European Journal of Technique

journal homepage: https://dergipark.org.tr/en/pub/ejt

Vol.11, No.1, 2021

Numerical Investigation of Fatigue Behaviors of Non-Patched and Patched Aluminum Pipes

Hamit Adin[1*], Bilal Yıldız[2], Mehmet Şükrü Adin[3]

[1*]Batman University, Department of Mechanical Engineering, Batman, Turkey. (e-mail: hamit.adin@batman.edu.tr).
[2] Batman University, Department of Mechanical Engineering, Batman, Turkey. (e-mail: bllyildiz@hotmail.com.tr).
[3] Batman University, Department of Mechanical Engineering, Batman, Turkey. (e-mail: mehmetsukru.adin@batman.edu.tr).

ARTICLE INFO

Received: March., 08. 2021
Revised: April., 04. 2021
Accepted: May, 20. 2021

Keywords:
Aluminum
Composite
Patch
Fatigue
Ansys

Corresponding author: *Hamit Adin*

ISSN: 2536-5010 | e-ISSN: 2536-5134

DOI: https://doi.org/10.36222/ejt.893327

ABSTRACT

In this study, the fatigue behaviors of non-patched and patched aluminum pipes were investigated numerically. The Finite Element Method was used for fatigue analysis in the study. Finite Element Method was implemented with Ansys Workbench (15.0) program. Al 6063 type aluminum pipe, DP-460 type adhesive and [0/90]2 reinforced angled glass-epoxy composite patch material were used in the analyzes. As a result of the numerical study, it was observed that patch size is an effective parameter in fatigue strength and that quarter-circle and semi-circular composite patches increase the fatigue life. It was also observed in the analyzes that the quarter-circle patched aluminum pipes achieved higher fatigue strength.

1. INTRODUCTION

The development of materials science has been a very important factor in the progress of technology in the process of history. For this reason, material science needs to be developed for the development of humanity. These two phenomena make up an inseparable whole. Developing materials science offers us solutions that are different, simple, practical, reliable and bring significant cost advantages for businesses when today's conditions are considered. These developments in material science provide cost advantages in the field of industry as well. Nowadays, instead of replacing damaged parts, it is generally preferred to carry out repairs to avoid time and money loss. In choosing repair methods, it is aimed to minimize time and cost. Particularly in tearing and cracking, patching method is preferred by using adhesive [1-6]. Therefore, there is no need for repair with mechanical connection forms such as screws, rivets, and welding. With this method, the destructive damages that may occur in the material can be prevented. In the literature, it is possible to find many studies on patching using adhesives. Some of these studies are presented below:

Lee et al. investigated the effect of different geometric shapes (rectangular, triangular, inverted triangular and parallelogram) on bonding strength [7]. In the study, consistent with the numerical results, they obtained the highest bonding strength in the inverted triangular patch. Gavgali et al. experimentally and numerically investigated the fatigue and static strengths of single-lap and three-step-lap joints, which were subjected to tensile and four-point bending tests [8]. In the study, they stated that the change in the geometry of the area where the bonding was made had a profound effect on both fatigue and fracture behavior of the joint. Sahin et al. investigated lifetimes of single-lap joints of five different adherend thicknesses obtained using AA2024-T3 aluminum alloy and DP460 structural adhesive under varying tensile fatigue loads [1]. In the study, they stated that the static tensile strength of the joints increased due to the increase in adhesion thickness. Karaman numerically investigated the behavior of double-sided lap joint of AA-5083 aluminum sheets with elliptical holes under bending load [9]. In the analysis, the bending damage loads of the samples were found. From the results, it was revealed that the patched samples carried a higher loads. Erkek experimentally investigated the effects of thermal aging on the buckling behavior of composite sheets repaired with a patch using adhesive from the outer part. In the study, it was observed that temperature and adhesive thickness variations affect the buckling load [10]. Ergün examined AA-5083 aluminum sheets with elliptical holes and glass fiber reinforced composite patches by joining them with DP-460 type adhesive. In the study, experimental and numerical results were found to be close to each other [11]. Adin et al. bonded the composite material with AA-5083 aluminum material using DP-460 adhesive and examined the tensile strength. As a result of their studies, they stated that lap width and patch width are important [12]. Canbolat examined the repair of aluminum sheets by composite patches in case of damage. In the study, it was observed that damage loads and damage mechanisms converged experimentally and numerically [13]. Zarrinzadeh et al. investigated experimentally and numerically the effects of fatigue on crack growth in a cylindrical aluminum pipe with cracks. In the study, they stated that they approached the realistic behavior of the structure [14]. In another study, Zarrinzadeh et al. examined the fatigue life after patching on a cylindrical cracked aluminum pipe. Different from previous works, glass-epoxy composite material was used as patch material. In addition, they investigated the effect of patch length on fatigue life. As a result of the study, they found a directly proportional relationship between the increase in the number of layers and the fatigue life, and an inversely proportional relationship between the patch length and the fatigue life [15]. Liu et al. investigated the change in fatigue life as a result of patching the cylindrical cracked aluminum pipe with composite material. As a result of the study, they determined that there is a directly proportional relationship between the number of layers of the composite material and their fatigue life [16]. During the use of pipes, damages occur in the form of small cracks due to various internal and external effects [16-18]. In general, cutting out the damaged area and changing it with a new one causes loss of money and time. In this study, aluminum pipes with various cracks were repaired with patches made of glass-epoxy composite material. Later, the draft-pressure fatigue behavior of the patched pipes produced in this way was investigated by the finite element method. On the basis of the studies in the literature, the purpose of the research is to find the effect of the patch on the fatigue life of the structure. Studies in the literature investigate how fatigue life is affected after patching [19]. Although they used different parameters and materials, almost all of them obtained findings on the positive effects of the patch presence.

