Araştırma Makalesi
Adıyaman Üniversitesi
Mühendislik Bilimleri Dergisi
22 (2024) 1-17

COMPARISON OF MECHANICAL PROPERTIES OF WOVEN HYBRID METALLIC FABRICS WITH DIFFERENT ARRANGEMENT OF INTERMEDIATE ALUMINUM SHEETS

Ali İhsan KAYA[1], Kaan Emre ENGİN[2*], Şerif ÇİTİL[3]

[1,2,3] Adıyaman Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Adıyaman, 02040, Türkiye

Geliş Tarihi/Received Date: 08.11.2023 Kabul Tarihi/Accepted Date: 19.03.2024 DOI: 10.54365/adyumbd.1384174

ABSTRACT

In this study, hybrid metallic fabrics were produced by the traditional weaving method using 0.2 mm thick Aluminum (Al) 1005 H14 material and polyethylene fishing line (PL). During the production of hybrid metallic fabrics, a fishing line was used as a warp, and an Al 1005 H14 wire of the same thickness was used as a weft. The fabrics were cut into layers with dimensions of 30 mm width and 300 mm length. Each layer was bonded using FM® 73M structural adhesive. Laminates of hybrid composites with different arrangements of layers were fabricated with an Al 5005 H34 spacer sheet. The resulting laminates were cured by applying additional pressure in a temperature-controlled hydraulic press, after which the specimens were cut for tensile testing with a saw according to ASTM D3039 standard. The effect of Al 5005 H34 intermediate material on weight was determined. Tensile testing of three samples from each laminate group was performed and the results were analyzed. It has been observed that the mechanical properties of fabrics containing Al 1005 H14 and PL have improved, and it has been understood that it is possible to achieve good strength properties while reducing the weight of the material.

Keywords: *Hybrid metallic fabric, FM® 73M Structural Adhesive, Aluminum, Polyethylene fishing line,* Weaving

ARA ALÜMİNYUM LEVHALAR İÇEREN FARKLI DİZİLİME SAHİP DOKUMA HİBRİT METALİK KUMAŞLARDA MEKANİK ÖZELLİKLERİN KARŞILAŞTIRMASI

ÖZET

Bu çalışmada, 0.2 mm kalınlığında Alüminyum (Al) 1005 H14 malzeme ve polietilen misina (PL) kullanılarak geleneksel dokuma yöntemi ile hibrit metalik kumaşlar üretilmiştir. Hibrit metalik kumaşların üretimi sırasında çözgü olarak misina, atkı olarak ise aynı kalınlıkta Al 1005 H14 teli kullanılmıştır. Üretilen kumaşlar 30 mm genişlik ve 300 mm uzunluk boyutlarına sahip katmanlar halinde kesilmiştir. Her katman FM® 73M yapısal yapıştırıcı kullanılarak yapıştırılmıştır. Al 5005 H34 ara levha parçası ile katmanların farklı dizilimlerde olduğu hibrit kompozit laminatların imalatı yapılmıştır. Elde edilen laminatlar, ısı kontrollü bir hidrolik preste ek basınç uygulanarak kürlenmiş, sonrasında numuneler ASTM D3039 standardına göre çekme testi için kesilmiştir. Al 5005 H34 ara malzemesinin ağırlık üzerindeki etkisi belirlenmiştir. Her bir laminat grubundan üçer numunenin çekme testi gerçekleştirilmiş ve sonuçlar analiz edilmiştir. Al 1005 H14 ve PL içeren kumaşların mekanik özellikleinin iyileştiği görülmüş ve bir yandan malzemenin ağırlığını azaltırken, aynı zamanda iyi mukavemet özelliklerine ulaşmanın mümkün olduğu anlaşılmıştır.

Anahtar Kelimeler: *Hibrit metalik kumaş, FM® 73M Yapısal Yapıştırıcı, Alüminyum, Polietilen misina, Dokuma*

e-posta[1] : alikaya@adiyaman.edu.tr ORCID ID: https://orcid.org/ 0000-0002-3040-5389
* e-posta[2] : kengin@adiyaman.edu.tr ORCID ID: https://orcid.org/ 0000-0002-6439-7700 (Sorumlu Yazar)
e-posta[3] : scitil@adiyaman.edu.tr ORCID ID: https://orcid.org/ 0000-0002-3714-3772

1. Introduction

Because adhesive joints combine many types of materials and have good damping characteristics, high corrosion and fatigue resistance, fracture retardation, and labor, time, and cost savings, they are widely utilized in load-bearing structures across a wide range of industries. In addition to these better qualities, adhesive joints are the subject of several research that are being conducted in the literature [1, 2] because of their lightweight and simplicity of application. Therefore quick solution suggestions for joining materials using adhesive joints have been suggested and continue to be put forward.

Single and double acting joint types are the most often utilized connection kinds in adhesive connections. A study [3] used bonding models in single and double reinforced lap joints. The failure loads and mechanisms for three different types of joints—adhesive bonding, bolt fastening, and adhesive-bolt hybrid joining—were examined by Kweon et al. [4]. They used FM73 film-type adhesive and EA9394S type adhesive to bond aluminum and composite materials and compared the durability of the joint types. Kairouz and Matthews [5] examined single-lap bonded joints of cross-ply adherends and stated that joints' failure mode and strength were directly influenced by the surface layer orientation. da Silva et al [6], used the Taguchi method to study the effect of the adherend and the adhesive, adhesive thicknesses, the durability, the overlap and the surface treatment on the lap shear strength. Çitil et al. surveyed [7] the mechanical properties under tension of double strap joints of aluminum alloy AA 2024-T3 with gap and with filled intermediate section and found no influence of intermediate element on double-strap bonding joints. In another study [8], they discovered that lap joints with better surface geometry could withstand higher loads. They then looked at the new joint kinds of AA 2024-T3 aluminum alloy with distinct surface geometries. The impact of surface preparation on the strength and performance of single-lap aluminum-copper alloy joints for automotive applications was investigated by Boutar et al. [9]. They noticed that the single lap joint's shear strength was inversely proportional to the roughness of the surface, and less wetable conditions were occurred with the rougher the surface. Naat et al. [10] reviewed the quasi-static strength and fatigue behavior of adhesively bonded joints having different surface texture. Layec et al. [11] studied the effect of bifunctional water-soluble polymers on the adhesive bond of aluminum during transportation when bifunctional water-soluble polymers were located between the adhesive and aluminum substrate. Reneckis et al. [12] studied on the aluminum-glass fiber and aluminum-aluminum reinforced polymers' bond strength under the oil and water contamination conditions. They concluded that mineral oil contamination was more dangerous than water contamination. Single lap joints of hybrid aluminum and carbon–epoxy adhesively-bonded components were studied by Ribeiro et al. [13] Another effect of hybridization of single lap joints of fiber/metal reinforced adhesively bonded composites' bonding strength was surveyed by Thomas et al. [14]. Experimental and numerical strength of carbon fibre, aluminum and high strength steel reinforced plastics multi-material adhesive joints were investigated by Banea et al. [15]. Santos et al. [16] studied on the AF 163-2K, titanium alloy and carbon fiber reinforced polymers (CFRP) hybrid structures for peel strength improving. Hu et al. [17] investigated the etching of A6060 T5 substrates with NaOH concentration influence on bonding of hybrid aluminum and CFRP. Carbon/epoxy and AA2024-T3 aluminum alloy single lap hybrid structures with four different sequence were studied by Gültekin et al. [18]. Gültekin and Yazici [19] studied on the aluminum alloy (AA2024-T3) bonded joints improved with functionalized boron carbide and boron nitride nanoparticles. Pramanik et al. [20] reviewed the joining of aluminium alloys and CFRP. Another review study was carried out by Marannano and Zuccarello [21] on aluminum and CFRP laminates hybrid joints. Aluminum alloy (AA2024-T3) sheets in the case of curved lap joints were studied by Çitil [22]. Under four-point bending loads, Al-GFRP single lap joints' fatigue life and crack initiation were studied [23]. The effects of material types and adherent thickness on the fracture behavior of hybrid Al, Steel and CFRP single-lap bonding joints were examined [24]. Similar and dissimilar lap joints of GFRP and AA8011 Aluminum were studied to observe shear strength change [25]. Different nanoparticles reinforcing effect on the shear strength of dissimilar adherents of Al-GFRP single lap joints were examined [26]. Effect of adhesives having different stiffness with CFRP/2024-T3 aluminum hybrid joints' performance was investigated [27].

