Int. J. Adv. Eng. Pure Sci. 2023, 35(4): 523-530
DOI: 10.7240/jeps.1343432

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

A Comparison of Force Distribution Effects of Ductile and Brittle Adhesives at Different Hole Positioning

Sermet DEMİR [1], **Uğur KEMİKLİOĞLU** [2]

[1]*Doğuş Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, İstanbul, Türkiye*

[2]*Başkent Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Ankara, Türkiye*

Abstract
Composite joints are used in many industries such as aerospace, army, automotive, and marine because of their light, durable and corrosion-resistant properties. Composite joints can be made by applying different methods using elements such as adhesives, rivets, bolts, and nuts. Considering the lightness of a product, the most preferred connection type is adhesive joints. In most structures with adhesively bonded composite joints, weight is avoided to reduce energy consumption. In this study, fiber-reinforced thermoset plastics were manufactured as adherend, and two different adhesives were used; one has ductile, and the other has brittle properties. Holes were drilled on adhesively bonded single lap joints at different locations to investigate the mechanical effect of adhesives and adherend. The preferred specimen material was epoxy-infused e-glass fiber laminate manufactured using the vacuum infusion method. Tensile tests were performed on drilled, adhesively bonded joints. The force-elongation curves were generated and compared to each other depending on the positions of the drilled holes. The failure force of the samples with holes drilled in the middle of the bonded area was higher than those with holes drilled at the edge.
Keywords: Adhesives, Bonded joints, Hole effect, Weight reduction, Tensile test

I. INTRODUCTION

Composite materials exhibit outstanding features when compared to conventional materials. Although different composite manufacturing techniques can produce complex parts, there is an increasing need to join composite plates and sheets [1], [2]. Since their lightweight structures provide high energy efficiency, adhesively bonded joints are increasingly preferred in space, aeronautics, and vehicles. Besides, adhesive joints have some advantages, such as creating uniform stress distribution, high specific stiffness and strength, joining different materials, practical operation, corrosion and fatigue resistance, low cost, and suitability for bonding composite adherends with complex shapes and geometries [3], [4]. Adhesive bondings are preferred for joining similar and dissimilar materials as layers using different adhesives with the help of different joint configurations, such as single lap, double lap, beveled lap, and joggle lap bonded joints [5], [6]. Many studies on these techniques, like stress analysis, adhesion strength, fracture, and fatigue failure of adhesive joints with different adhesives, have also been studied in depth from mechanical aspects such as structural integrity, axial impact, and temperature effect [6]–[8]. Loading and environmental conditions, mechanical characteristics of adhesive and adherends, adhesive thickness, and the quality between adhesive and adherends were clarified as the main factors affecting primary damage mechanisms [8]–[10]. Therefore, it is essential to use the stress distribution of adhesively bonded joints fully.

In the literature, studies were reviewed on adhesively bonded joints that generally focused on the behavior of adhesive type, nanoparticle addition, and bonding methods to improve the performance of the joints [11]. Also, the effect of defects in the overlap was studied on the mechanical behavior of bonded joints using finite elements and experimental methods [12]–[15]. Durodola [16] investigated graded adhesive joints' analysis, method, fabrication, and experimental testing. It is concluded that the load was never distributed uniformly in the case of the strain, and stress distribution along the joint length was not uniform. Thus, the stress state was complex and advised to be clarified. He [17] has comprehensively researched finite element analysis (FEA) of adhesively bonded joints in static and fatigue loading, environmental effects, and dynamic characteristics. The FEA was a handy tool to determine the mechanical properties of adhesively bonded joints for any geometrical shape and load conditions. However, the adhesive layer meshing and the degrees of freedom number in the bonded joint were clarified as the main problems. In addition, the FEA benefits in the initial design and preliminary research are emphasized, but the necessity of experimental testing was also stated.

Functionally graded bonded joints offer even more opportunities for stress concentration reduction and stress distribution tailoring required for an adhesive layer. Li et al. [18] conducted an experimental study to observe the tensile performance of adhesively bonded composite joints. Design parameters such as adherend thickness, width, and overlap length were selected, and test results were compared. Jairaja et al. [19] showed that many different types of defects could affect the load-carrying capacity of an adhesively bonded joint. It has been stated that bond strength is dependent on the nature of defects and applied loads. Therefore, experimentally determining the stress distribution of different joint variations is crucial.

Corresponding Author: Sermet DEMİR, **Tel:** 0216 444 79 97-dahili, **e-mail:** sdemir@dogus.edu.tr

Submitted: 15.08.2023, **Revised:** 03.12.2023, **Accepted:** 25.12.2023

Stein et al. [20] have developed the Finite Fracture Mechanics model to understand the mechanical behavior of various joint configurations. They emphasized the importance of section forces and moments for predicting the failure load of different joint configurations. The failure behavior was described using stress and energy criteria, and they selected seven experimental test series to compare using three-dimensional parameters. The developed model was in good agreement with conservative results.