The tubular Al 6063 aluminum used in our study is a frequently preferred material in the industry. In case of damage of this material, its fatigue behavior was investigated after repair with a composite patch.

2. MATERIAL AND METHOD

In our study, numerical fatigue analyzes were performed using the Finite Element Method. Numerical analyzes were performed using the Ansys Workbench (15.0) finite element package program. In the analyzes, Al 6063 type aluminum pipe base material, $[0/90]_2$ reinforced angle glass-epoxy patch and DP-460 industrial adhesive were used. In the analyzes, tensile-compression load was applied to the samples, and fatigue was achieved. Samples were modeled in three dimensions. The mechanical properties of Al 6063 type Aluminum pipe, $[0/90]_2$ reinforced glass-epoxy composite material and DP-460 type industrial adhesive materials used in the analyzes are given in Table 1, Table 2 and Table 3 [11, 20].

TABLE 1
MECHANICAL PROPERTIES OF AL 6063 TYPE ALUMINUM PIPE

Elasticity module	69000 MPa
Poisson ratio	0.33
Tensile strength	150 MPa
Yield strength	90 MPa

TABLE 2
MECHANICAL PROPERTIES OF $[0/90]_2$ REINFORCED ANGLE GLASS-EPOXY COMPOSITE PATCH

E_1	47902 MPa
$E_2 = E_3$	20395.25 MPa
$G_{12} = G_{13} = G_{23}$	4941 MPa
ϑ_{12}	0.253
$\vartheta_{13} = \vartheta_{23}$	0.106

TABLE 3
MECHANICAL PROPERTIES OF DP-460 TYPE INDUSTRIAL ADHESIVE

Elasticity Module	2077.1 MPa
Poisson's ratio	0.38
Tensile strength	44.616 MPa
Adhesive thickness	0.25 mm
Shear stress	23.99 MPa
Shear strength	33.35 MPa
Shear module	560 MPa

The dimensions of the aluminum pipe used in the study are given in Fig. 1. All dimensions selected in the modeling of pipe samples were determined by considering the industrial uses of aluminum pipes. As seen in Fig. 1, the large diameter (D) of the aluminum pipe is 90 mm, the small diameter (d) is 86 mm, the length is 250 mm, and the pipe thickness is 2 mm. Cracked damaged pipes were examined in the analyzes [21]. The crack lengths in the pipes were taken as 1, 3, 5, 7 and 10 mm. The cracks occurred in the middle of the length of the pipe and perpendicular to the direction where the draft-compression loads were applied. Damaged pipe with a crack length of 10 mm is shown as an example in Fig. 1.