As can be seen from the literature, it is understood that many researchers have only investigated different parameters of metallic or metal-composite hybrid joints. However, there is a lack of studies on woven metallic hybrid joints in the literature. Therefore, hybrid metallic fabrics were fabricated using Al 1005 H14 and polyethylene fishing lines. Al 1005 H14 material wire of 0.2 mm thickness was used as weft and polyethylene fishing line (PL) of the same thickness was used as warp and woven by means of traditional rug weaving equipment. In the same way, woven fabrics consisting of only polyethylene fishing line with the same thickness in both warp and weft directions were produced. FM® 73M structural adhesive film was used as structural adhesive material, and both the warp and the weft directions of the hybrid metallic laminates' mechanical characteristics were determined. This study's objective is to fill the gap in the literature and to produce hybrid composites that can provide higher strength compared to their weight, to produce lighter materials that can keep unmanned aerial vehicles in the air for longer periods of time, and to examine the effects of the increased adhesion surface on the adhesion strength due to the use of small diameter aluminum wires instead of materials used as a whole sheet in traditional applications.

2. Materials and Method

2.1. Hybrid Fabrics Weaving

To produce the metallic hybrid fabrics, Al 1050 wires having 0.2 mm thickness were obtained from a local shop. Material property data of Al 1050 H14 used in weaving fabrics and Al 5005 H34 used at the outer surface and as an intermediate among laminates were given in Table 1. The weft was made of provided metal wires, while warp was made of polyethylene fishing line. The polyethylene fishing line used as a warp was obtained from the local fishery store. The fishing line, known as "effe sumo x8," is composed of eight braided structures of same material, however with a reduced thickness. The technical specifications of this microfiber fishing line were given in Table 2. Fishing line and aluminum wires of the same thickness were employed in the manufacturing process to create hybrid metallic fabrics. The use of fishing line as a warp in this research was motivated by the need to mitigate ruptures that occurred during trials. These ruptures were attributed to friction that arose during the compressing process of the aluminum wefts. By opting for fishing lines as the warp material, the researchers aimed to avoid such ruptures from occurring.

The aluminum wires were incorporated into the system following this foundation line, as illustrated in Figure 1, and the fishing line threads were attached to the conventional weaving apparatus as warp. A layer of traditional cotton thread was weaved to produce a basis line for the aluminum wires to be linked as weft. The warp density of the fishing line threads was obtained by calculating a knot density of 55 per 1 cm^2 for all fabrics. The reason for choosing this density was the preliminary weaving trials. After obtaining warp density data from trials, hybrid fabrics were produced solely by manual labor, shown in Figure 1(a) and Figure 1(b), respectively. The final state of the fabrics after the weaving process could be seen in Figure 2. The same thickness of all polyethylene fishing line (both as warp and weft) fabrics was also produced with the same procedure as in Figure 1.

Table 1. Mechanical properties of Al 5005 H34 sheets and Al 1050 H14 wire of 0.2 mm thickness

Material	Tensile Strength, Ultimate (MPa)	Tensile Strength, Yield (MPa)	Tensile Modulus (GPa)	Elongation at Break (%)
Al 1050 H14	110	103	69	10
Al 5005 H34	159	138	68.9	8

Table 2. Typical Properties of fishing line of Effe Sumo X8

Material	: Polyethylene
Durability of 0.2 mm Thickness to load (kg)	: 18.14

(a) (b)

Figure 1. (a) Production of fabrics with traditional weaving equipment, (b)production process of hybrid metallic fabrics of 0.2 mm thickness

Figure 2. Traditional weaving equipment and weaved hybrid metallic fabrics

2.2. Preparation of Specimens with Adhesive

Because of their increased notch sensitivity and low shear stress, structural adhesives are frequently used to join composite materials. [28]. In this study, FM® 73M, belonging to CYTEC company, was used as structural film adhesive in the laminate structures created with hybrid metallic fabrics and intermediate Al 5005 H34 sheets. It is a general-purpose structural adhesive film, toughened aerospace epoxy, as highlighted in the datasheet. Between -55°C and 82°C, it is meant to perform excellent structural performance. Bonding of many structural systems, such as metals and composites are made with FM® 73M to ensure good durability thanks to its suitability for this kind of bonding [29]. Table 3 contains the properties of FM® 73M adhesive material.

Table 3. FM® 73M film adhesive's properties [29]

Nominal Weight, (g/m^2)	Nominal Thickness, (mm)	Color	Tensile shear at 24ºC for metal to metal (MPa)	Floating roller peel at 24ºC metal to metal (kN/m)	Blister detection at 24ºC for metal to metal (MPa)	Climbing drum metal-to-metal peel at 24ºC (Nm/m)
210	0.18	Yellow	41.9*	11.74*	33.56*	323.34*

* Calculated by interpolation as per data sheet

Initially, after the production of fabrics, layers were prepared by cutting the produced hybrid metallic fabric with a width of 300 mm and a length of 300 mm (Figure 3a). Secondly, fabric samples and FM® 73M of 30 mm width and 300 mm length were prepared from these layers not only in the parallel direction of the weft axis (referred to as the x-axis hereinafter), but also in warp direction (referred to as the y-axis hereinafter) as seen in Figure 3b and Figure 3c respectively for preparing laminates. Since the produced hybrid fabric material was anisotropic, both warp and weft axes were taken into account with sequencing Al 5005 H34 intermediate sheet. The same cutting procedure was followed for all polyethylene-weaved fabrics and FM® 73M, as in Figure 3. Since weaved polyethylene fabric was isotropic, it was cut into specimens regardless of weaving direction.

