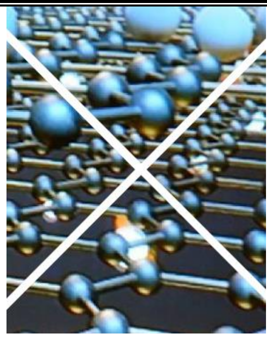
TIJMET, Vol. 004 (2021) 51-60

The International Journal of

Materials and Engineering Technology

ISSN: 2667-4033
TIJMET ID: 210401006 (10 pages)
Type of the Paper: Research Article
Received 24.01.2021 Revised: 21.04.2021 Accepted: 27.04.2021 Published (Online): 12.05.2021
Journal homepage: http://dergipark.gov.tr/tijmet



AN EXPERIMENTAL INVESTIGATION ON THE CHARPY IMPACT RESPONSE OF GLASS/EPOXY COMPOSITES AGED IN SEAWATER

AHMET ERKLİĞ[1a], ZEYNAL ABIDIN OĞUZ [*2b], ÖMER YAVUZ BOZKURT[1c]

[1]Gaziantep University, Engineering Faculty, Mechanical Engineering Department, Gaziantep, TURKEY.
[2]General Directorate of State Hydraulic Works, 02040, Adıyaman, TURKEY.
[*]oguzeynal02@hotmail.com

Abstract

This study highlights the influence of seawater absorption on Charpy impact properties of glass/epoxy composites. For this study, two groups of glass/epoxy composites that were produced by using the vacuum infusion method were immersed in seawater at 25°C and 70°C temperatures, and one group has immersed in any condition. Specimens were kept in water until getting saturation point. The immersed specimens reached saturation at the end of the sixth week (1000 h). Charpy impact test (having 15 J impact capacity) was conducted in three groups that are dry samples, saturated samples, and re-dried samples after saturation. From the Charpy impact test result, it was observed that impact properties degradation occurred due to hydrothermal aging. Compared to their non-immersed state, the maximum impact stress - energy of the immersed specimen has dropped seriously, regardless of temperature. Also, as temperature increased, the reduction rate of maximum impact stress - energy increased. Similar results occurred in the re-dried group. That is the decrease rate in aged samples at 25°C is 27.3%, whereas this rate is 30.03% in aged samples at 70°C. However, when compared to their dry state, the decrease in maximum impact stress in the re-dried group is considerably lower than in the saturated group. The decrease rate in re-dried samples aged samples at 25°C is 2.6%, whereas this rate is 7.77% in re-dried samples aged at 70°C.

Keyword: Hydrothermal Aging, Seawater, Charpy Impact Test

How to cite this article:
Erkliğ, A., Oğuz, Z.A., Bozkurt, Ö.Y., An experimental investigation on the charpy impact response of glass/epoxy composites aged in seawater, The International Journal of Materials and Engineering Technology, 2021, 4(1): 51-60.

ORCID ID:
[a]0000-0003-3906-3415, [b]0000-0002-8566-2331, [c]0000-0003-0685-8748

1. Introduction

Composite materials have become more popular to be used in wider areas because they are lighter, higher strength, more resistant to corrosion and environmental factors compared to traditional materials. Polymer-based composite materials are used in a wide range of areas such as sports, construction, automotive, marine, aerospace industries. In such applications, composite materials can be exposed to various harsh conditions such as distilled water, sea water, alkaline environment, variable temperature, humidity, dry-hot air. Since composite materials are exposed to moisture and wet conditions, the effect of hydrothermal aging on composite materials has been studied by many researchers recently. Water absorption and mechanical loads are accepted as parameters affecting the structure of composite materials. Different aging conditions such as temperature, humidity, different liquid types, or their combination may cause to deterioration of the structure of composite materials [1]. The reaction of composite materials exposed to temporary impact loading and the methods to improve their properties to resist this kind of non-static loading can be special importance in the aerospace industry and other industries. However, some points should be taken into consideration for the materials to be used in these sectors. First of all, it should be known how polymer-based composite materials react to sea water. Although polymer-based composite materials are not subject to galvanic corrosion, they can absorb moisture or water at different rates in varying water types and temperatures. This may cause the deterioration of fiber, resin system, or fiber-matrix interface.

The effects of environmental factors on composite materials have been discussed in many different studies. Many studies have been researched the fiber modification influence on the mechanical behavior of fiber-reinforced polymers (FRP).

The influence of water coupled with the heat on Glass/Epoxy composite in the existence of the molten salts in sea water has been studied by different researchers [3-8]. Since sea water suction causes plasticization and hydrolysis in composite materials, structural deterioration occurs. It is explained [9] that the influence of sea water on GFRP materials varies with matrix material and aging condition. In Glass/Epoxy materials, especially, the mode of failure is changed from a brittle matrix and ductile fiber to ductile matrix and brittle fiber.