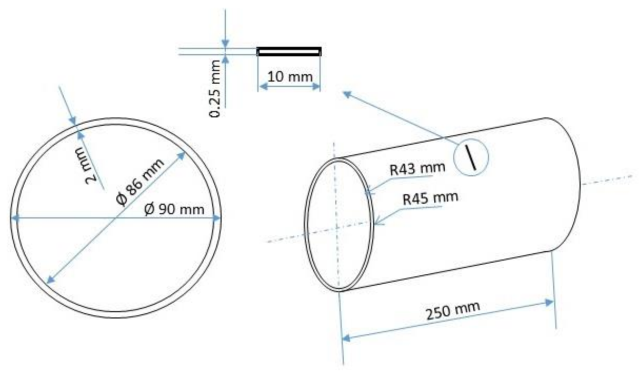

Figure 1. Dimensions of damaged Al 6063 aluminum pipe.

In our study, the repair process was carried out using quarter and semi-circular glass-epoxy patches. The dimensions of the patches used in the repair are shown in Fig. 2a and b. The length of the glass-epoxy patch material is 50 mm and its thickness is 0.4 mm.

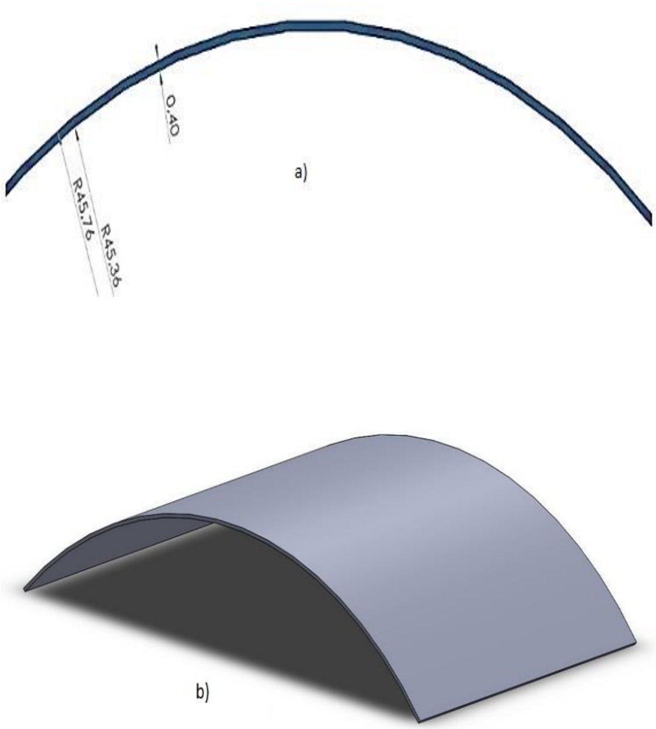

Figure 2. [0/90]$_2$ reinforced angle glass-epoxy patch; a) front view b) isometric view (Unit: mm).

Analyzes were carried out in three parts as non-patched, quarter-circular and semi-circular patched. In the analyzes, the patches were positioned at the center of the pipe based on the center of the crack zone. Fiber orientation and reinforcement angles of the patches are given in Fig. 3.

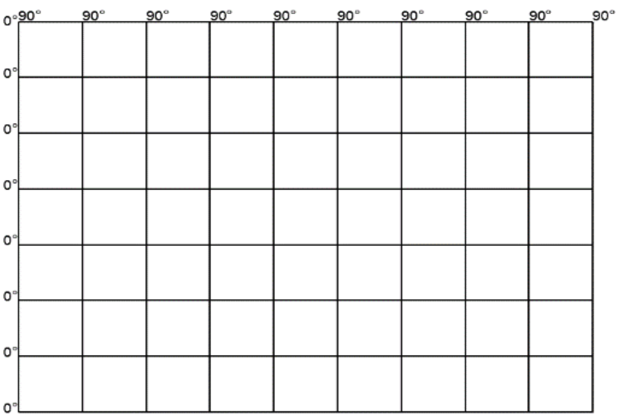

Figure 3. Fiber orientation angles of glass-epoxy composite patches.