(a) (b) (c)

Figure 3. (a) Hybrid metallic fabrics cut in 300x300 mm size, (b) 30x300 mm hybrid metallic fabrics cut in weft direction (c) warp direction

Cavezza et al. [30] and Kuczmaszewski's [31] review studies emphasized the significance of metal adherent preparation surfaces, which significantly impacted the substrate's top layer chemistry, for the system's endurance. It was stated in another study by Davis and Brown [32] that, unlike composites, surface preparation of metals was a vital part of having a dependable adhesive bond. Cleaning the metal surfaces is necessary to ensure that the adhesive and adhering substance form a strong chemical bond, as stated by Pethrick [33]. Therefore, the surface that the adhesive comes into touch with must be free of materials like paint, oil, or dust in order to ensure effective adhesion between the adhesive and the surface of the layers. For this reason, the surfaces of the samples that needed to be bonded before bonding were cleaned and degreased. After the surface preparation process, a layered structure of different sequencing laminates was obtained by placing FM® 73M structural film adhesive between each metallic fabric and aluminum sheet, as in Figure 4. Green elements in Figure 4 were research parameters, the fabrics of hybrid materials and all polyethylene fishing lines.

As could be seen from Table 4, three sequencing of laminates with the outermost and middle Al 5005 H34 sheets of 0.5 mm thickness and the structural adhesive of 0.018 mm thickness between these sheets and produced fabrics were considered.

Figure 4. Al sheets, hybrid fabrics and adhesives sequences

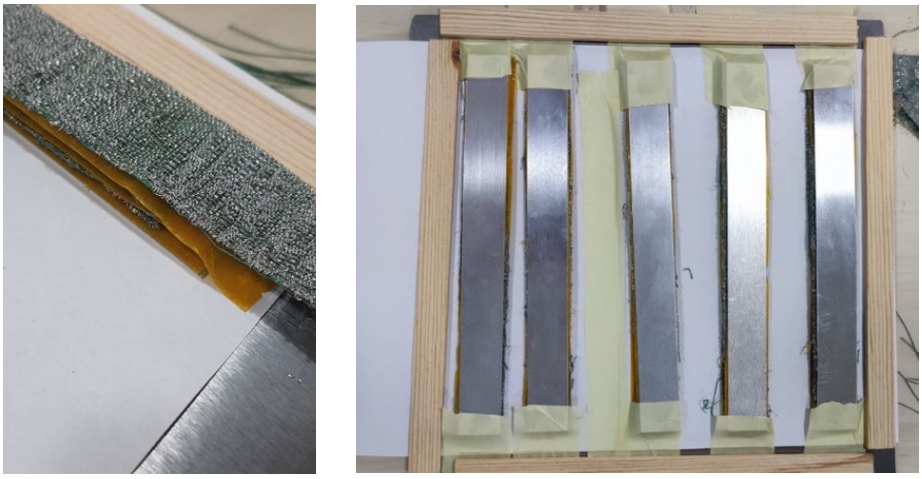
Table 4. Sequencing of laminates

Number	Sequencing	Direction regard to weaving
Type I	ALS/SA/HF/SA/ALS/SA/HF/SA/ALS	X
Type I	ALS/SA/HF/SA/ALS/SA/HF/SA/ALS	Y
Type I	ALS/SA/PFL/SA/ALS/SA/PFL/SA/ALS	-
Type II*	ALS/SA/HF/SA/HF/SA/HF/SA/ALS	X
Type II*	ALS/SA/HF/SA/HF/SA/HF/SA/ALS	Y
Type II*	ALS/SA/PFL/SA/PFL/SA/PFL/SA/ALS	-

*ALS: Aluminum Sheet, SA: Structural Adhesive, HF: Hybrid Fabric, PFL: Polyethylene Fishing Line
**studied in another paper by same authors

The layered structure of a prepared specimen is illustrated in Figure 5a. The specimen thickness was determined by the woven hybrid metallic and polyethylene fabrics, as the thicknesses of the intermediate sheet, outermost sheets, and adhesives were constant. Consequently, to achieve the anticipated laminate thicknesses between the mold and specimens, wooden laths were fabricated in accordance with the total thickness after measuring the thickness of each fabric from three distinct positions using a micrometer. Wooden slats that mirrored the overall thickness of the specimens were positioned around them to prevent the samples from being squeezed within a temperature-controlled hydraulic press as illustrated in Figure 5b.

The specimen, which was prepared and ready for pressing, underwent a curing process for a duration of two hours. This process took place at a temperature of 120 ºC, which aligns with the recommended curing temperature specified in the datasheet for the structural adhesive. The curing process was conducted under a pressure of 0.1 MPa inside a temperature-controlled hydraulic press, as seen in Figure 6a. In Figure 6b, it can be shown that several sequencing specimens, consisting of intermediate Al 5005 H34 sheet, were positioned between a specifically constructed die set. These specimens were subjected to a consistent weight throughout the curing process. It is important to acknowledge that die sets have also undergone degreasing and dust purification prior to their application. The formation of laminates with varying sequencing occurred subsequent to the hydraulic press being maintained at ambient temperature for a duration of 24 hours.



(a) (b)

Figure 5. (a) Laminate layers that prepared and (b) samples that ready-to-cure

(a) (b)

Figure 6. (a) The temperature-controlled hydraulic press and (b) specimen under the weight in the curing chamber

The pressed samples were initially produced with 30 mm width and 300 mm length in terms of dimensions. Then, the samples aforementioned were cut with a sawing machine from 30 mm width and 300 mm length to 25 mm width and 250 mm length dimensions according to ASTM D3039 standard. After the curing and cutting process, it was observed that the lengths, widths and thicknesses of the samples were varied between 250 mm ± 2 mm, 25 mm ± 0.2 mm and 5.25 mm ± 0.25 mm, respectively. Tensile sample weights were ascertained with a weighing apparatus with an accuracy of 10^{-4} grams.

2.3. Tensile Testing

Tensile test specimens were acquired by cutting bonded materials with varying sequential structures, following the ASTM D3039 standard, using sawing equipment. The resulting specimens were prepared in accordance with the prescribed standard for further tensile testing. Tensile tests were conducted on three samples for each sequenced structure. The UTEST brand universal tensile testing machine with 20 kN load capacity was used to perform tensile tests on various hybrid metallic aluminum and polyethylene fishing line fabrics with an intermediate aluminum sheet bonded structure. The experiments were conducted in an ambient laboratory setting with a crosshead speed of 2 mm/min. The specimen subjected to tensile test with UTEST brand universal tensile testing equipment was shown in Figure 7. The tensile studies were carried out using three replicates from each group. The failure surfaces of the samples were analyzed subsequent to performing the tensile tests.

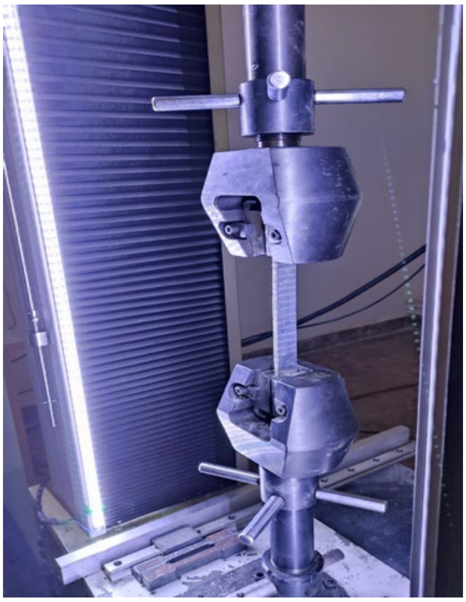


Figure 7. Specimen subjected to tensile testing

3. Results and Discussion

One of the most important features of adhesive joints is that they can join different types of materials. Adhesives are used not only for joining the parts but also for repair purposes. The type of glue, the components being joined, the surface to which it is applied, the overlap length, thickness, temperature, and joint pattern all affect the construction of a long-lasting adhesive junction. In bonding joints, choosing a suitable adhesive depending on the material is extremely important for the strength of the connection. When two distinct types of materials are joined, the impact of the adhesive bond on the strength of the components will differ significantly. The mechanical characteristics of the materials and the part hardness determine the adhesion mechanism. [2, 34-35].

