechanical	49.76
4	B2-M1	Mc bond	Mechanical	50.27
5	B2-M2	Mc bond	Mechanical	70.77
6	B2-M3	Mc bond	Mechanical	58.94
7	B1-C1	Araldite	Chemical	21.92
8	B1-C2	Araldite	Chemical	40.38
9	B1-C3	Araldite	Chemical	22.03
10	B2-C1	Mc bond	Chemical	34.16
11	B2-C2	Mc bond	Chemical	26.31
12	B2-C3	Mc bond	Chemical	33.55
13	B1-SB1	Araldite	Sand blasting	35.08
14	B1-SB2	Araldite	Sand blasting	18.76
15	B1-SB3	Araldite	Sand blasting	35.08
16	B2-SB1	Mc bond	Sand blasting	29.88
17	B2-SB2	Mc bond	Sand blasting	38.04
18	B2-SB3	Mc bond	Sand blasting	22.33

Table 4. Analysis of variance.

	DF	Adj SS	Adj MS	F-Value	P-Value
BOND	1	140.4	140.4	0.56	0.467
Error	16	4042.8	252.7		
Total	17	4183.3			

Table 5. Analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Surface treatment	2	2239	1119.3	8.63	0.003
Error	15	1945	129.6		
Total	17	4183			

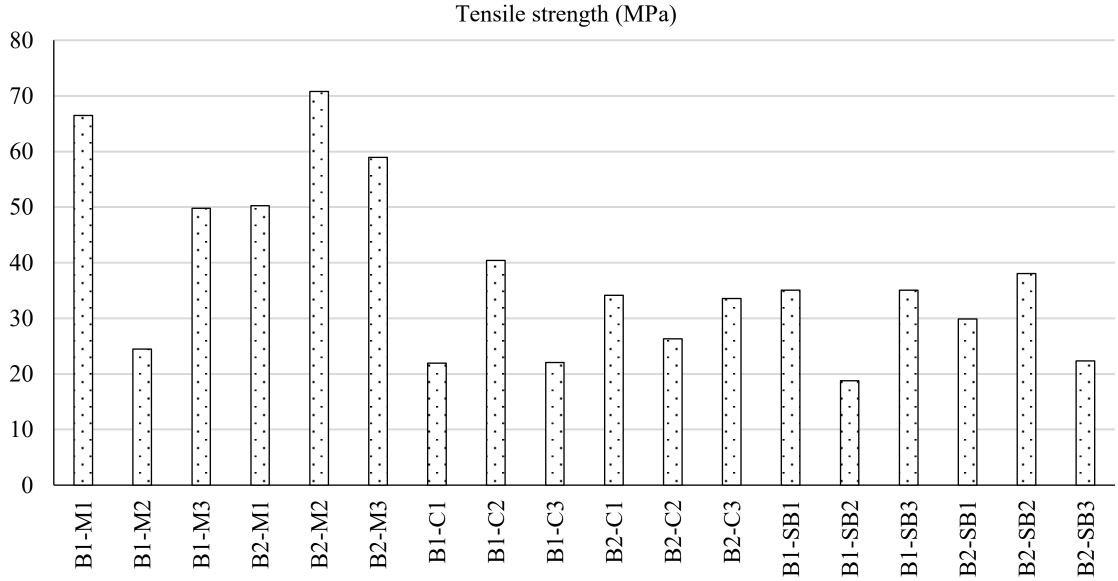

Figure 4. Part number Vs tensile strength.