2.1. Fatigue analysis

In numerical analyzes, all three-dimensional models were made in the SolidWorks program according to the measurements given in Fig.1, and then finite element analyzes were made in the Ansys Workbench program [22]. Aluminum pipes are modeled as non-patched, quarter-circular and semi-circular composite patches. In addition, in case of three different patches for each crack length, a total of 15 different modelings was performed using the mechanical values given in Table 1, Table 2 and Table 3, and then numerical analyzes were carried out. In analysis, elasticity module, shear stress and poisson's ratio were introduced to the system respectively, and mesh operation was performed by selecting the mesh structure [23-28]. Then, fatigue analyzes of patched and non-patched pipes were carried out according to five different crack parameters. Fatigue analyzes were performed as tensile-compression [29-34]. When the analysis models were created, one side was accepted as a fixed support, as seen in Fig. 4, and 40.5 MPa, which is 45 percent of the yield strength of Al 6063 Aluminum pipe, was used. All analyzes were made in the case of quarter-circular and semi-circular composite patches with the same pipe sizes, five different crack lengths and two different geometric shapes. In addition, in order to measure the gain, analyzes were made in the non-patched form of the aluminum pipe and a total of 15 different analyzes were carried out. The mesh (mesh structure), which should be used in the finite element separation process, contains a special place that significantly increases the accuracy of the analysis results [35, 36]. Again, taking into account the studies in the literature, 0.25 mm for DP-460 and 1 size for Al 6063 and Glass - epoxy were selected. Other details of the mesh process are like this; three different face-sizing modules for three different materials were added to the Ansys Workbench feature tree section. After selecting individual element sizes and models, the Triangle Surface Mesher method was selected and the program was run.

TABLE 4
NUMBER OF NODE AND ELEMENT

Pipe	Crack length (mm)	Number of nods	Number of elements
Non-patched	1	1.193.979	651.523
	3	1.198.924	655.243
	5	1.199.661	655.753
	7	1.199.149	655.502
	10	1.199.588	655.129
Quarter-circular patched	1	1.217.890	655.051
	3	1.222.835	658.771
	5	1.225.504	660.683
	7	1.223.090	659.052
	10	1.223.499	658.657
Semi-circular patched	1	1.235.435	657.583
	3	1.240.380	661.303
	5	1.241.117	661.813
	7	1.240.605	661.562
	10	1.241.044	661.189

After the meshing process, data on the nodes and number of elements belonging to different samples divided into finite elements are given in Table 4.

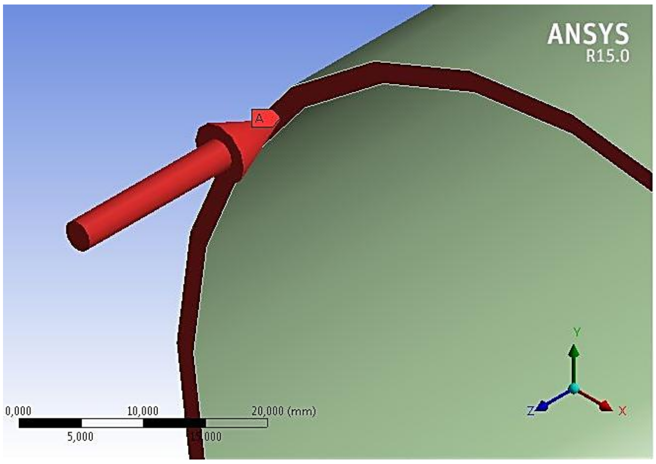

Figure 4. Representation of the 40.5MPa force applied to the analyzed sample.

3. FINDINGS AND DISCUSSION

After repair of aluminum pipes with different crack lengths Non-patched, quarter and semi-circular composite patched, the fatigue life is shown in Table 5 depending on the crack length. Here, N symbolizes the number of cycles.

TABLE 5
FATIGUE LIFES

	Non-patched	Quarter-circular patched	Semi-circular patched
Crack length (mm)	Fatigue Life (N)	Fatigue Life (N)	Fatigue Life (N)
1	11333	15365	14746
3	1704	4872	4807
5	1502	6735	5333
7	993	4307	2543
10	521	2944	2337

In the fatigue life calculation of the aluminum pipe made non-patched in Fig. 5a, it can be seen that the fatigue life decreased from 11333 cycles to 521 cycles during the progression of crack length from 1 mm to 10 mm. It was determined that this decrease is due to the crack length. In addition, it was observed from Fig. 5b and Fig. 5c that quarter and semi-circular composite patched aluminum pipes decreased their fatigue life due to the progress of the crack length. In the studies of Zarate and other researchers, the subject of research is the effect of the structure of the patch on the fatigue life [19]. However, it was seen from this study that the shape of the patch is also important.