Zhang et al. [21] modelled a three-dimensional micromechanical finite element method to examine the mixed-mode response of a single Z-pinned composite laminate. Experimental studies validated the presented approach and claimed that the apparent fracture toughness of individual z-pins could be improved using their model. Another study [22] was about an experimental investigation of the usefulness of z-pins to maximize the structural properties of stiffened joints comprised of carbon/epoxy composite. Pull-off tests were carried out on T-joint with and without z-pins. They showed that z-pins did not improve the stiffness or failure initiation load of T-joints. In contrast, they effectively increased the ultimate failure strength, failure displacement, and adsorbed energy capacity.

Chang et al. [23] experimentally investigated the static tensile strength, fatigue life, and failure mechanisms of single lap joints made of carbon/epoxy composite as a function of the through-thickness reinforcement by fibrous pins. They suggested that the pinning increases the ultimate strength, elongation limit, and fatigue life. However, they studied pinned composite lap joints' monotonic and fatigue properties. They showed that ultimate failure, induced by pin pull-out, a shear fracture, or tensile laminate rupture, is based on the pins' volume content and diameter. The mechanical properties and stress state can be predicted by using analytical methods. Although the accuracy of current models is very high, a deep experimental investigation of the stress distribution of bonded surfaces is essential for different types of joints. However, all models were two-dimensional and limited to a case where the stress was higher in the loading condition [24]. Another study investigated the effect of different adhesives on aluminum adherends. It was explained that aluminum adherends are more durable than polymers [25].

In the study, two different ductile (Loctite 9466) and brittle (Loctite 9461) adhesives were used, and Glass Fiber fiber-reinforced polymer (GFRP) composites bonded with these two different adhesives as single lap joints. The joints were holed in different positions, and the mechanical properties of bonded joints were examined and compared by the hole effect in joints requiring weight reduction. The following sections of this paper provide a detailed account of our study. In the next section, we describe the methods and materials used, including the manufacturing of samples. Subsequently, the main results of our analyses are presented. Finally, we engage in a discussion regarding the implications of our findings and provide concluding remarks to underscore the broader significance of our study.

II. MATERIALS AND METHOD

Glass fiber is commonly used in various industries for its excellent mechanical, thermal, and electrical properties. It is cheaper than other materials, such as carbon or kevlar and is significantly less brittle when used in composites. Because of these properties, GFRP was preferred for adhesive samples in this study.

Vacuum-assisted resin infusion method was used in the production of the plate. Eight plies of e-glass fiber fabric with a 300 g/m2 density were prepared and positioned in the same direction to reach the required thickness. They were covered with peel-ply. All the process was carried out on a custom-made composite manufacturing table. The system was heated to 100 ºC, and a vacuum was applied for 20 minutes before infusion. Thus, any possible leakage was checked, and the air was fully evacuated from the vacuum bag. Epoxy resin and hardener were used as the matrix material. The mixing ratio of resin and matrix material by weight was 1/3. Resin infusion was initiated and controlled occasionally until the epoxy reached all parts of the fabric.

The surface treatment of the glass fiber can improve the adhesion between the fiber and the paper or other materials. It can also provide other benefits, such as improved abrasion resistance or reduced static electricity. However, no finishing process was applied in this study. Glass fiber epoxy laminate has two surfaces, one rough and the other smooth, due to the peel-ply applied during the production phase. For the bonding process, the side of the plate with a rough surface is preferred for a stronger bond.

Samples were cut from the produced plate by the wet-cutting method. Sample dimensions are given in Figure 1a. Two different adhesive materials, Loctite 9461 & Loctite 9466, were used to bond the rough surfaces of these plates. Half of the plates adhered with Loctite 9461, whereas the other half adhered with Loctite 9466 adhesive materials. An equal amount of adhesive was used for each sample during adhesive application. Low weights are placed on the bonding area to prevent any slippage during curing, which will not affect the adhesion performance. Then, these specimens were cured for three days at room temperature. The dimensions of single lap joints and the curing procedures of these joints are shown in Figure 1.