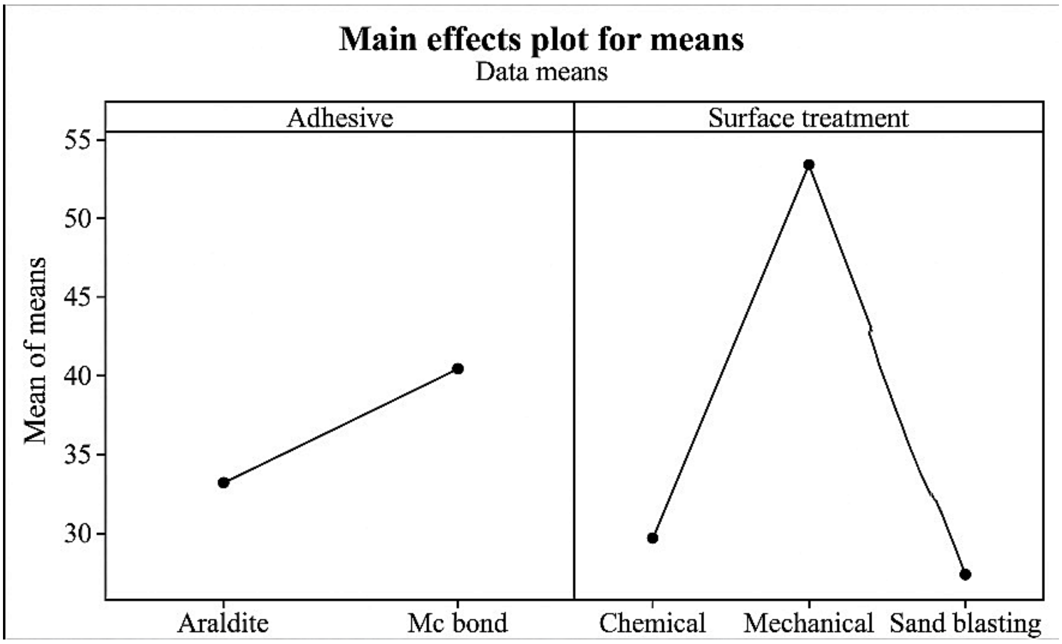

Figure 5. Main effect plot for means.

Main Effect Plot for Means

In this study, two various type of adhesives, Araldite and MC-bond and three different type of surface treatments, mechanical, chemical and sand blasting techniques were applied. The adhesives were considered to be the two factors, the surface treatments as three levels, according to the Taguchi's L18 combination of DOE. Figure 5 illustrates about the main effect plot for means. The main effects plot for means were modeled by mini-tab software. "Larger is better", was contemplated for both adhesives and surface treatments with respect to Taguchi's method. The MC-bond reveals better means value of 42 which is higher when compared with the Araldite means value of 38. Similarly, the mechanical surface treatment exhibited more means value of 54 that is greater than the chemical surface treatment means value of 30 and sand blasting means value of 26. It was shortly summarized that the main effect plot for means exposed that the MC-bond is better than the Araldite and mechanical surface treatment is superior to the chemical and sand blasting techniques.

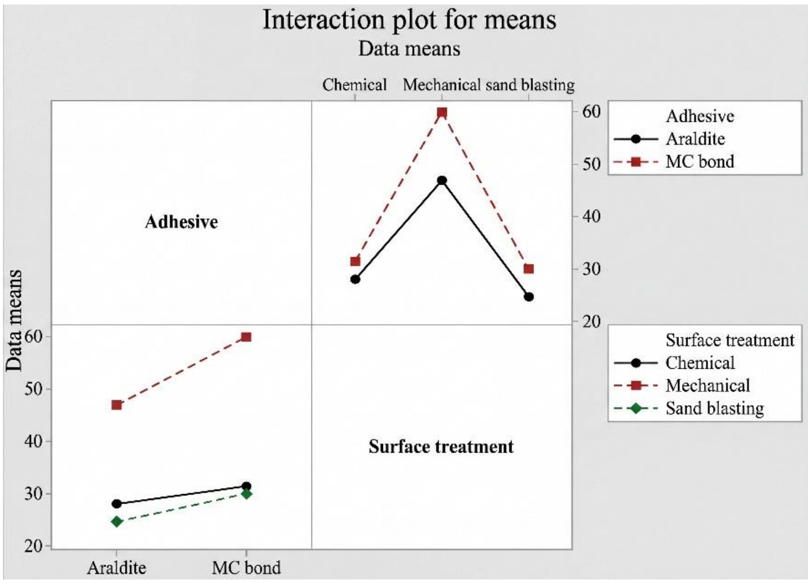

Figure 6. Interaction plot for means.