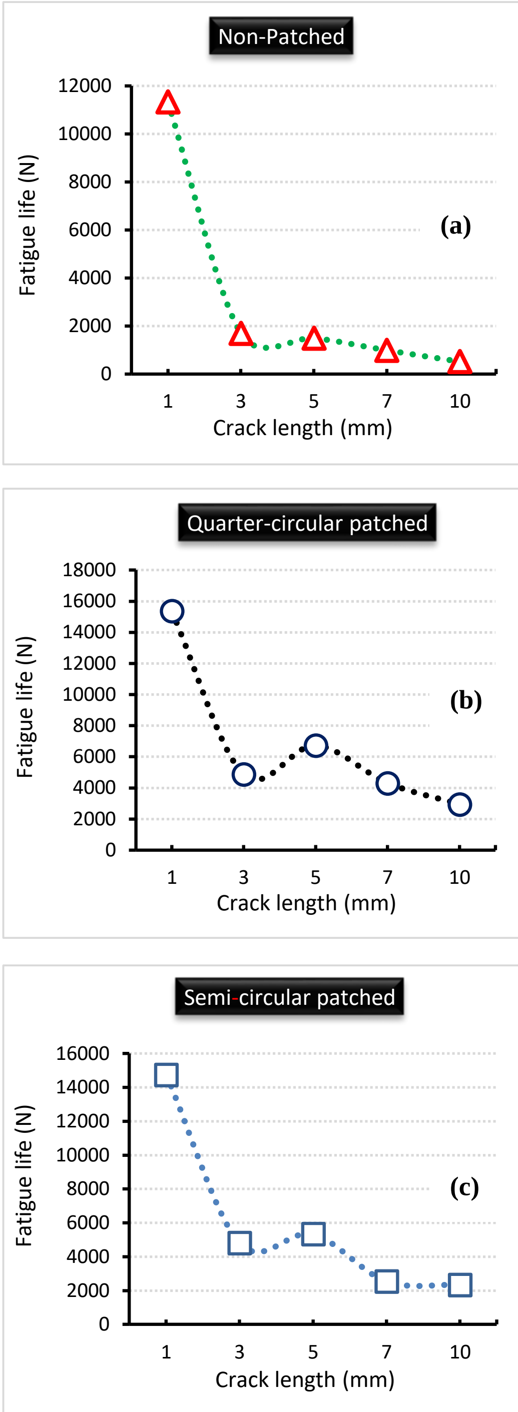

Figure 5. The fatigue lives of (a) non-patched, (b) quarter-circular and (c) semi-circular composite patched aluminum pipes.

Furthermore, it is seen from the comparison of all three cases in Fig. 6 that the fatigue life of the quarter-circular composite patch applied aluminum pipe has a better fatigue life than the semi-circular composite patch applied aluminum pipe. It is thought that the fatigue life increases of the patched specimens with 5 mm long cracks in Figure 5b and c are due to reaching the optimum point.