Using weighing apparatus with an accuracy of 10^{-4} gr, the weights of the tensile samples were ascertained for this investigation. With same weighing apparatus, each specimen was weighed three times, with the average values being taken into account. The weight results of different sequenced specimens not only with intermediate but also without the intermediate aluminum sheet, which was studied in another paper by same authors [36], was given in Table 5. Density of each specimen group was calculated by taking average thickness of 5.25 mm for each group and results were obtained in kg/m^3. As in Table 5, The Type-II laminates were found to have a lighter structure and a density that was roughly 10-15% lower than that of Type-I laminates within each particular sequencing group.

Table 5. Specimens' average weights (gr)

	X-Direction	Y-Direction	Fishing Line
Type-I, Average weights	38.71462	36.3998	38.80133
Type-I, Density (kg/m^3)	1.179,87	1109.37	1182.52
Type-II, Average weights*	33.83413	31.06943	34.97352
Type-II, Density (kg/m^3)	1031.13	946.88	1065.86

*Studied in another paper of same authors [36]

When the weight data of laminates in Table 5 were examined, among the intermediate metal-containing laminates, it was observed that the specimen with the polyethylene fishing line had the maximum weight and that its weight value was extremely near to the weight of the x-direction specimen. Further, it was obtained that the lightest sample among the intermediate metal-containing laminates occurred in the samples of the y-direction. These results were compatible with results of another study of authors that sequenced laminate without intermediate Al material [36]. When the laminates of fabrics that do not contain any intermediate metals were compared with those that intermediate metal-containing laminates, it could be observed that they have a light structure of approximately 4.5 g to 5 g in each specific sequencing groups.

Laminates of different sequenced materials were subjected to tensile test in a Universal UTEST test equipment and the results of Type-I in x-axis direction were given in Figure 8. The test results of specimen in x-direction were in agreement each other. It was obtained that the ultimate tensile strength varies between 50 MPa and 60 MPa and the corresponding strain values vary between approximately 0.06 and 0.075. The stress-strain values of the laminates of Type-I in the x-direction were found to be compatible with one another when the stress-strain distributions of Type-I composite materials were examined. Figure 8 illustrates that the samples had an approximate yield strength (σ_x) of 13.25 MPa and a corresponding strain value (ε_x) of 0.0035%. The samples' average ultimate strength (σ_x) was discovered to be 54.83 MPa, while the corresponding average strain (ε_x) was found to be 0.057%. As a result, the aluminum wire/polyethylene line reinforced composite material's average modulus of elasticity (E_x) for the x-direction laminates was roughly 3780 MPa..

When Figure 8 was reviewed, it was discovered that the stress-strain values of the Type-I laminates in the y-direction and the x-direction were compatible with one another. The graph indicates that the samples had an average yield strength of 14.71 MPa and a corresponding strain value of 0.0039%. The samples' average ultimate strength value (σ_y) was determined to be 50.7 MPa, and the average strain value (ε_y) that correlated with it was discovered to be 0.045%. As a result, the y-direction laminates of aluminum wire/polyethylene line reinforced composite material had an average modulus of elasticity (E_y) of roughly 3770 MPa. The conclusion was that the Type-I modulus of elasticity was found to be equal in both the x and y directions. Tensile test results of y-direction of Type-I of hybrid weaved laminates with intermediate Al 5005 H34 sheet were given in Figure 9. The tensile test results of y-direction were obtained in agreement with each other, as in Figure 8.

The ultimate tensile strength values were observed to vary between 50 MPa and 55 MPa and the corresponding strain values were between 0.045 and 0.06 approximately. Moreover, it was obtained that average ultimate strength of x-direction and y-direction laminates were close to each other whereas strain values of x-direction laminates were bigger than laminates of y-direction.

Stress-strain distributions in the y-direction of aluminum wire/polyethylene line reinforced composite materials of Type-I were given in Figure 9. The stress-strain values of the laminates of y-direction were found to be compatible with each other as was the case for x-direction of Type-I when Figure 8 was examined. The graph indicates that the samples had an average yield strength (σ_y) of 14.71 MPa and a corresponding strain value (ε_y) of 0.0039%. The samples' mean ultimate strength value (σ_y) was determined to be 50.7 MPa, while the mean strain value (ε_y) was discovered to be 0.045%. Consequently, the y-direction laminates of aluminum wire/polyethylene line reinforced composite material yielded an estimated value of 3770 MPa for the average modulus of elasticity (E_y).

The conclusion was that the Type-I modulus of elasticity was found to be equal in both the x and y directions.

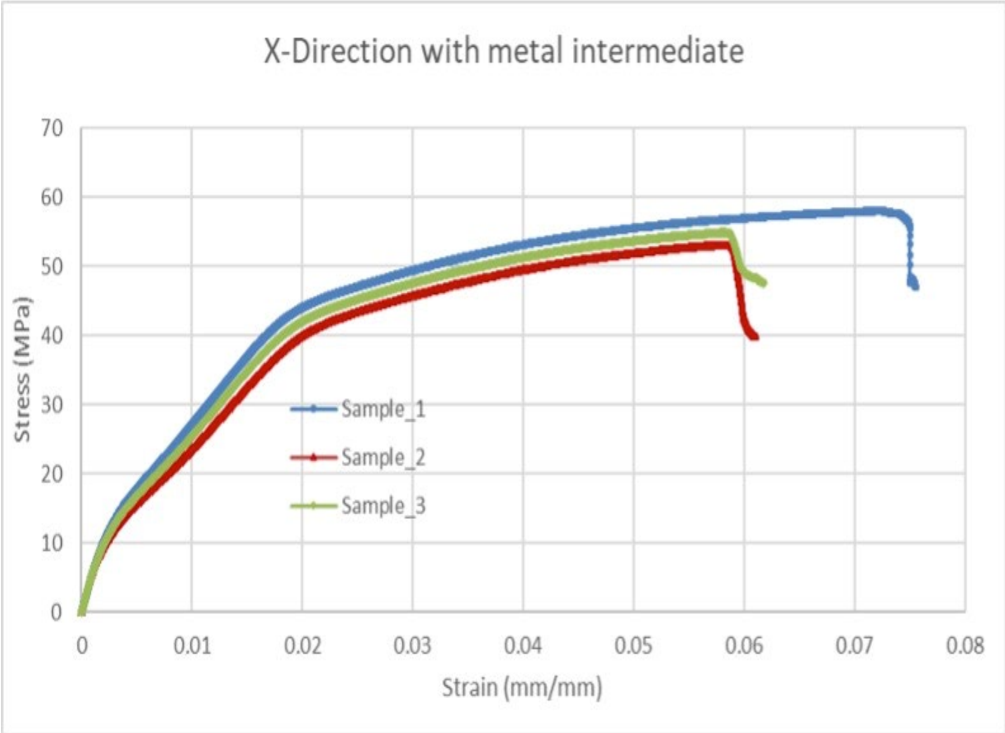


Figure 8. Tensile tests of Type-I laminates containing aluminum intermediate (X-direction)

