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Research Article

Charpy Impact Response of Notched Aluminum 5754-H111 of Repaired with Carbon/Epoxy and E-Glass/Epoxy

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Abstract

In this study, aluminum sheets with three different notch depths were repaired with carbon/epoxy and e-glass/epoxy composites and than were investigated experimentally for their response to Charpy impact. [90/45/-45] oriented triaxial fabrics were used in patch reinforcement materials. Composite laminates were prepared in [90/45/-45/45/-45/90] orientation by placing these three axial fabrics on top each other. Hand lay-up technique was used in the preparation of laminated composites. The reinforcement fabrics wetted by hand lay-up were cured by hot molding at 100 °C and 7 bar pressure. Composite plates were produced in 40x40 cm dimensions. Aluminum plates were also provided in 40x40 cm dimensions. Both aluminum and composites were cut with water jet to obtain samples and patches from these plates. The aluminum and composite elements cut to the desired dimensions, were glued to each other on one-side with a double component methyl methacrylate adhesive. In the experimental stage, some mechanical properties of the composites were determined first. Afterwards, the energy absorption capacities of the aluminum plates as repaired and unrepaired in three different notch lengths (3 mm, 5 mm, 7 mm), was determined by conducting Charpy notch impact tests. In addition, Scanning Electron Microscope (SEM) analysis of the composite patches were performed. This study, which was conducted to determine to what extend the composite patches affect the notch impact toughness of the aluminum plate, aims to be a guiding resource for engineers and researchers for composite patch repairs.

Keywords: Charpy impact response, E-glass, Carbon fiber, Epoxy.

Karbon/Epoksi ve E-Cam/Epoksi ile Onarılmış Çentikli 5754-H111 Alüminyum Charpy Darbe Tepkisi

Öz

Bu çalışmada, üç farklı çentik derinliğine sahip alüminyum levhalar, karbon/epoksi ve e-cam/epoksi kompozitleri ile tamir edilmiş ve Charpy darbe tepkileri deneysel olarak araştırılmıştır. Yama melzemeleri [90/45/-45] oryantasyonlu üç eksenli kumaşlar ile takviyelendirimiştir. Bu üç eksenli kumaşlar üst üste konumlanırılarak [90/45/-45/45/-45/90] oryantasyonlu kompozit laminalar oluşturulmuştur. Laminaların oluşturulmasında el yatırması tekniği kullanılmıştır. El yatırması ile ıslatılan takviye kumaşları 100 °C ve 7 bar basınç altında kürleştirilmiştir. Kompozit plakalar 40x40 cm ölçülerinde üretilmiştir. Alüminyum plakalar ise yine 40x40 cm ölçülerinde teemin edilmiştir. Bu plakalardan numune ve yamalar elde etmek için hem alüminyum hemde kompozitler su jeti ile kesilmiştir. İstenilen ölçülerde kesilen alüminyum ve kompozit elemanları, çift bileşenli metil metakrilat yapıştırıcı ile tek taraflı olarak birbirine yapıştırılmıştır. Deneysel aşamada öncelikle kompozitlerin bazı mekanik özellikleri belirlenmiştir. Sonrasında üç farklı çentik boyundaki (3 mm, 5 mm, 7 mm) onarılmış ve onarılmamış alüminyum levhaların enerji emme miktarları Charpy çentik darbe deneyleri ile tespit edilmiştir. Ayrıca kompozit yamaların Taramalı Elektron Mikroskobu (SEM) analizi yapılmıştır. Kompozit yamaların alüminyum plakanın çentik darbe tokluğunu hangi düzeyde etkilediğinin belirlenmesi için yapılan bu çalışma, mühendislere ve araştırmacılara kompozit yama onarımları için bir yol gösterici kaynak olması hedeflenmiştir.

Anahtar Kelimeler: Charpy darbe tepkisi, E-cam, Karbon fiber, Epoksi.