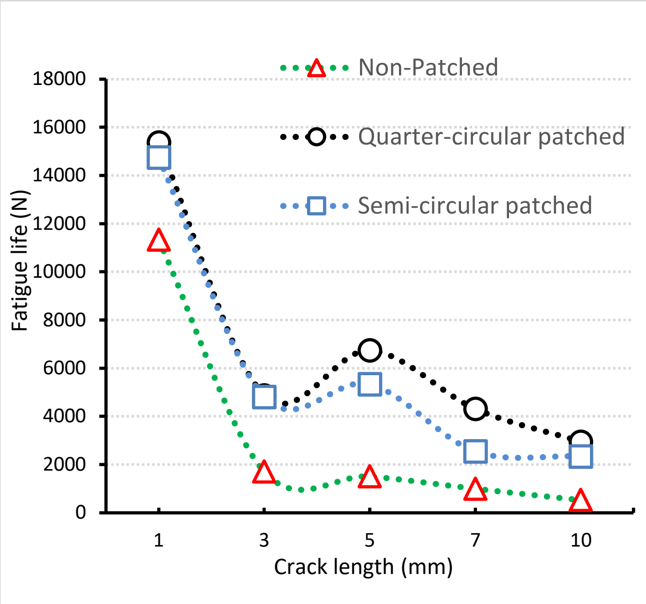

Figure 6. Comparison of fatigue lives of aluminum pipes according to patch shape

When Fig. 5b, c and Fig. 6 are examined, the effect of the patch on fatigue life can clearly be seen. Here, it was found that there is an inversely proportional relationship between the highest fatigue life and crack length. In other words, it was observed that the highest fatigue life was realized in samples with a crack length of 1 mm. When the fatigue life was examined according to the patch condition, the highest cycle number was obtained in the samples patched in quarter-circular form. The findings obtained about the fatigue life of different crack lengths as a result of patch repair and patch repair process seen in Fig. 6, formed by examining Table 5 with the cycle numbers, constitute the first step of the study. The second stage is on the efficiency of the repair process. In order to measure the efficiency, the differences between the fatigue life of the patched and non-patched samples are shown in Table 6 as % ratios. As seen in Table 6, it was determined that the fatigue life increases as a result of repairing the cracked pipe damage with a patch. Here, it was observed that the highest increase in life was in the quarter-circular patched pipe with 10 mm cracks and the increase rate was 565%.

TABLE 6
DIFFERENCES BETWEEN THE FATIGUE LIVES OF THE PATCHED AND NON-PATCHED SAMPLES

Crack length (mm)	Difference in fatigue life of non-patched and quarter-circular patched pipes (%)	Difference in fatigue life of non-patched and semi-circular patched pipes (%)
1	136	130
3	286	282
5	448	355
7	434	256
10	565	449

Fatigue life increase of quarter and semi-circular patched samples compared to non-patched ones are given in Fig. 7. The increases are given as percentages.

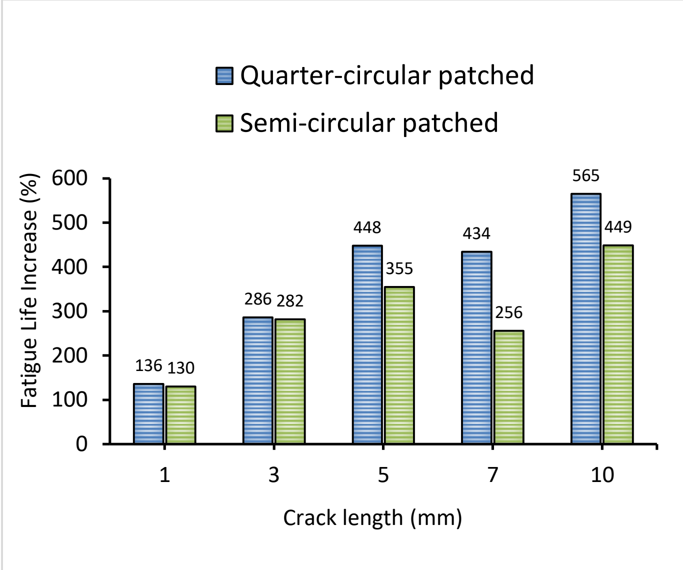

Figure 7. Comparison of the fatigue lives of non-patched and patched samples

As seen in Fig. 7, there is an inverse proportion between fatigue life and crack length. In this comparison, it was seen that the greatest contribution was achieved when the crack length was 10 mm. The reason for this contribution is that the patch coverage area varies. When all the results are examined, it is seen that there is a positive contribution of the patching process to the fatigue life. In addition, it was observed that the fatigue life of the quarter-circular patched pipes was higher than the semi-circular patched pipes.

4. CONCLUSION AND RECOMMENDATIONS

In this study, numerical damage analysis was carried out on non-patched or patched, assuming that 1, 3, 5, 7 and 10 mm long and 0.25 mm high cracks were formed in the center of Al 6063 type aluminum pipes. The patch material used in the study is $[0/90]_2$ reinforced angled glass-epoxy composite and the adhesive is DP-460. Ansys Workbench (15.0), which is a Finite Element Analysis program, was used in numerical analysis. The following conclusions were drawn from the data obtained on fatigue, stress and deformation.

As a result of patching the samples, it was observed that the fatigue lives increases. The most important point to be considered here is that the patch effect increases with the increase in the length of the crack. Increased fatigue life showed that it is possible to reuse the damaged pipe by patching. Considering the usage areas and costs of aluminum pipes, it is understood that it is more appropriate to patch them instead of replacing the damaged ones. For this reason, the use of pipes repaired with glass-epoxy composite patch will benefit both manufacturers and the national economy. In addition, if the cover area of the patch is patched with an area larger than the quarter-circular form, the patched pipe will have the highest fatigue strength.

REFERENCES

[1] R. Sahin and S. Akpinar, "The Effects of Adherend Thickness on the Fatigue Strength of Adhesively Bonded Single-Lap Joints," *Int J Adhes Adhes,* p. 102845, 2021.