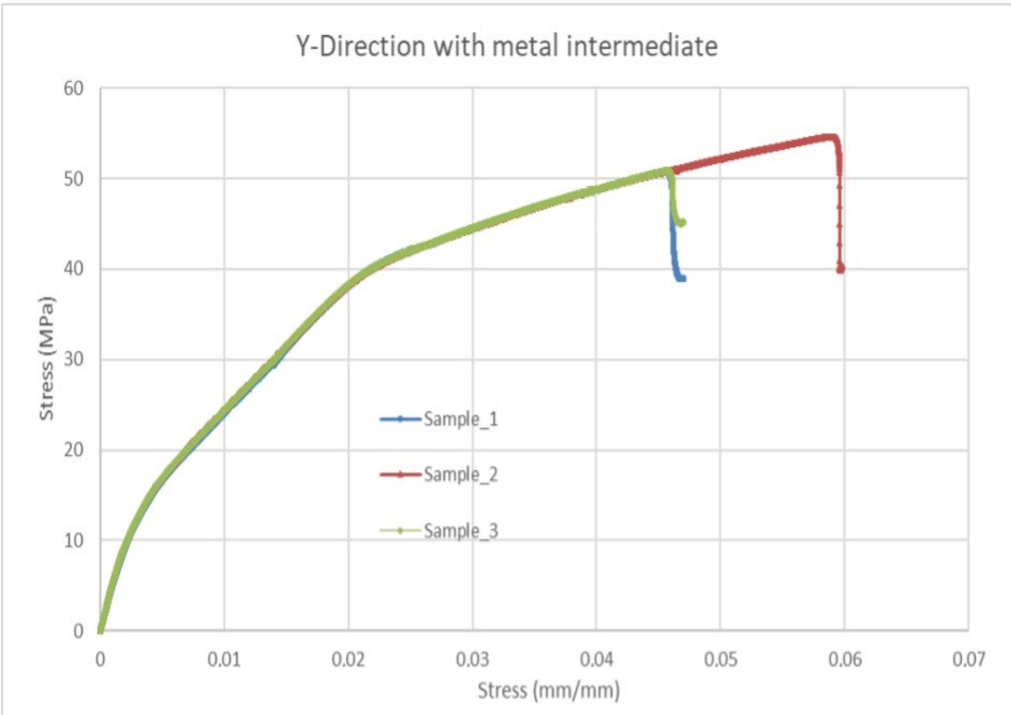


Figure 9. Tensile tests of Type-I laminates containing aluminum intermediate (Y-direction)

Tensile test results of all polyethylene line weaved fabrics laminates with Al 5005 H34 intermediate material were given in Figure 10. It could be stated that ultimate tensile strengths of these laminates were between 50 MPa and 53 MPa, which was a little smaller than y-direction hybrid laminates but close to values of x-direction hybrid laminate. Strain values were varied between 0.045 and 0.063, which were again close to x-direction hybrid laminates but smaller than y-direction hybrid laminates.

Figure 10 showed the stress-strain distributions of the single Type-I PL reinforced composite materials. The stress-strain values of the samples were found to be comparable with one another, as shown in Figures 8 and 9, based on the results shown in Figure 10. The graph indicates that the PL laminates had an average yield strength (σ_x) of 10.68 MPa and a corresponding strain value (ε_x) of 0.0016%. The samples had an average breaking strength value (σ_x) of 50.28 MPa, and the average strain value (ε_x) was observed to be 0.045%. The average modulus of elasticity ($E_x = E_y$) of all PL weaved fabrics of aluminum sheet intermediate containing composite material was obtained as 6670 MPa.

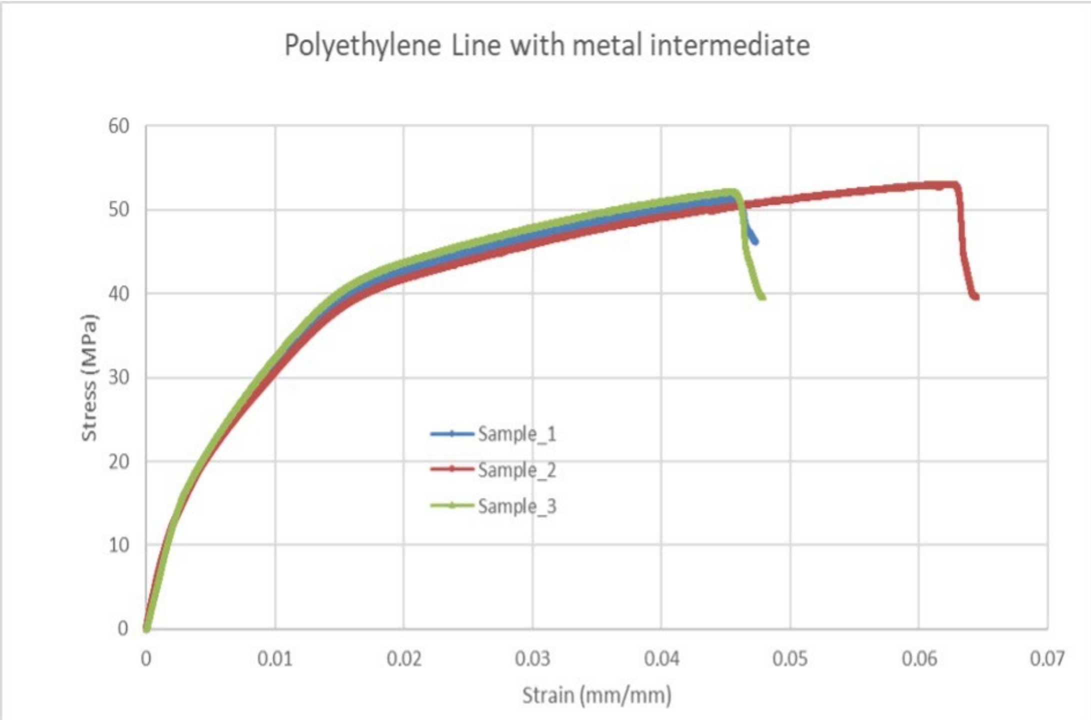


Figure 10. Tensile tests of Type-I laminates of PL textiles containing aluminum intermediate

In Figure 11, average values x-direction, y-direction hybrid laminates and all polyethylene line laminates were compared. Average values of three specimen in each laminate group were considered to draw this figure. It was obtained that; test results of x-direction and all polyethylene line laminates were in agreement with each other whereas y-direction laminates were bigger than the intermediate Al 5005 H34 material in all laminates, both in terms of strain value and ultimate tensile strength. In another paper, same authors investigated same laminate sequencing but without intermediate Al 5005 H34 material [36]. The laminates were all x-direction and y-direction aluminum/polyethylene hybrid fabrics, and all polyethylene fabrics. Same structural adhesive, production process and tests were applied. The average tensile test values of the laminates in the mentioned study were calculated and compared to the tensile test values of the samples with intermediate Al 5005 H34 material in this study separately in terms of x-direction, y-direction and all polyethylene line.