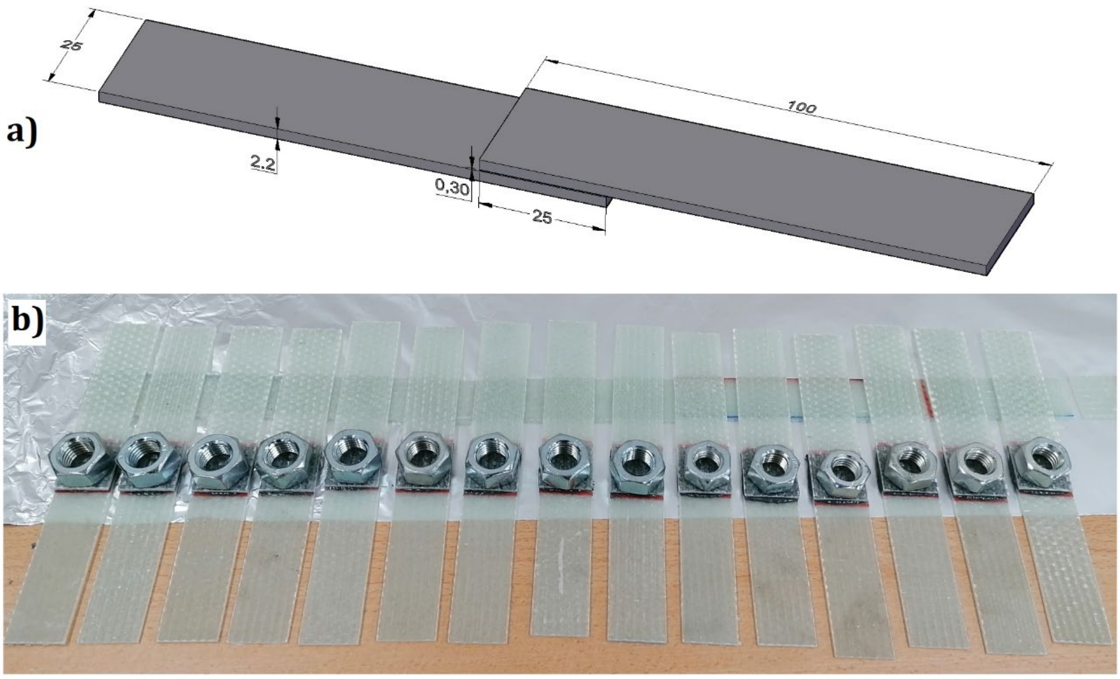


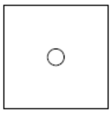
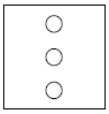
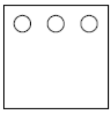
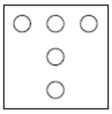
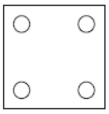
Figure 1. a) The dimensions of adhesively bonded single lap joints specimens, b) prepared samples

This study aims to investigate the force distributions in adhesive-bonded specimens with different hole forms drilled on the bonding surface. Therefore, different combinations and numbers of hole patterns were determined. The diameter of each hole is 4 mm. In the first design, there is a single hole in the center of the connection point. The second pattern contains three holes parallel to the traction direction of the material. The next design consists of 3 holes horizontally, inverse to the previous one. The fourth pattern combines the previous two designs in a T-shape. The last shape is formed by drilling holes in each corner of the connection point. The distance of the holes from the edges is 2 mm, and the distance between them is equal. Different abbreviations were used for the patterns. Their shapes and abbreviations are given in Figure 2.

The cutting speed and force applied during drilling can impact the quality of the hole in composite materials. Excessive heat can damage the material if the cutting speed is too low, while a too-high cutting speed may cause fraying or splintering. Insufficient force can result in poorly formed holes, while excessive force can cause delamination or cracking in the material. Using the appropriate cutting speed and drilling force for the specific composite material being drilled is important to achieve a clean, accurate hole. However, in this study, the use of CNC for drilling was not required as it was considered that the effect of hole forms or damage, such as delamination on adhesion, would be limited.

The cured specimens were drilled with a column drill bench fitted with a 4 mm diameter insert according to the patterns in Figure 2. The drilling process was applied at low and constant speed in three stages to prevent the formation of delamination. Three samples were prepared for each experiment to reduce random error and environmental effects.

Table 1. Locations and abbreviated names of drilled samples

Hole Positioning	Name	Number of Holes	Abbreviation
	One Hole	1	OH
	Vertical Hole	3	VH
	Horizontal Hole	3	HH
	T Hole	5	TH
	Four Hole	4	FH

Hole positioning, drilling, and tensile test procedures are shown in Figure 2. Subsequently, tensile tests were applied to these specimens at a 1 mm/min rate via Testometric M500-30CT Universal Tester (The

Testometric Company Ltd., Rochdale, UK). After the experiments, all specimens broke from the bonding area. Both cohesive and adhesive failure modes were observed. No substrate failure occurred in any test.