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1. Introduction

Impact toughness and fracture behavior of aluminum alloys have technical importance in providing fail safe component design in structural applications (Tajally, et. al., 2010). Design methods based on Charpy impact tests often provide solutions to avoid brittle fracture (Wallin, et. al., 2020). Features such as high specific strength, corrosion resistance, high fatigue strength make advanced composite materials an ideal patch repair element (Khalili, et al., 2009). In the repair of cracked metal plates with composite, surface treatments are generally applied to prevent adhesion failure (Papanikos, et. al., 2007). Aluminum adheres better to glass fiber reinforced composites than other composites (Dharaj, et. al. 2020). Although notches are necessary for engineering design, they tend to promote crack initiation as a result of stress concentration in their environment (Torabi, et. al., 2018). Patches reduce the stress around the crack area so that the stresses can be transferred from the cracked aluminum sheet to the patch part, and there is no further crack propagation in the area (Pradhan, et. al., 2020). Notches in structural components are one of the places where stress concentrations occur, so a lot of research has been done on notches in recent years (Sadrjarghouyeh, et. al., 2015), (Htoo, et. al., 2016), (Cazacu, et. al., 2020), (Papuga, et. al., 2019).

Composite materials, due to their properties such as lightness and durability, have been used extensively in recent years (Çallıoğlu and Kavla, 2019). Fiber-reinforced polymers (FRP) are frequently used as primary and secondary structures in aerospace structures. Although their specific strength and stiffness are remarkable, their weak mechanical properties throughout the thickness cause the formation of separation cracks and consequently low fracture toughness under out-of-plane loads. The main reasons for low fracture toughness are the absence of reinforcing elements throughout the thickness and the amount of resin between the layers causing a rapid spread of seperation cracks in the region (Yıldız, et. al., 2019).

In this study, aluminum 5754-H111 plates were notched in three different depths (3 mm, 5 mm, 7 mm). The effect of these notches on fracture toughness was determined by Charpy impact tests. Later, these notches were repaired with e-glass/epoxy and carbon/epoxy composites and how this repair changes the impact energy absorption was investigated. In the study, some mechanical properties of aluminum and composite materials were determined by performing tensile tests. Finally, SEM images of composite materials were taken and analyzed.

2. Material and Method

2.1. Fabrication Process

In this study, aluminum 5754-H111 was used as substrate material from Metal Reyonu Company, Kocaeli. As shown in Fig. 1 some of the main properties of aluminum are high specific strength and high corrosion resistance (Elahi, et. al., 2016). Samples were cut from 2 mm aluminum sheets in 10x55 mm dimensions and three different notch depths (3 mm, 5 mm, 7 mm) with Kardes Cam water jet (Denizli). Carbon and glass fabrics are triaxial and orientation angles are in the order of [90/45/-45] from Metyx Company, Kocaeli. The layer weight is 300 g/m^2 for carbon and 280 g/m^2 for glass. After applying 70-30% wt. of epoxy+curing agent to the fabrics by hand lay-up method, they were positioned in the [90/45/-45/45/-45/90] orientation and hot molded in six layers (100 °C, 3 h. 7 Bar). Patches from the produced composite plates were cut with water jet in 8x30 mm width x length.

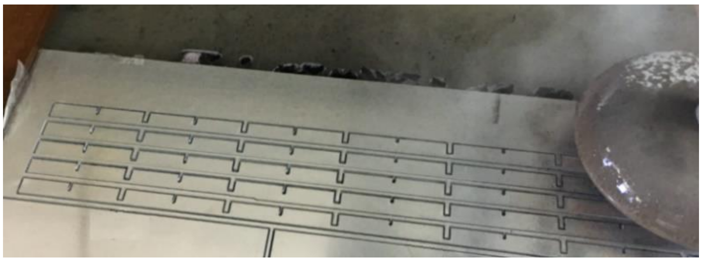

Fig. 1. Cutting of samples with water jet.