Interaction Plots

Figure 6 demonstrates about the interaction plot for means of adhesives and surface treatments of aluminium alloy with polymer joint. Araldite and MC-bond as adhesives and mechanical, chemical and sand blasting surface treatments were taken for consideration. The interaction plot for means were designed through mini-tab software. "Larger is better", was considered for both adhesives and surface treatments, as per Taguchi's technique. Since, the MC-bond possess the means value of 60 which is higher than the araldite value of 48, MC-bond was considered to be the best adhesive for aluminium alloy with polymer joint. Similarly, the mechanical surface treatment has higher means value of 60 when compared with the chemical and sand blasting surface treatment means value of 30 and 29, respectively. Hence, the mechanical surface treatment was considered to be the best method in the achievement of appropriate surface texture than the other surface treatments.

CONCLUSIONS

The characterization of adhesive joint between AA6061 alloy and nylon 6 were investigated. The two factors, araldite and MC-bond and the three levels, mechanical, chemical and sand blasting surface treatments were considered in L18 orthogonal array, according to Taguchi's technique. The Taguchi's design of experiments were executed which supported the optimal choice of various sample combinations. The B2-M2 component number with MC bond, treated mechanically of bonding thickness, 0.5 mm and the corresponding tensile strength of 70.77 Mpa displayed the best trial in DoE. The MC-bond adhesive was found to be the ideal joint which was 60% higher than the other combinations, being trialed. The mechanical surface treatment was observed to be dominant in the attainment of needed surface structure that was 60% greater than the sand blasting method of 25% and chemical surface treatment method of 30%. It was feasible to summarize that the AA6061-Nylon 6 adhesive joints can be efficiently implemented for the fabrication of aerospace and automotive structures with enhanced performance and better absorption of energies, under dynamic loading. The study on different metallic materials and polymer composites, cross sectional assessment of joint, surface finish and corrosion analysis of adhesive joints could be the future scope of this research. Thus, the work demonstrates about the significance of understanding the characterization of dissimilar joint and the optimization of the process by DoE which are very essential in the research zone.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Abbreviations

DOE: Design of Experiment, CFRP: Carbon Fiber Reinforced Plastic, SLJ: Single Lap Joint, AEEA: Hydroxyl Ethyl Ethylene Diamine, EMI: Ethyl Methyl Imidazole, PMMA: Poly Methyl Methacrylate, DIC: Digital Image Correlation, FEA: Finite Element Analysis, DAJ: Dual Adhesive Joint and UDM: Ultrasonic Dual Mixing.