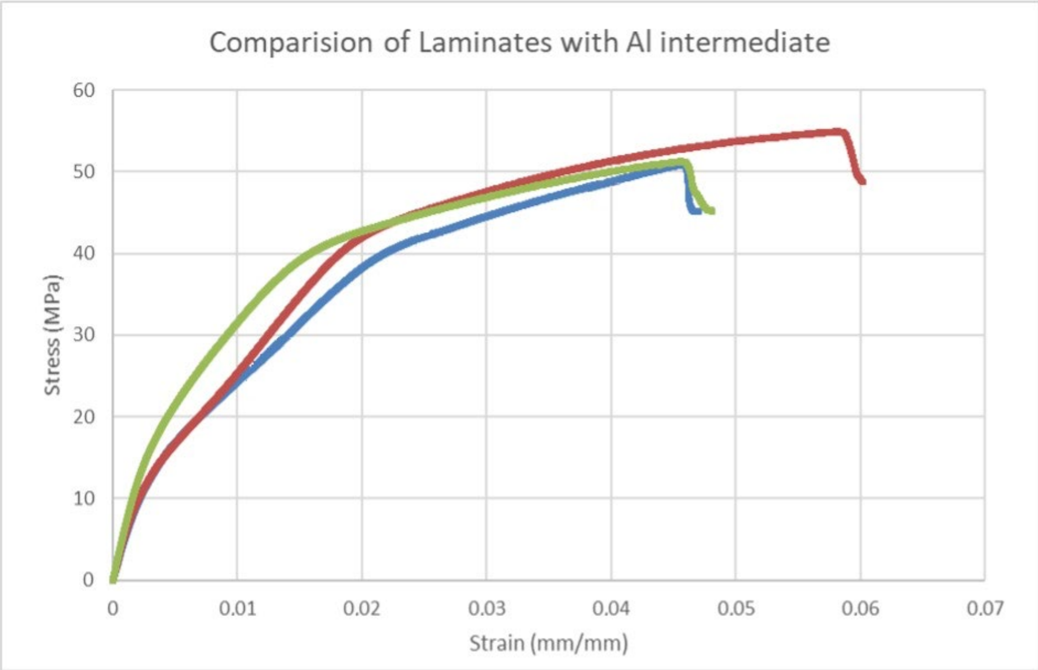


Figure 11. All Type-I intermediate material containing laminates comparison (Red: X-direction, Blue: Y-direction and Green: PL fabrics)

Comparison of the average tensile test results for specimens with and without an intermediate material, both possessing the identical sequence structure in the x-direction was presented in Figure 12. It was evident that the average stress outcome of the intermediate containing Al 5005 H34 was higher compared to the intermediate without it. However, the strain values obtained were very similar.

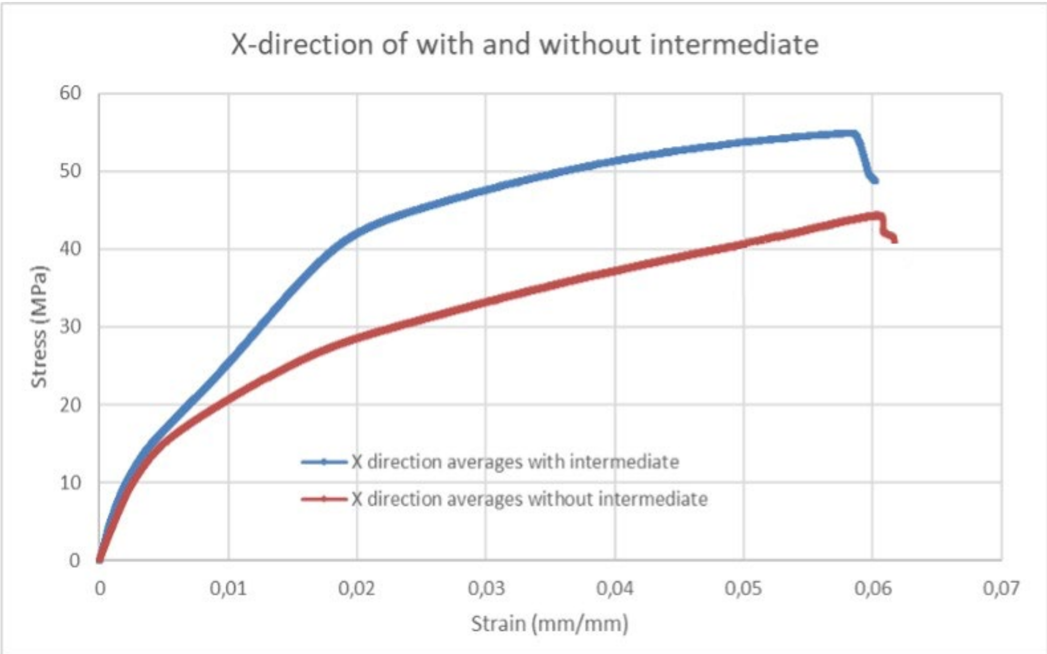


Figure 12. Tensile test comparison of Type-I and Type-II laminates (X-direction)

Figure 13 presented a comparison of the average tensile test results obtained with and without intermediate material using the same y-direction sequence structure. The y-direction laminates, both with and without intermediate material, yielded identical results to the x-direction laminates. However, the average ultimate strength margin for the y-direction laminates, with or without intermediate material, was slightly greater than that of the x-direction laminates.

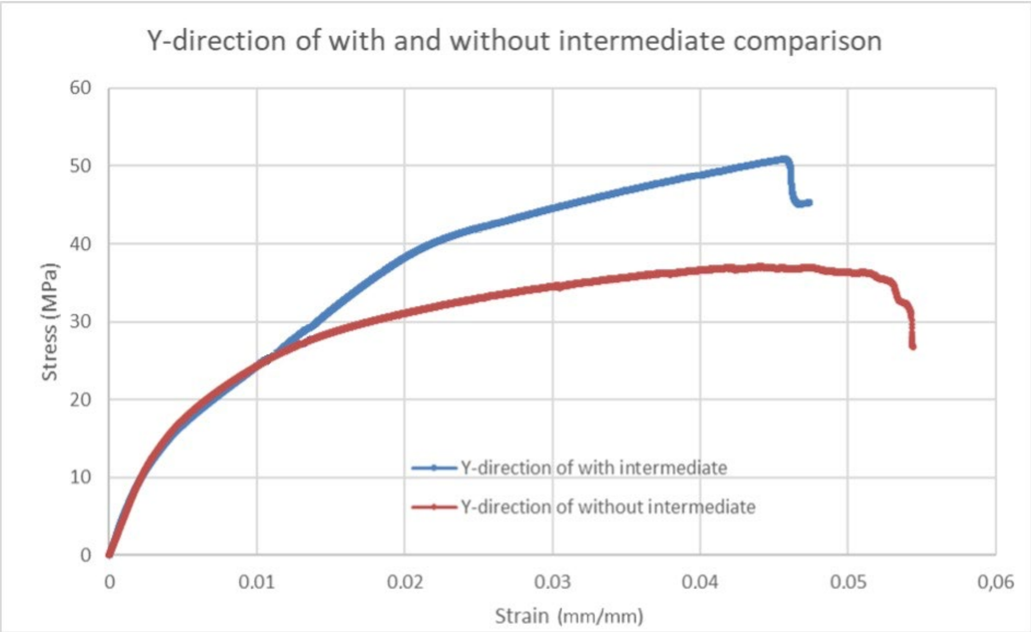


Figure 13 Tensile test comparison of Type-I and Type-II laminates (Y-direction)

Comparison of average tensile test results of with and without intermediate material with same sequence structure of polyethylene fishing line laminates were given Figure 14. Average ultimate strength of laminates with intermediate Al material clearly was bigger than without Al material laminates nevertheless average strain values of with intermediate material was smaller without intermediate Al material.