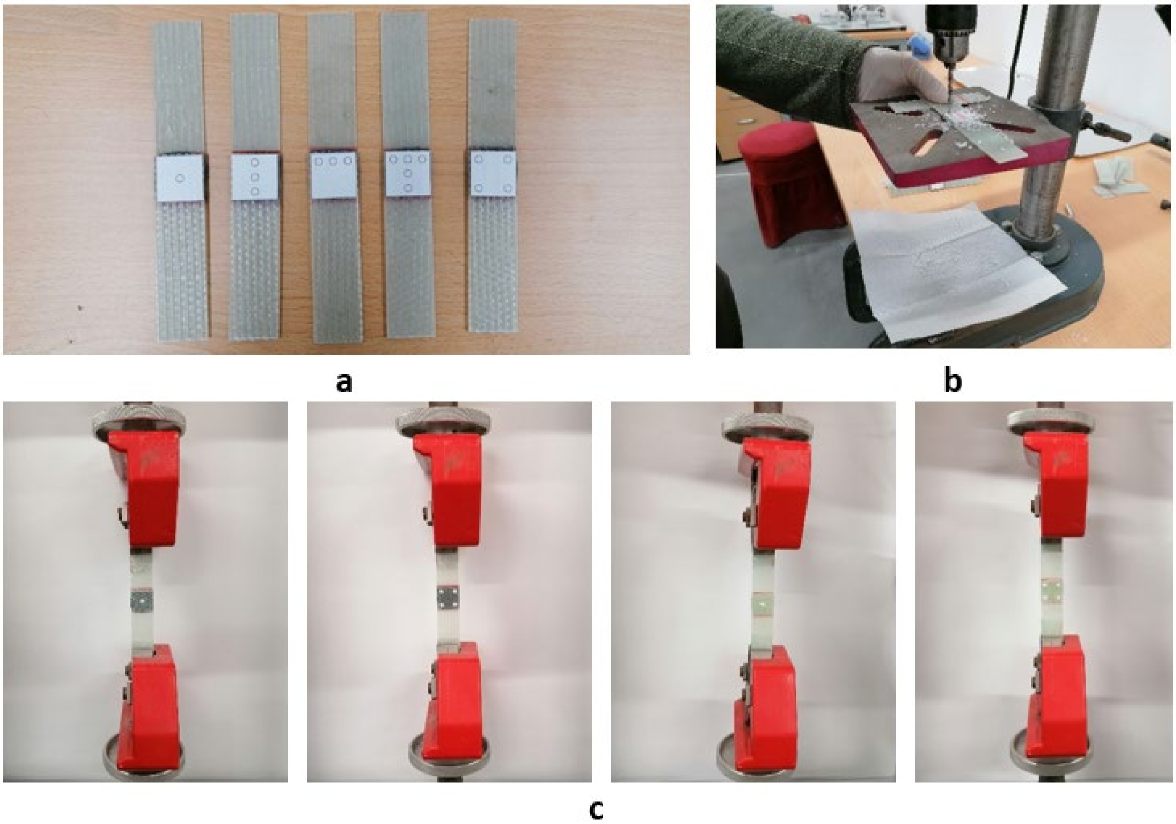


Figure 2. Specimen preparation and testing procedure: a) Hole positioning; b) Drilling; c) Tensile tests for the specimens of OH-9461, FH-9461, OH-9466 & FH-9466, respectively.

III. RESULTS AND DISCUSSION

The specimens were subjected to tensile tests, and force-extension diagrams were analyzed. Loctite 9461 epoxy adhesive is known to be more brittle than Loctite 9466. The results obtained were evaluated in light of this information. The mechanical properties of single lap joints with different hole orientations and patterns were compared. Load-displacement diagrams of single-hole (OH) joints for both adhesives are shown in Figure 3. As expected, the highest tensile strength for both adhesives was realized in the single-hole connection. Tensile strengths were measured as 6505 N and 10034 N for 9461 and 9466, respectively. Since Loctite 9466 has a more ductile structure, it elongated more (approximately 40%) and showed more strength.

In similar studies, single-screw or multiple-pin connections were preferred for hybrid connections [26]. In studies with a large number of pins, the focus was on the area ratio rather than the number of holes since the number of pins is very high. However, in our study, we tried to reveal the pattern effect by keeping the dimensions of all holes the same. Since the VH and HH joints have the same hole number, the force-elongation diagrams of those joints obtained for both adhesives are shown in Figure 4 together.

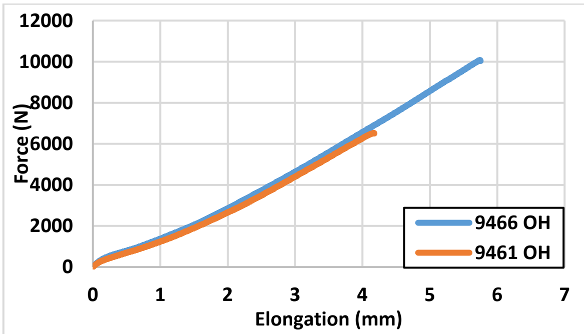


Figure 3. Force – Elongation diagram of One Hole (OH) joints

It is seen that the failure force of both joints decreases compared to OH joints. Damage occurs at 7790 N in the adhesively bonded junction created with Loctite 9466, whereas damage occurs at around 6050 N in the adhesively bonded joint formed with Loctite 9461. The decrease in the strength of 9466 was much higher than 9461. Here, it can be said that the decrease in the adhesion surface has a higher effect on ductile adhesives. Three holes drilled on the glued surface are in the edge region, showing that the damage forces are reduced compared to a single hole drilled at the middle point.

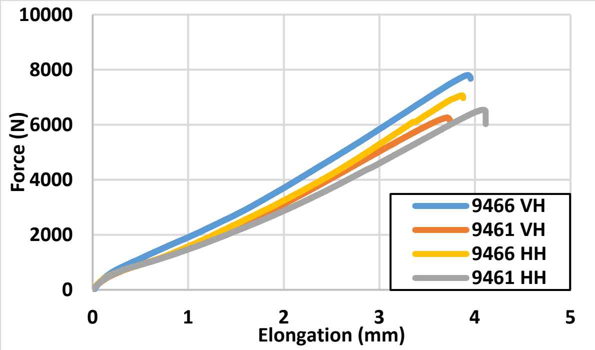


Figure 4. Force – Elongation diagram of (a) Vertical Hole (VH) and (b) Horizontal Hole (HH) joints.

The elongation of the joint with Loctite 9461 adhesive, which has a brittle feature, has increased compared to Loctite 9466. However, the failure force of Loctite 9466 is higher than Loctite 9461. The force-elongation diagrams of T-hole (TH) joints for both adhesives are shown in Figure 5.