Adhesion quality depends on two main factors, surface free energy and surface roughness. Therefore, surface treatment before adhesive bonding, in the production process of fiber metal hybrid laminates (FMLs), is the most critical step that can not be ignored (Laban, et. al., 2017). The thin, slippery layer on the aluminum plates was removed with a rotary felt. These aluminum plates were cleaned with Weicon general cleaner spray. After it is ready to bond with the surface, the carbon/epoxy composite were glued with Weicon RK-7100 two component methyl methacrylate adhesive and as shown in in Fig. 2.

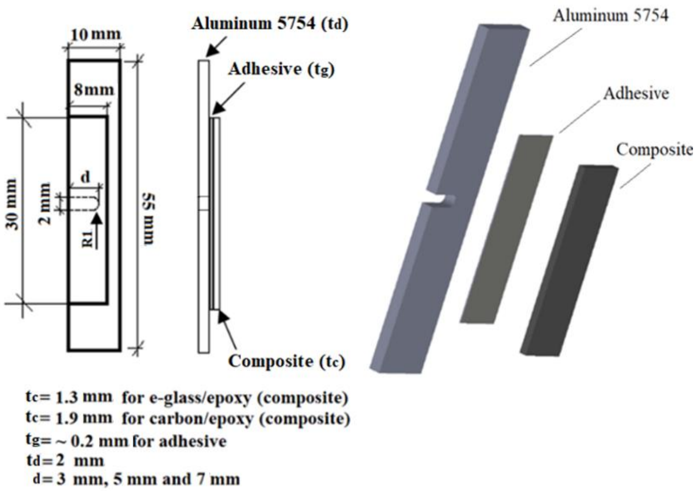

Fig. 2. Dimensions and three-dimensional representation of the sample.

2.2. Experimental Studies

Firstly, the mechanical properties of the materials used in this study were determined by performing tensile tests with Instron 8801 tester. Afterwards, the unrepaired and repaired configurations of the samples were tested with the Digital Charpy notch impact device shown in Figure 3 to determine impact absorption energies and to determine the effect of the patch on the impact. Finally, composite materials SEM analyzes were performed by taking internal structure images with Zeiss Supra 40VP electron microscope.

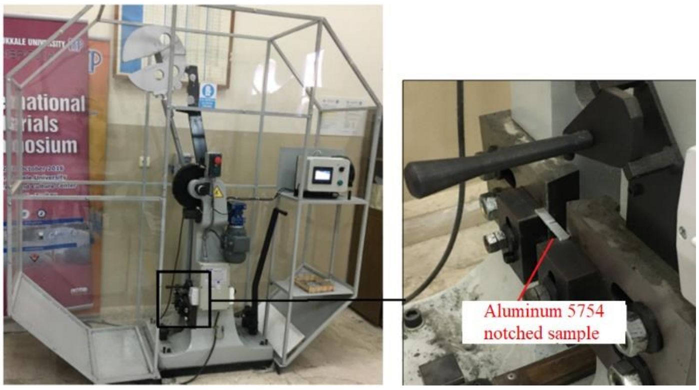

Fig. 3. Charpy impact test.

3. Results and Discussion

3.1. Tensile Properties

Tensile tests of the materials used in the study were carried out with Instron 8801 (50kN) tester at ambient humidity conditions and ambient temperature. The tests were conducted with an axial draw load at a speed of 1mm/min with displacement control. Stress-strain curves are given in Fig. 4, carbon/epoxy (a), e-glass/epoxy (b) and aluminum 5754-H111 (c). Tensile strengths of the composite samples with the orientation of [90/45-45/45/-45/90] are measured as 112 MPa for e-glass/epoxy, 238 MPa for carbon/epoxy approximately and aluminum 5754-H111 plate has a tensile strength of 170 MPa. Carbon fiber is lighter in structure and more durable than most metallic materials. Because it is formed by the combination of very fine cappilary fibers, these fibers have less internal structure defects and parallel to this, the tensile strength characteristic is high.