REFERENCES

1. Nasreen, A., Bangash, M. K., Shaker, K., & Nawab, Y. (2023). Effect of Surface Treatment on Stiffness and Damping Behavior of Metal-Metal and Composite-Metal Adhesive Joints. Polymers 2023, 15, 435.
2. Machado, J. J. M., Nunes, P. D. P., Marques, E. A. S., & da Silva, L. F. (2019). Adhesive joints using aluminium and CFRP substrates tested at low and high temperatures under quasi-static and impact conditions for the automotive industry. Composites Part B: Engineering, 158, 102–116.
3. Wang, S. N., Li, Y., Guo, Y. M., Cai, B., Zhang, G. P., Liu, Z. X., & Wang, P. C. (2019). Development of a two-component structural adhesive for bonding of metals and polymeric composites. International Journal of Adhesion and Adhesives, 90, 38–46.
4. Kojouri, A. S., Karami, J., Kalteremidou, K. A., Fan, J., Sharma, A., Vassilopoulos, A. P., ... & Van Hemelrijck, D. (2024). An experimental and analytical study of mode I fracture and crack kinking in thick adhesive joints. Composites Part B: Engineering, 284, 111695.
5. Bagiatis, V., Critchlow, G. W., Price, D., Wang, S., Harvey, C. M., & Yuan, B. (2021). Thermally induced strain in joints with dissimilar adherends bonded with a flexible adhesive. International Journal of Adhesion and Adhesives, 107, 102853.
6. Neto, R. C., Vogas, E. F., Akhavan-Safar, A., Carbas, R. J. C., Sampaio, E. M., & da Silva, L. F. M. (2024). Impact of surface preparation method on the fracture toughness of adhesive joints subjected to diverse loading modes. International Journal of Adhesion and Adhesives, 133, 103763.
7. Carvalho, D. F. T., Campilho, R. D. S. G., Ramalho, L. D. C., Moreira, R. D. F., & Madani, K. (2024). Application of the dual-adhesive technique for static improvement of single-step joints. Procedia Structural Integrity, 54, 398–405.
8. Sousa, F. C., Zamani, P., Akhavan-Safar, A., & da Silva, L. F. M. (2024). A comprehensive review of the SN fatigue behaviour of adhesive joints. Journal of Advanced Joining Processes, 9, 100178.
9. Favi, C., Moroni, F., Lutey, A. H., & Boix Rodríguez, N. (2024). Disassembly analysis of hot-melt adhesive in mechanical joints. Procedia CIRP, 122, 611–616.
10. Bagni, C., Halfpenny, A., Hill, M., & Tarasek, A. (2024). A practical methodology for the fatigue life estimation of adhesive joints. Procedia Structural Integrity, 57, 598–610.
11. Smagulova, D., Samaitis, V., & Jasiuniene, E. (2024). Machine learning based approach for automatic defect detection and classification in adhesive joints. NDT & E International, 148, 103221.
12. Kadioglu, F., & Demiral, M. (2025). Design of Adhesively-Bonded Single Lap Joints for Automotive Applications Under Compressive Loading. Results in Engineering, 104176.
13. Ghosh, P. K., Kumar, K., Preeti, P., Rajoria, M., & Misra, N. (2016). Superior dissimilar adhesive joint of mild steel and aluminium using UDM processed epoxy based TiO2 nano-filler composite adhesive. Composites Part B: Engineering, 99, 224–234.
14. Jairaja, R., & Naik, G. N. (2019). Single and dual adhesive bond strength analysis of single lap joint between dissimilar adherends. International Journal of Adhesion and Adhesives, 92, 142–153.
15. Santos, J. C., Campilho, R. D., Moreira, R. D., & Madani, K. (2024). Cohesive zone evaluation of different design solutions for adhesive joints in canoeing boats. Procedia Structural Integrity, 61, 79–88.
16. Kusukawa, K. (2024). Effects of laminate stacking sequence on the strength properties of aluminum alloy–carbon fiber-reinforced plastic dissimilar single-lap adhesive joints. Available at SSRN 4829349.
17. Nodeh, M., Maslouhi, A., & Desrochers, A. (2025). Effect of manufacturing parameters and environmental factors on the mechanical behavior of AA5052-H36 adhesively bonded overlap joints. International Journal of Adhesion and Adhesives, 138, 103940.

18. Khosravani, M. R., Frohn-Sörensen, P., Engel, B., & Reinicke, T. (2025). Improvement of strength in single-lap adhesive joints of AlSi10Mg alloys fabricated by laser powder bed fusion. European Journal of Mechanics-A/Solids, 109, 105458.
19. Pizzorni, M., Benvenuto, M., Lertora, E., & Mandolfino, C. (2025). Adhesive bonding of CFRP with a 3D-printed short-fiber composite: an experimental study on the effects of geometry and adhesive system on joint performance. Composites Part B: Engineering, 112155.
20. Moazzami, M., Akhavan-Safar, A., Ayatollahi, M. R., Poulis, J. A., da Silva, L. F. M., & De Freitas, S. T. (2023). A degradable mode I cohesive zone model developed for damage and fracture analysis of dissimilar composite/metal adhesive joints subjected to cyclic ageing conditions. Theoretical and Applied Fracture Mechanics, 127, 104076.