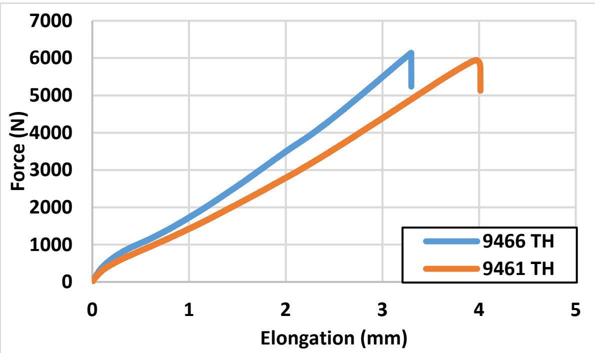


Figure 5. Force – Elongation diagram of T – Hole (TH) joints

The presence of horizontal and vertical holes in TH joints leads to a decrement in the failure load and elongation values of Loctite 9466 compared to Loctite 9461. It is seen that Loctite 9461 adhesive with brittle shows ductile features in T-hole adhesives. Similarly, Loctite 9466 adhesive, which has ductile properties, shows brittle properties. Both samples were damaged at around 6000 N in tensile tests for the TH pattern. The adhesion strength gradually decreases as the drilled holes approach the edge areas of the connection. A similar situation was also observed in VH- HH connections. The strength of HH joints positioned closer to the edge of the joint made with 9466 is lower than that of VH joints.

The force-elongation diagrams of FH joints for both adhesives are shown in Figure 6. It is seen that the lowest failure force of both connections occurs in such samples. In addition, the force and elongation values of the Loctite 9461 sample increased even more when compared to Loctite 9466.

The joint region takes the s-shape as the force increases in adhesive joints made with a ductile adhesive. Thus, the moment forces on the adhesion zone also increase. Since the distance from the rotation point is the highest at the ends, a weakness here causes the connection to break faster. It is thought that the advantage of ductile connection in TH and FH connection types is lost for this reason. Since holes were drilled at both ends in the FH connection, the damage occurrences were approximately the same for both adhesives.

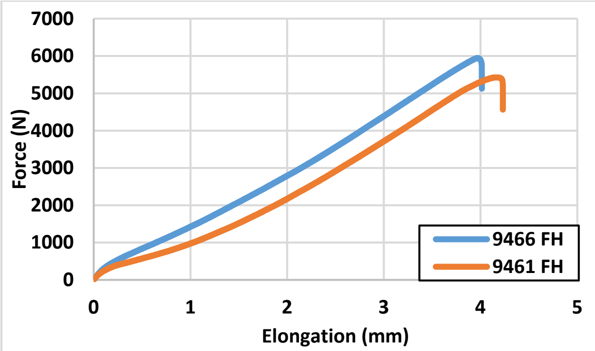


Figure 6. Force – Elongation diagram of Four Hole (FH) joints

In the study of CFRP and aluminum single-lap joints, strain profiles in the loading direction show the importance of location in hybrid joints [27]. The highest number of holes were drilled in TH and FH patterns. Although there were five holes in the TH pattern, the strength value was higher than FH for both adhesive types since their locations were closer to the center regions. The FH pattern has more parts in terms of bonding area. However, the holes are positioned near all edges, so the strength performance was lower. A similar situation was observed in VH and HH patterns. Although the bonding area was the same, VH showed a better performance.

When the hole parameters drilled in different locations on the bonding surface are examined together, it is seen that the failure forces vary for adhesives with different properties. Force-elongation diagrams created for different hole parameters of both adhesives separately are given in Figure 7. Increasing the number of holes in the ductile adhesive greatly affects the bond strength. This was observed less in 9461 with a brittle structure. Depending on the number and position of holes, the bond strength for both adhesives weakened.

In Figure 8, Dino-Lite (Naarden, Netherlands) optical microscope images of the damaged surfaces of the specimens after the tensile test are shown. For both adhesives, cohesive adhesive failure was intensively observed. Especially for HH and TH bonded adhesives, adhesive failure was observed around the holes close to the end region. It can be assumed that delamination occurred between the adhesive and the sample specimen during the drilling process. However, adhesive damage appears less in other areas, indicating that there may be other effective factors. Another possibility is that the connection has been weakened in this area due to the drilling process.