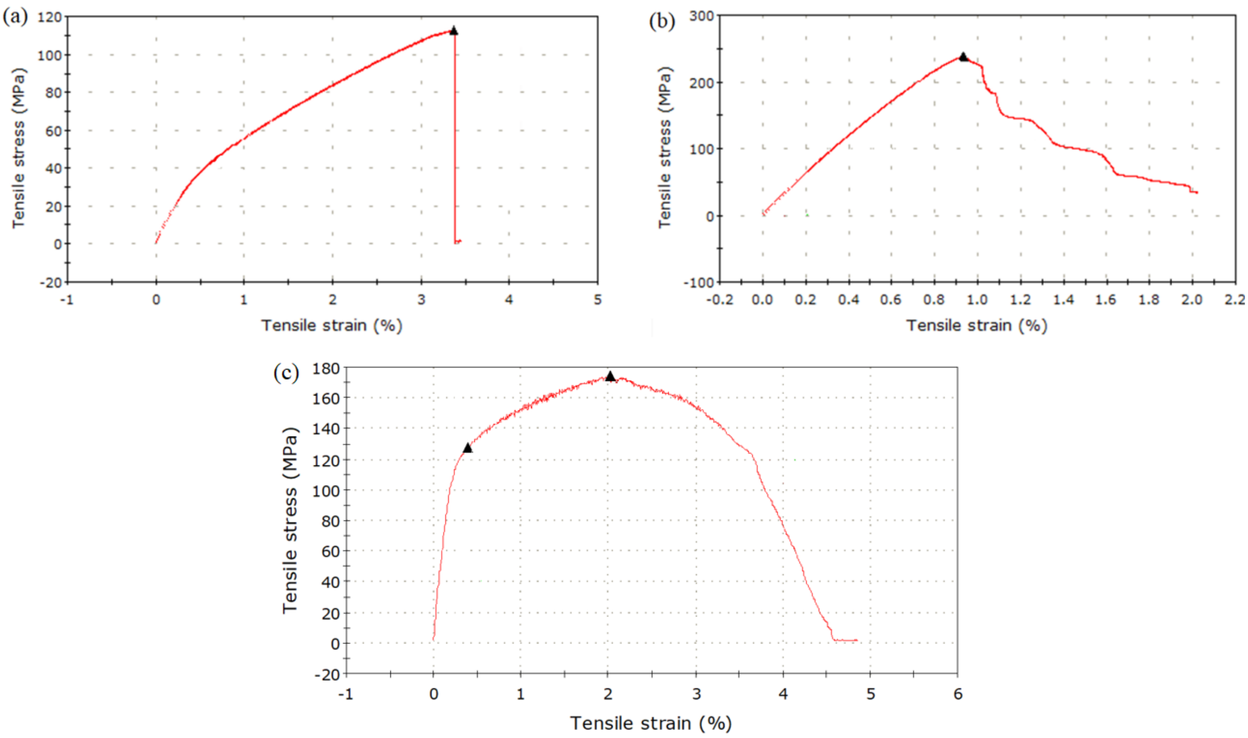

Fig. 4. Stress-strain curves of used materials; e-glass/epoxy (a), carbon/epoxy (b), aluminum 5754-H111 (c).

Elasticity modules of the materials were determined from tensile tests. As seen in Fig. 5, elasticity modules for e-glass/epoxy, carbon/epoxy and aluminum 5754 were determined as 9 GPa, 30 GPa and 65 GPa respectively. In the uniaxial tensile test of the composite, the most important factor determining the elasticity is the orientation of the fibers. The layers forming the structure of the tested composites do not contain axially oriented fibers. Therfore the modulus of elasticity of aluminum is higher compared to these composites.