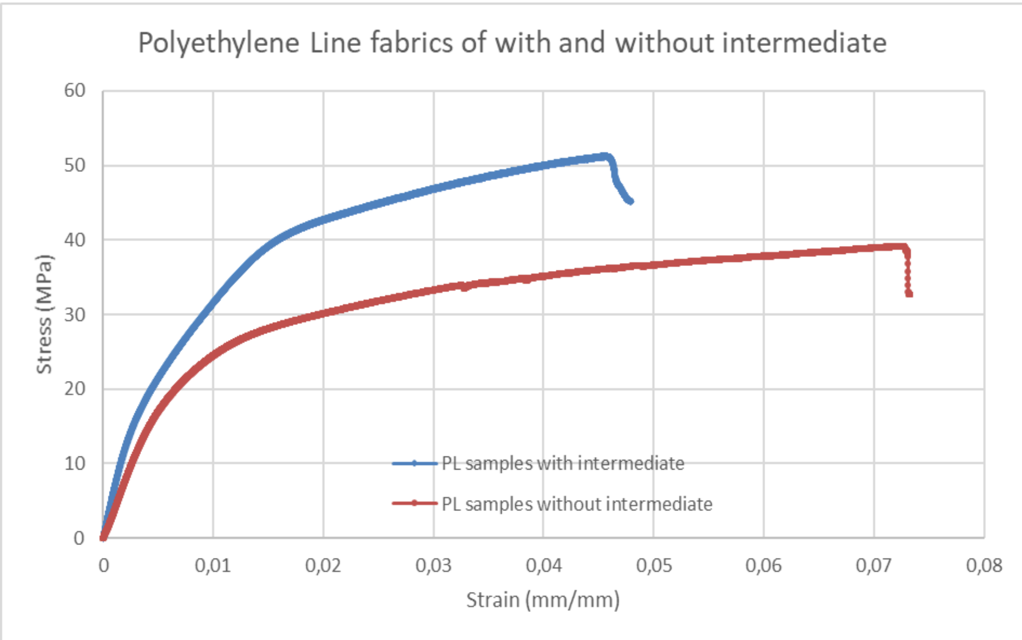


Figure 14. Tensile test comparison Type-I and Type-II of PL fabrics

When Figure 14 was compared to Figure 12 and Figure 13, it could be stated that averages strain margin was much bigger than not only all x-direction laminates but also y-direction all laminates.

When average values of x-direction, y-direction hybrid laminates and all PL laminates of Type-I were viewed from Figure 11, It could be stated that, test results of x-direction, y-direction and all PL with intermediate Al-containing laminates were in agreement each other whereas x-direction laminates were bigger than in terms of strain as well as ultimate tensile strength. Comparison of average tensile test results of with and without Al intermediate containing material with same sequence structure of x-direction, y-direction and all PL of Type-I and Type-II composites were given respectively in Figure 12, Figure 13 and Figure 14. It could be seen that the yield strength regions were approximately same regardless of intermediate material for both composites in x-direction and y-direction given respectively in Figure 12 and Figure 13. Therefore, it would be more beneficial to use the lighter laminates that intermediate metal-free sequence in applications of where yield strength was matter. Nonetheless, in both the x- and y-direction, the final strength of composites containing intermediate Al was shown to be greater than that of composites without intermediate ones. Comparison of average tensile test results of with and without intermediate Al material with same sequence structure of polyethylene fishing line laminates were given Figure 14. It should be stressed that the yield strength regions were distinctively different regarding intermediate Al material for all PL laminates. Besides, average ultimate strength of laminates with intermediate Al material clearly was bigger than without Al material laminates and average strain margin in Figure 14 was much bigger than not only for x-direction laminates but also y-direction laminates regarding without Al material.

In conclusion, it was found that the load amount of the laminates in the x-axis direction was higher than the y-axis, and the strength value was higher when results of mechanical properties of Type-I and Type-II were compared depending on the direction. In addition, it was noted that the yield strength values of Type-I and Type-II were relatively near to one another in both the x- and y-axis directions. Strength value of PL fabrics of Type-I laminates were smaller than x-axis and but close to y-axis direction. Type-I laminates were found to be 10%–12% heavier than Type-II laminates, but the strength of the intermediate Al-containing Type-II composite was found to be higher than that of the intermediate non-containing Type-I laminates. Conversely, the intermediate non-containing Type-II samples were found to have a relatively low-density value in comparison to the intermediate Al-containing Type-I laminates. Besides, it could be stated that metal and non-metal materials could be weaved in the form of fabric which resulted in low density and high strength materials that aerospace and aviation industries were highly preferred to use. The results showed that thanks to the reduction of the wire diameter of the metal material, the defects in the internal structure of the material would decrease in a weaved fabric accordingly. Therefore, a structure with fewer defects would result in higher material strength values and lower density values.

All samples were examined following the tensile tests of laminates in order to ascertain the adhesion failure mechanism in the bonded regions. It was discovered that this mechanism involved cohesive and adhesive failure that happened at the interface between the adhesive and substrate, within the adhesive, and within the coating layer. Consequently, the failure mechanism served as an indication that the cohesive forces within the adhesion region were insufficiently robust, and a feeble boundary layer was present. [37].

4. Conclusion

Diverse sequences of a novel hybrid aluminum/polyethylene fabric featuring an intermediate layer of Al were analyzed in this study, as was a pure polyethylene fabric featuring an intermediate layer of Al. A brief overview of the conclusions derived from this study would be as follows:

• It was observed that fabrics containing Al and PL could be sequentially woven using conventional rug weaving tools,

• It was discovered that Type-I laminates with intermediate Al content weighed between 10% and 12% more than Type-II laminates,

• When findings were compared based on the direction, the strength value of Type-I composites' X-axis direction was found to be higher than that of Type-I composites' Y-axis direction,

• It was discovered that the strength values of PL fabrics including laminates were almost Y-direction,

• It was found that the modulus of elasticity was the same for both the X and Y axes,

• Regarding the use of Al-intermediate material, it was found that the yield strength region of the X- and Y-direction of Type-I and Type-II were close,

• Comparing intermediate Al-containing Type-I laminates to intermediate non-containing Type-II samples, the density value of the latter was much lower,

• Depending on a comparison of Type-I and Type-II materials' strength-to-weight ratios, it is possible to conclude that by weaving metal and non-metal substances together the strength values of the materials would increase while the density values would decrease.

Acknowledgement

The present work received funding from the coordinatorship of scientific research projects at Adiyaman University, with project number MÜFMAP/2021-0001. Furthermore, the authors would like to express their gratitude to the executives of Turkish Airlines for their kind donation of the structural film adhesive.

Conflict of Interests

The authors of the article declare that they have no personal or financial conflict of interest with any institution, organization or person.