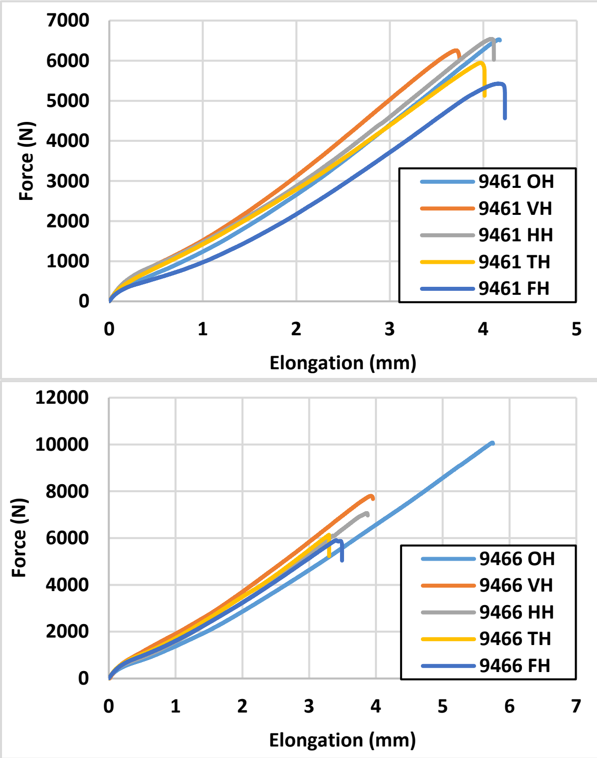


Figure 7. Force – Elongation diagrams of joints for different hole locations for Loctite a) 9461, b) 9466.

OH and VH joints show the least separation around the hole. Li et al. investigated the strength enhancement of bonded composite laminate joints reinforced with composite pins [28]. Numerical analysis and experimental results show that the least stress occurs around the central hole, while the highest values are observed at the edges. The separations in the edge regions of OH and VH with a central hole pattern show similar results. In a similar study, damage surface examinations showed that the separation started from the edges and the region far from the tensile direction [29]. The observation of the highest strength pattern in the specimens with a central single hole is consistent with the previous study.

The most preferred hole location for hybrid joints is in the center of the joint region. The placement of the pin significantly influences the mechanical behavior and performance of hybrid joints. Parkes emphasized the necessity of reinforcement in preventing rapid, unstable delamination by highlighting the beginning of bond-line damage in adhesive joints and its impact on joint stability [30]. This underscores the critical role of pin placement in enabling reinforcement and enhancing joint stability. Furthermore, Graham examined the utilization of compliant adhesives in hybrid joints to enhance load sharing when combined with fasteners [31]. This highlights the need for a comprehensive evaluation of pin placement to optimize both load distribution and joint characteristics. The results obtained in this study show that hole location is an influential factor. Although more disadvantageous in terms of adhesion area, the better performance of different patterns is in line with the optimization research proposed in previous studies.

IV. CONCLUSION

This study used two different adhesives ductile (Loctite 9466) and brittle (Loctite 9461). The mechanical behavior of composite materials bonded with these two different adhesives in different hole orientations was investigated. The mechanical behavior of the hole effect on the adhesively bonded joints in the joints where the weight needs to be reduced was examined and compared. As a result of positioning the holes created on the bonding surface's center, it has been observed that the ductile or brittle properties of the adhesives do not change. Also, it was observed that there was no change in the ductility properties of the adhesives in vertical and horizontal holes. Although three holes were created on one side of the bonding surface in HH joints, the failure force was lower than those of the VH joints since there was no hole on the other side. Besides, the failure force in HH joints is higher than in VH joints, which shows that the excess holes formed at the edge of the bonding surface reduce the strength.

The ductility property of TH joints varied for both adhesives. Katsivalis performed quasi-static tensile tests on glass/steel joints using bolted, brittle (Araldite 2020) and ductile (Araldite 2047-1) adhesive joints [32]. It was shown that joints reinforced with ductile adhesive were stronger than joints with more brittle adhesives, although the strength was lower. This occurred because, inside the adhesively bonded area, a considerably bigger plastic zone for the ductile adhesive formed. During the formation of plastic deformation, the effect of the holes or the proportion of the bonding area can be influential. For this reason, adhesives with brittle properties can be preferred in TH joints that are desired to save material weight. The ductility property of FH joints also varied for both adhesives. This type of joint's strength is at the lowest level compared to other hole parameters. Therefore, it is not recommended to use FH joints. It is seen that the holes formed perpendicular to the tensile axis reduce the strength, especially in the HH and FH joints. It can be said that holes formed in the middle rather than the edge of the bonding surface do not reduce the strength much. For this reason, holes created in the edge areas should be avoided.