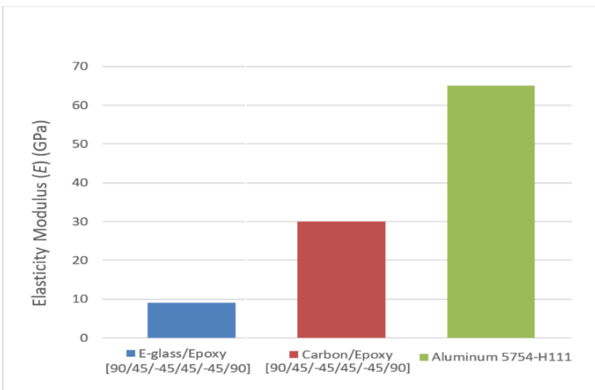

Fig. 5. Elasticity modules of sample materials.

3.2. Charpy impact response

The Charpy impact test is a strain test used to determine the amount of energy a material absorbs during fracture. Notch toughness of the material is measured with the absorbed energy. It is widely used today due to its ease of use and cheapness. The apparatus attached to a pendulum is dropped from a certain height and hits the notched sample. The energy absorbed by the material is calculated based on the apparatus height before breaking and the apparatus height after the break. The amount of energy absorbed by the test samples was determined and presented in Fig. 6. Energy absorption capabilities of unrepaired samples with notch depths of 3 mm, 5 mm and 7 mm were determined to be approximately 4.2, 1.94, 029 J respectively. The energy absorption of the samples repaired with e-glass/epoxy were determined to be 154.3, 156.7, 157.6 J respectively. Finally, samples repaired with carbon/epoxy absorbed 153.1, 157.9 and 159 J of energy, respectively (for 3 mm, 5 mm, 7 mm notches). From the Charpy tests, it was seen that both glass/epoxy and carbon/epoxy patch improved the strength up to 150-160 J at all notch depths.

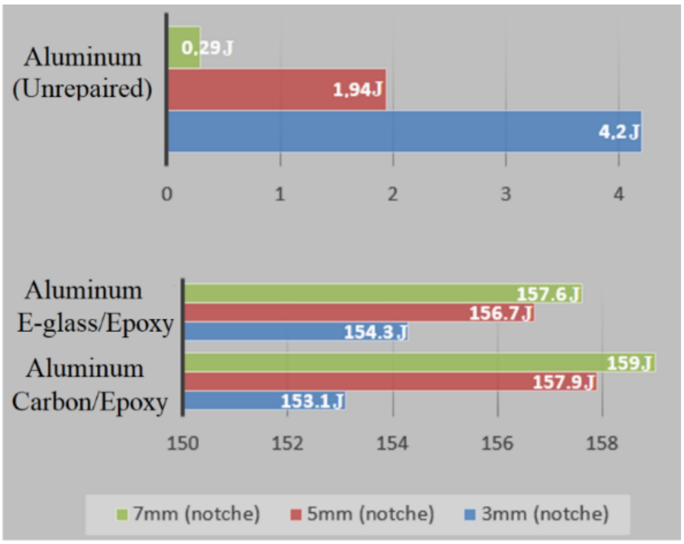

Fig. 6. Absorbed Charpy impact energies.

Fig. 7. shows 3 mm notched sample repaired with carbon composite. Since the samples with the highest wall thickness in the notch region were 3mm notched samples, the type of fracture (ductile or brittle) was observed most clearly in these samples. As can be seen from the form of fracture in Fig. 7(a), the aluminum plate showed a characteristic ductile fracture behaviour. Fig. 7(b) shows the patched side of the sample. Here the form of damage to the composite patch is brittle fracture.

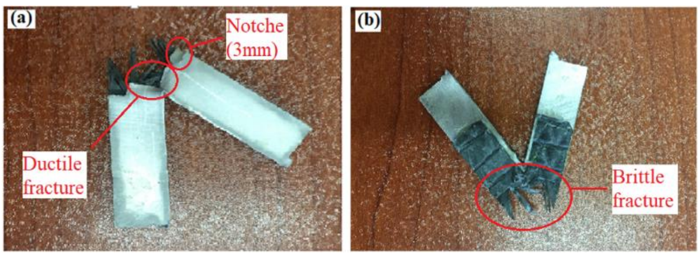

Fig. 7. 3 mm notched carbon/epoxy patched sample; unrepaired side (a), repaired side (b).