[2] S. Bayramoglu, S. Akpinar, and A. Çalık, "Numerical analysis of elasto-plastic adhesively single step lap joints with cohesive zone models and its experimental verification," *J Mech Sci Technol,* vol. 35, no. 2, pp. 641-649, 2021.

[3] İ. Saraç, H. Adin, and Ş. Temiz, "A research on the fatigue strength of the single-lap joint joints bonded with nanoparticle-reinforced adhesive," *Weld World,* pp. 1-8, 2021.

[4] İ. Saraç, H. Adin, and Ş. Temiz, "Experimental determination of the static and fatigue strength of the adhesive joints bonded by epoxy adhesive including different particles," *Composites Part B: Engineering,* vol. 155, pp. 92-103, 2018.

[5] R. K. Ergün, H. Adin, A. Şişman, and Ş. Temiz, "Repair of an aluminum plate with an elliptical hole using a composite patch," *Mater Test,* vol. 60, no. 11, pp. 1104-1110, 2018.

[6] Ü. Kurtkan and H. Adin, "The investigation of the tensile behaviors of single L-joint type bonded with adhesive and rivet: Untersuchung der Zugeigenschaften von durch Kleben und Nieten gefügten Einzel-L-Verbindungen," *Materialwiss Werkst,* vol. 49, no. 8, pp. 963-977, 2018.

[7] H. Lee, S. Seon, S. Park, R. Walallawita, and K. Lee, "Effect of the geometric shapes of repair patches on bonding strength," *The Journal of Adhesion,* vol. 97, no. 3, pp. 207-224, 2021.

[8] E. Gavgali, R. Sahin, and S. Akpinar, "An investigation of the fatigue performance of adhesively bonded step-lap joints: An experimental and numerical analysis," *Int J Adhes Adhes,* vol. 104, p. 102736, 2021.

[9] Y. Karaman, "Numerical Investigation of Effect of Bending Behavior On Aluminum Plates With Elliptical Holes Patched By Sticking A Composite Patches," Master thesis, University of Batman, Batman, Turkey, 2017.

[10] B. Erkek, "Investigation of the Effects of Thermal Aging on the Buckling Behavior of Composite Sheets Repaired Using Patches and Adhesives.," Master thesis, Dicle University, Diyarbakir, Turkey, 2018.

[11] R. K. Ergün, "Experimental and Numerical Investigation of the Effect of Repairing Elliptical Perforated Aluminum Sheets with Composite Patch on Stress Behavior.," Master's thesis, Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey, 2014.

[12] M. Ş. Adin and E. Kılıçkap, "Strength of double-reinforced adhesive joints," *Mater Test,* vol. 63, no. 2, pp. 176-181, 2021.

[13] C. Canbolat, "Repair of 2024 Al plates with Glass-Fiber composite patch.," Master thesis, Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey, 2018.

[14] H. Zarrinzadeh, M. Z. Kabir, and A. Deylami, "Experimental and numerical fatigue crack growth of an aluminium pipe repaired by composite patch," *Eng Struct,* vol. 133, pp. 24-32, 2017.

[15] H. Zarrinzadeh, M. Z. Kabir, and A. Deylami, "Crack growth and debonding analysis of an aluminum pipe repaired by composite patch under fatigue loading,", *Thin Wall Struct,* vol. 112, pp. 140-148, 2017.

[16] J. C. Liu, M. J. Qin, Q. L. Zhao, L. Chen, P. F. Liu, and J. G. Gao, "Fatigue performances of the cracked aluminum-alloy pipe repaired with a shaped CFRP patch," *Thin Wall Struct,* vol. 111, pp. 155-164, 2017.

[17] C. Lam, J. Cheng, and C. Yam, "Finite element study of cracked steel circular tube repaired by FRP patching," *Procedia engineering,* vol. 14, pp. 1106-1113, 2011.

[18] T. E. Özdemir, "Short Fatigue Cracks Occurring in Welded Steel Constructions.," Master thesis, Celal Bayar University, Manisa, Turkey, 2009.

[19] B. A. Zarate, J. M. Caicedo, J. G. Yu, and P. Ziehl, "Bayesian model updating and prognosis of fatigue crack growth," *Eng Struct,* vol. 45, pp. 53-61, 2012.

[20] E. Vatangül, "Determination of Mechanical Properties of Composite Materials and Thermal Stress Analysis with Ansys 10 Program," Master Thesis, Dokuz Eylul University, Izmir, Turkey, 2008.