References

[1] Çitil Ş. Eğrisel yüzeyli yapıştırma bağlantılarında malzemenin yapıştırıcı üzerine etkisinin incelenmesi. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi 2018;9(1):225-234.

[2] Da Silva LFM, Marques EAS. Joint strength optimization of adhesively bonded patches. J. Adhesion 2008; 84:915–934.

[3] Apalak MK, Engin A. Geometrically non-linear analysis of adhesively bonded double containment cantilever joint. Journal of Adhesion Science Technology 1997;11(9):1153-1195.

[4] Kweon JH, Jung JW, Kim TH, Choi JH, Kim DH. Failure of carbon composite-to-aluminum joints with combined mechanical fastening and adhesive bonding. Composite Structures 2006;75(1-4):192-198.

[5] Kairouz K C, Matthews F L. Strength and failure modes of bonded single lap joints between cross-ply adherends. Composites 1993; 24(6): 475-484.

[6] Da Silva LFM, Carbas RJC, Critchlowb GW, Figueiredo MAV, Brown K. (2009). Effect of material, geometry, surface treatment and environment on the shear strength of single lap joints, International Journal of Adhesion & Adhesives 2009;29:621–632.

[7] Çitil Ş, Ayaz Y, Temiz Ş. Stress analysis of adhesively bonded double strap joints with or without intermediate part subjected to tensile loading. The Journal of Adhesion, 2017;93(5):343-356.

[8] Çitil Ş. Comparison of stepped, curved, and S-Type lap joints under tensile loading. In Materials Design and Applications, Springer, Cham; 2017.

[9] Boutar Y, Naïmi S, Mezlini S, Ali MBS. Effect of surface treatment on the shear strength of aluminium adhesive single-lap joints for automotive applications. International Journal of Adhesion and Adhesives 2016; 67:38-43.

[10] Naat N, Boutar Y, Naïmi S, Mezlini S, Da Silva LFM. Effect of surface texture on the mechanical performance of bonded joints: a review. The Journal of Adhesion 2021:1-93.

[11] Layec J, Ansart F, Duluard S, Turq V, Aufray M, Labeau MP. Development of new surface treatments for the adhesive bonding of aluminum surfaces. International Journal of Adhesion and Adhesives 2021:103006.

[12] Reneckis V, Vilutis A, Jankauskas V. Investigation of technological factors influencing the strength of bonded Al–alloy. In IOP Conference Series: Materials Science and Engineering 2021;1140(1):012042.

[13] Ribeiro TEA, Campilho RDSG, Da Silva LF, Goglio L. Damage analysis of composite–aluminium adhesively-bonded single-lap joints. Composite Structures 2016;136:25-33.

[14] Thomas R, Fischer F, Gude M. Adhesives for increasing the bonding strength of in situ manufactured metal-composite joints. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 2021;235(13):3256-3269.

[15] Banea MD, Rosioara M, Carbas RJC, Da Silva, LFM. Multi-material adhesive joints for automotive industry. Composites Part B: Engineering 2018;151:71-77.

[16] Dos Santos DG, Carbas RJC, Marques EAS, Da Silva LFM. Reinforcement of CFRP joints with fibre metal laminates and additional adhesive layers. Composites Part B: Engineering 2019;165:386-396.

[17] Hu Y, Yuan B, Cheng F, Hu X. NaOH etching and resin pre-coating treatments for stronger adhesive bonding between CFRP and aluminium alloy. Composites Part B: Engineering 2019;178:107478.

[18] Gültekin K, Akpinar S, Özel A, Öner GA. Effects of unbalance on the adhesively bonded composites-aluminium joints. The Journal of Adhesion 2017;93(9):674-687.

[19] Gültekin K, Yazici ME. Mechanical properties of aluminum bonded joints reinforced with functionalized boron nitride and boron carbide nanoparticles. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications 2022;236(1):37-49.

[20] Pramanik A, Basak AK, Dong Y, Sarker PK, Uddin MS, Littlefair G, Chattopadhyaya S. Joining of carbon fibre reinforced polymer (CFRP) composites and aluminium alloys–A review. Composites Part A: Applied Science and Manufacturing 2017;101:1-29.

[21] Marannano G, Zuccarello B. Numerical experimental analysis of hybrid double lap aluminum-CFRP joints. Composites Part B: Engineering 2015;71:28-39.

[22] Çitil Ş. Experimental and numerical investigation of adhesively bonded curved lap joints under three-point bending. Mechanics 2018;24(6):824-832.

[23] Zamani P, Jaamialahmadi A, Da Silva LF. The influence of GNP and nano-silica additives on fatigue life and crack initiation phase of Al-GFRP bonded lap joints subjected to four-point bending. Composites Part B: Engineering 2021;207:108589.

[24] Sun G, Liu X, Zheng G, Gong Z, Li Q. On fracture characteristics of adhesive joints with dissimilar materials–An experimental study using digital image correlation (DIC) technique. Composite Structures 2018;201:1056-1075.

[25] Reddy NS, Jinaga UK, Charuku BR, Penumakala PK, Prasad AS. Failure analysis of AA8011-pultruded GFRP adhesively bonded similar and dissimilar joints. International Journal of Adhesion and Adhesives 2019; 90: 97-105.

[26] Cakir MV, Kinay D. MWCNT, nano-silica, and nano-clay additives effects on adhesion performance of dissimilar materials bonded joints. Polymer Composites 2021; 42(11): 5880-5892.

[27] Carbas RJC, Marques EAS, da Silva LFM. The influence of epoxy adhesive toughness on the strength of hybrid laminate adhesive joints. Applied Adhesion Science 2021; 9(1): 1-14.

[28] Morgado MA, Carbas RJC, Marques EAS, da Silva LFM. Reinforcement of CFRP single lap joints using metal laminates. Composite Structures 2019; 230: 111492.

[29] Solvay. Properties of FM73M. https://www.solvay.com/en/product/fm-73. (Access date: 01.09.2023).

[30] Cavezza F, Boehm M, Terryn H, Hauffman T. A review on adhesively bonded aluminium joints in the automotive industry. Metals 2020; 10(6): 730.

[31] Kuczmaszewski J. Fundamentals of metal-metal adhesive joint design. Lublin University of Technology, Poland. 2006.

[32] Davis M, Bond D. Principles and practices of adhesive bonded structural joints and repairs. International journal of adhesion and adhesives 1999;19(2-3): 91-105.

[33] Pethrick RA. Design and ageing of adhesives for structural adhesive bonding–a review. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: design and applications, 2015; 229(5): 349-379.

[34] Da Silva LFM, Lopes MCQ. Joint strength optimization by the mixed-adhesive technique, International Journal of Adhesion & Adhesives 2009; 29: 509–514.

[35] Adams RD, Harris JA. Stress analysis of adhesive-bonded lap joints, The Journal of Strain Analysis for Engineering Design 1974; 9(3): 185-196.

[36] Engin KE, Kaya AI, Citil S. Investigation of mechanical properties of woven hybrid metallic fabric. In 2nd International Conference on Industrial Applications of Adhesives 2022: Selected Contributions of IAA 2022, 2022; 2:115-133.

[37] Seong MS, Kim TH, Nguyen KH, Kweon JH, Choi J. H. A parametric study on the failure of bonded single-lap joints of carbon composite and aluminum. Composite structures 2008; 86(1-3): 135-145.