3.3. Scanning electron microscope (SEM) analysis

In recent years, SEM analysis has been used as a useful method for fractographic examination of composite materials. SEM images of the fracture surfaces of the layered composite samples given in Fig. 8(a) e-glass/epoxy and Fig. 8(b) carbon/epoxy images show characteristical signs of brittle fracture. It was observed that the matrix roughness of the e-glass/epoxy sample was higher. The interaction of the epoxy matrix surrounding the fibers with the fiber is very important in terms of load transfer. The amount of matrix adhered to the fiber layers reveals the fiber-matrix interface adhesion quality. Adhesion quality affects the toughness of the composite material.

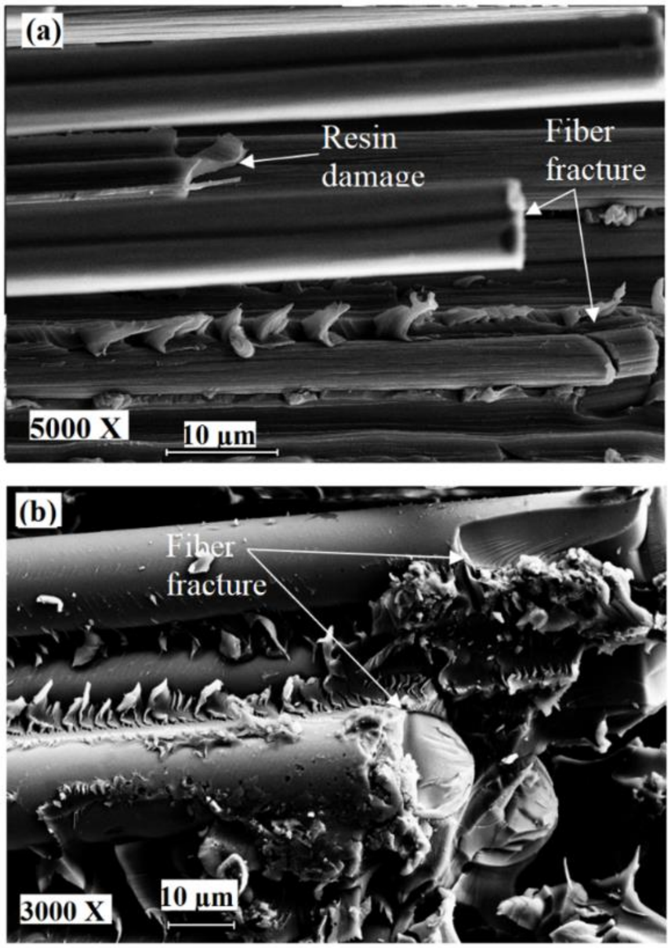

Fig. 8. SEM images; carbon/epoxy (a), e-glass/epoxy (b).

4. Conclusions and Recommendations

The repair process of noched aluminum with patches is more practical than other methods such as welding and rivets. Thus, patch capabilities of laminated composites were investigated in this study. The difference (orginality) of the study from the literature is the notch and patch types.

In this study, notched 5754 H111 aluminum samples repaired with single sided glass/epoxy and carbon/epoxy were investigated experimentally in Charpy impact tests. In addition, some mechanical properties of the materials used for the sample were determined and SEM analyzes of the composites used for repair were made.

The following results were obtained from this study;

- While the energy absorption of the unrepaired samples was in the 0.2-4.2 J band, the energy absorption was increased to the 150-160 J band in both composite repairs (E-glass/epoxy, Carbon/epoxy).
- Carbon/epoxy composites are relatively more effective reinforcing the notched plates then e-glass/epoxy composites in Charpy impact energy apsorption.
- The tensile strength of carbon/epoxy patches are approximately 53% higher than e-glass/epoxy patches.
- SEM images show that both composite patches (E-glass/epoxy, Carbon/epoxy) have strong fiber matrix interface bonds.
- Different notch and patch types are proposed as a subject for further study.

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