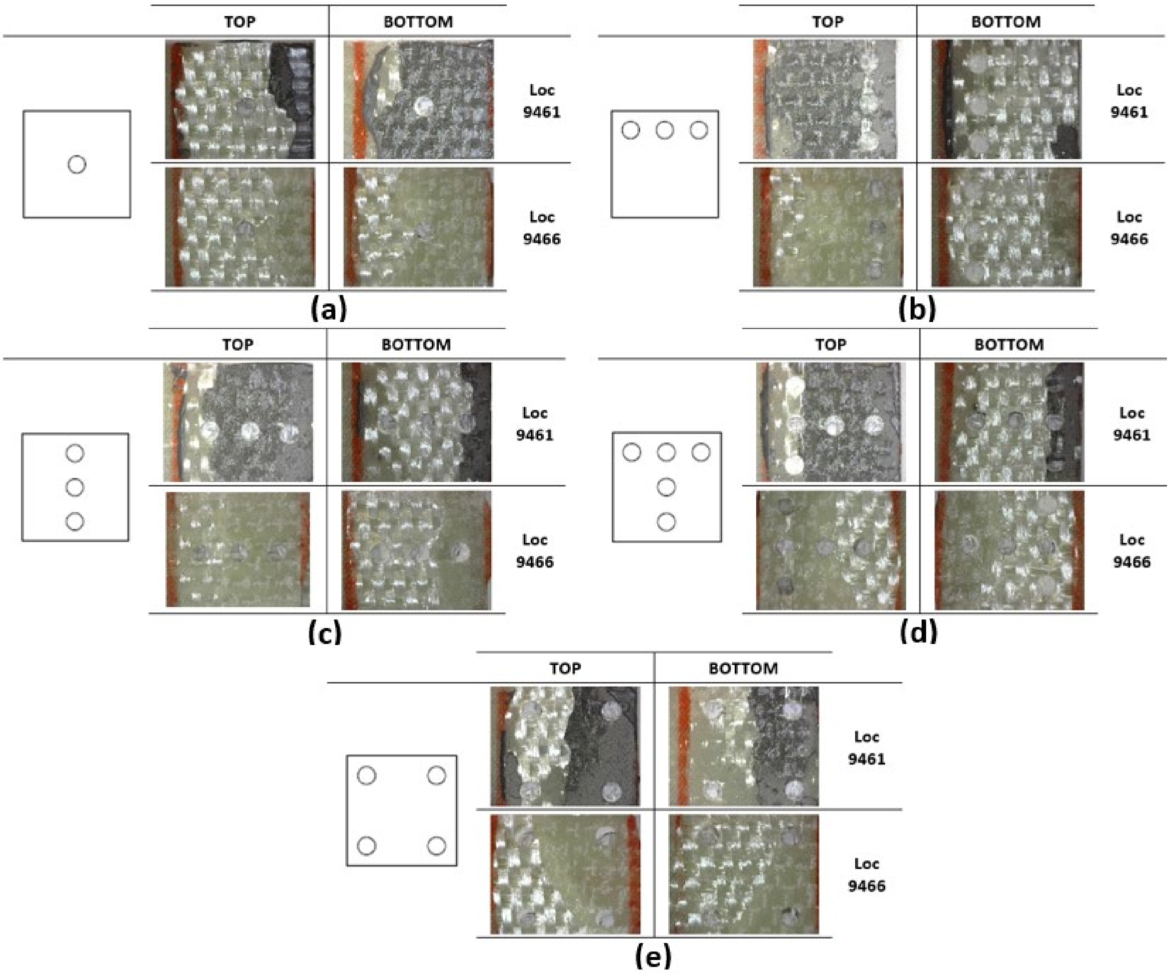


Figure 8. USB Microscope images after failure: a) OH, b) HH, c) VH, d) TH, e) FH. Bright areas are substrate surfaces.

ACKNOWLEDGMENT

This work has been supported by Dogus University Scientific Research Projects Coordination Unit under grant number 2021-22-D1-B02.

REFERENCES

[1] El Zaroug, M, Kadioglu, F, Demiral, M, Saad, D., Experimental and numerical investigation into strength of bolted, bonded and hybrid single lap joints: Effects of adherend material type and thickness. ***International Journal of Adhesion and Adhesives***, 87, 130–141 (2018).

[2] Yılmaz, Y, Çallıoğlu, H, Balbay, A., Investigation of quasi-static crushing and energy absorption behaviors of carbon nanotube reinforced glass fiber/epoxy and carbon fiber/epoxy composite tubular structures. ***Pamukkale University Journal of Engineering Sciences***, 28, 1 81–90 (2022).

[3] Khashaba, U, A, Najjar, I, M, R., Adhesive layer analysis for scarf bonded joint in CFRE composites modified with MWCNTs under tensile and fatigue loads. ***Composite Structures***, 184, 411–427 (2018).

[4] Günay, M, G., Torsion of variable stiffness composite laminated beams. ***Pamukkale University Journal of Engineering Sciences***, 28, 1, 18–25 (2022).

[5] Shishesaz, M, Hosseini, M., A review on stress distribution, strength and failure of bolted composite joints. ***Journal of Computational Applied Mechanics***, 49, 2 415–429 (2018).

[6] Khosravani, M, R, Soltani, P, Weinberg, K, Reinicke, T., Structural integrity of adhesively bonded 3D-printed joints. ***Polymer Testing***, 100 107262 (2021).

[7] Arikan, V, Dogan, A, Dogan, T, Sabanci, E, Al-Shamary, A, K, J., Effects of Temperature and Hole Drilling on Adhesively Bonded Single-Lap Joints. ***The Journal of Adhesion***, 91, 3 177–185 (2015).

[8] Bouchikhi, A, S, Megueni, A, Gouasmi, S, Boukoulda, F, B., Effect of mixed adhesive joints and tapered plate on stresses in retrofitted beams bonded with a fiber-reinforced polymer plate. ***Materials and Design***, 50 893–904 (2013).

[9] Kemiklioğlu, U, Okutan, B, B. Vibration effects on tensile properties of adhesively bonded single lap joints in composite materials. ***Polymer Composites***, 40, 3 1258–1267 (2019).

[10] Demir, K, Gavgali, E, Fatih, A, Akpinar, S., The effects of nanostructure additive on fracture strength in adhesively bonded joints subjected to fully reversed four-point bending fatigue load. ***International Journal of Adhesion and Adhesives***, 110 102943 (2021).