[21] V. Eskizeybek, "Fatigue Crack Progression in Stainless Steel Fiber Reinforced Aluminum Composites,"Master thesis, Selcuk University, Konya, Turkey, 2006.

[22] SolidWorks, Solid Works Material Library, Dassault Systèmes, 2020.

[23] S. H. Pektaş, "Simulation of Brake Mechanism Fatigue Test by FEA Method.," Master thesis, Dokuz Eylul University, İzmir,Turkey, 2006.

[24] Ö. Sunar, "Fatigue Analysis in Leaf Springs with Finite Element Method.," Master thesis, Celal Bayar University, Manisa, Turkey, 2015.

[25] S. Roth and M. Kuna, "Prediction of size-dependent fatigue failure modes by means of a cyclic cohesive zone model," *Int J Fatigue,* vol. 100, pp. 58-67, 2017.

[26] S. Salih, K. Davey, and Z. Zou, "Frequency-dependent cohesive-zone model for fatigue," *Int J Solids Struct,* vol. 152, pp. 228-237, 2018.

[27] İ. Saraç, "Investigation of the Effect of Using Nanoparticles in Epoxy Adhesive on Static and Fatigue Strength of Single-Action Bonding Joints," PhD thesis, University of Batman, Batman, Turkey, 2018.

[28] Z. Qian and H. Huang, "Coupling fatigue cohesive zone and magnetomechanical model for crack detection in coating interface," *Ndt&E Int,* vol. 105, pp. 25-34, 2019.

[29] M. Al-Waily, A. S. Hammood, and A. A. Kamaz, "Effect of Fiber Orientation on Fatigue of Glass-Fiber Reinforcement Epoxy Composite Material," *The Iraqi Journal For Mechanical And Material Engineering,* vol. 11, no. 2, pp. 344-358, 2011.

[30] M. Z. Kabir and A. Nazari, "The study of ultimate strength in notched cylinders subjected to axial compression," *J Constr Steel Res,* vol. 67, no. 10, pp. 1442-1452, 2011.

[31] H. Adin and A. Turgut, "Strength and failure analysis of inverse Z joints bonded with Vinylester Atlac 580 and Flexo Tix adhesives," (in English), *J Mech Sci Technol,* vol. 26, no. 11, pp. 3453-3461,2012.

[32] M. A. Ghaffari and H. Hosseini-Toudeshky, "Fatigue Crack Propagation Analysis of Repaired Pipes With Composite Patch Under Cyclic Pressure," *J Press Vess-T Asme,* vol. 135, no. 3, 2013.

[33] M. K. Ghovanlou, H. Jahed, and A. Khajepour, "Cohesive zone modeling of fatigue crack growth in brazed joints," *Eng Fract Mech,* vol. 120, pp. 43-59, 2014.

[34] B. Günaydın, "Fatigue Behavior of Composite Patch Repaired Surface Notched Filament Winding Tubes," PHd Thesis, Selcuk University, Konya, Turkey, 2010.

[35] T. Baklacıoğlu, "Determination of fatigue life in fractured structures using finite element method.," Master thesis, Anadolu University, Eskisehir, Turkey, 2005.

[36] S. Demir, "Fatigue Analysis of Single-rotor Driven Flanges with Multiple Screw Connection by Ansys Workbench 13.0 Due to Fatigue Strength Factor and Isotropic Thermal Changes.," Master thesis, Dumlupınar University, Kutahya, Turkey, 2012.

BIOGRAPHIES

Hamit Adin, born in 1972, received his PhD degree from the University of Fırat, Elazığ, Turkey in 2007 and has been Professor of Mechanical Engineering at the University of Batman, Turkey, since 2021. He has done research in the areas of mechanics, composite materials, adhesive, adhesion and finite element analysis. His research includes both theoretical and experimental studies.

Bilal Yıldız received his MSc diploma (Departmant of Mechanical Engineering) from Batman University in 2019. His research interests are composite materials, adhesive, adhesion and finite element analysis.

Mehmet Şükrü Adin is a PhD candidate of the Department of Mechanical Engineering, University of Batman, Batman, Turkey. He received his master's degree in Mechanical Engineering from the University of Batman in 2016. His research interests include mechanical properties of materials, composite materials, welding, finite element analysis, solid metal forming and alternative fuels .