[11] Avinc, I, Akpinar, S, Akbulut, H, Ozel, A., Experimental analysis on the single-lap joints bonded by a nanocomposite adhesives which obtained by adding nanostructures. ***Composite Part B***, 110 420–428 (2017).

[12] Heidarpour, F, Farahani, M, Ghabezi, P., Experimental investigation of the effects of adhesive defects on the single lap joint strength. ***International Journal of Adhesion and Adhesives***, 80, 128–132, (2018).

[13] Ribeiro, F, M, F, Campilho, R, D, S, G, Carbas, R, J, C, Silva, L, F, M., Strength and damage growth in composite bonded joints with defects. ***Composites Part B***, 100 91–100 (2016).

[14] De Moura, M, F, S, F, Daniaud, R, Magalhães, A, G., Simulation of mechanical behaviour of composite bonded joints containing strip defects. ***International Journal of Adhesion and Adhesives***, 26, 6 464–473 (2006).

[15] Tamborrino, R, Palumbo, D, Galietti, U, Aversa, P, Chiozzi, S, Luprano, V, A, M., Assessment of the effect of defects on mechanical properties of adhesive bonded joints by using non destructive methods. ***Composites Part B: Engineering***, 91 337–345 (2016).

[16] Durodola, J, F., Functionally graded adhesive joints – A review and prospects. ***International Journal of Adhesion and Adhesives***, 76, 83–89 (2017).

[17] He, X., A review of finite element analysis of adhesively bonded joints. ***International Journal of Adhesion and Adhesives***, 31, 4 248–264 (2011).

[18] Li, J, Yan, Y, Zhang, T, Liang, Z., Experimental study of adhesively bonded CFRP joints subjected to tensile loads. ***International Journal of Adhesion and Adhesives***, 57 95–104 (2015).

[19] Jairaja, R, Naik, G, N., Numerical studies on weak bond effects in single and dual adhesive bonded single lap joint between CFRP and aluminium. ***Materials Today: Proceedings***, 21 1064–1068 (2020).

[20] Stein, N, Weißgraeber, P, Becker, W., A model for brittle failure in adhesive lap joints of arbitrary joint configuration. ***Composıte Structure***, 133 707–718 (2015).

[21] Zhang, B, Allegri, G, Yasaee, M, Hallet,t S, R., Micro-Mechanical Finite Element Analysis of Z-pins under Mixed-Mode Loading. ***Composıtes Part A***, (2015).

[22] Koh, T, M, Feih, S, Mouritz, A, P., Experimental determination of the structural properties and strengthening mechanisms of z-pinned composite T-joints. ***Composite Structures***, 93, 9 2222–2230 (2011).

[23] Chang, P, Mouritz, A, P, Cox, B, N., Properties and failure mechanisms of pinned composite lap joints in monotonic and cyclic tension. **Composites Science and Technology**, 66 2163–2176 (2006).

[24] Saleh, M, N, Saeedifar, M, Zarouchas, D, Freitas, S, T, De., Stress analysis of double-lap bi-material joints bonded with thick adhesive International Journal of Adhesion and Adhesives Stress analysis of double-lap bi-material joints bonded with thick adhesive. ***International Journal of Adhesion and Adhesives***, 102480 (2019).

[25] Darla, V, Satish, Ben, B, Sai, Srinadh, K, Venkata, Rao, K., Evaluation of aluminum to composite bonded lap joints" ***High Performance Polymers***, 34, 10 1152–1163 (2022).

[26] Bodjona, K, Lessard, L. Hybrid bonded-fastened joints and their application in composite structures: A general review. ***Journal of Reinforced Plastics and Composites***, 35, 9 764–781 (2016).

[27] Chen, Y, Li, M, Yang, X, Luo, W., Damage and failure characteristics of CFRP/aluminum single lap joints designed for lightweight applications. ***Thin-Walled Structures***, 153, 106802 (2020).

[28] Li, W, Guo, S, Giannopoulos, I, K, He, S, Liu, Y., Strength enhancement of bonded composite laminate joints reinforced by composite Pins. ***Composite Structures***, 236, 111916 (2020).

[29] Xie, W, Luo, Z, Zhou, Y, Peng, W, Liu, Q., Experimental and numerical investigation on opposing plasma. ***Chinese Journal of Aeronautics***, (2022).

[30] Parkes, P, N, Butler, R, Meyer, J, de Oliveira, A., Static strength of metal-composite joints with penetrative reinforcement. ***Composite Structures***, 118, 1 250–256 (2014).

[31] Graham, D, P, Rezai, A, Baker, D, Smith, P, A, Watts, J, F., The development and scalability of a high strength, damage tolerant, hybrid joining scheme for composite-metal structures. ***Composites Part A: Applied Science and Manufacturing***, 64 11–24 (2014).

[32] Katsivalis, I, Thomsen, O, T, Feih, S, Achintha, M., Strength evaluation and failure prediction of bolted and adhesive glass/steel joints. ***Glass Structures and Engineering***, 3, 2 183–196 (2018).