Hawa et al. [10] investigated the impact response of hydrothermally aged glass fibre/epoxy composite pipes experimentally. Composite pipes as kept in tap water at 80°C temperature for 500, 1000, and 1500 h. The researchers selected 5, 7.5, and 10 J energy levels for impact tests. Impact test results showed that an increase in impact energy was caused to an increase in peak force and displacement. Axial stress decreased 20.29%, 51.17%, and 56.51% after the 500, 1000, and 1500 h aging period, respectively with 5 J impact energy. The decrease rate was 14.08%, 45.74%, and 50.21% after the 500, 1000, and 1500 h aging period, respectively with 7.5 J impact energy. The decrease rate was 34.53%, 45.78%, and 59.85% after the 500, 1000, and 1500 h aging period, respectively with 10 J impact energy.

Atas et al. [1] explored the thermal aging effect on the repeated impact behavior of glass/epoxy specimens. Specimens were kept starting from 100 hours for 1300 hours with 300 hour periods at 70% humidity and 95°C temperature in a climatic test cabin. For the repeated impact test, the authors selected an energy rating of 20 J, while energy levels of 20, 40, 60, 80, and 100 J were preferred for the single impact test. It was revealed for single impact test samples aged at the hygrothermal condition that the perforation threshold was decreased when compared with non-aged samples. Also, it was found that as the aging time was increased, the damaged area was increased for both impact tests. Moreover, the damaged area was bigger at smaller impact energy levels.

Deniz et al. [11,12] studied the fatigue properties of glass/epoxy pipes aged in sea water under impact loading. The composite piper aged in sea water for 3, 6, and 9 months. The 5, 7.5, and 10 J energy levels were used in this study for impact loading. Researchers observed perspiration, leakage, and eruption levels increased as a result of the sea water aging process.

Strait et al. [13] investigated the influence of sea water aging on the impact behavior of glass epoxy composites. The results showed that as a result of sea water absorption, the maximum absorbed impact energy decreased significantly. Consequently, there has been a serious decrease in impact strength.

Vijay et al. [14] investigated the sea water intake impact on the mechanical behavior of SiCp added glass-epoxy composites. At the end of the study, they have found that the tensile strength degradation occurs due to immersion in seawater and normal water.

El-Baky et al. [19] studied the hydrothermal aging effect on the impact properties of glass-polypropylene hybrid composites. Composite samples were immersed in distilled water and sea water at room temperature until saturation point. It was reported that the incorporation of polypropylene fiber layers to glass fiber-reinforced composites greatly improves the impact strength both edge-wise and flat-wise. For all composites analyzed, it was found that distilled water absorption is significantly higher than seawater intake. Further, it was noticed that the impact strengths of the samples are significantly reduced when they are immersed in distilled water or seawater.

Lulu et al. [20] evaluated the hygrothermal aging effect on the mechanical behavior of carbon fiber reinforced composites. The composite samples were kept in a hygrothermal condition with 95% relative humidity and 70°C. Short beam shear test, ballistic test, and water absorption test were conducted on samples. It was observed that the weight gain trend of composites follows Fick's law, with an equilibrium weight gain ratio of 0.74 percent at 1369 hours. Also, it was reported that the ILSS of samples decreased after the 2000 h aging period with a 50.6% ratio. Further, it was found that with increasing aging time, the composites' ballistic limit and critical energy absorption decreased noticeably.

Jesthi et al. [21] studied the mechanical properties of hybrid glass-carbon polymer composites hydrothermally aged in sea water. Composite samples aged in seawater for 90 days. The maximum water uptake ratio of the hybrid composite was found as lower than non-hybrid glass and carbon composites. It was revealed that hydrothermal seawater aging was caused to impact strength of hybrid and non-hybrid composites. The impact strength decrease rate of hybrid samples was found as between 9.6% and 12%.

This study focuses on the Charpy impact behavior of glass/epoxy composite kept in seawater at two different temperatures (25°C and 70°C). The glass/epoxy composites were in immersed hydrothermal aging conditions until specimens reach saturation point. After saturation, the composite samples were removed from the ambient conditions, and one group of samples subjected immediately to the Charpy impact test, one group of samples subjected to Charpy impact test after samples re-dried and the last group conducted to test as dry state. The effects of temperature on the impact strength of glass/epoxy were investigated in accordance with experimental results.

2. Materials and Methods

2.1. Materials

Woven S-glass fibre/epoxy composite plates were produced by using the method of vacuum-assisted resin-infusion method (VARIM) as twelve ply laminates. An epoxy system consisted of MGS L 285 resin and MGS H 285 hardener was used as matrix material in manufacturing with a mass ratio of 100:40. The properties of S-glass woven fabric are 202 g/m2, 3000-5000 MPa,72-82 GPa, and 0.15 mm respectively for density, tensile strength, elastic modulus, and thickness. The manufacturing steps were performed with a suitable system that includes a vacuum machine and a controllable heat table. At the first step, a release film was unrolled on the heater table then twelve-layer glass-fibre fabrics and peel ply were laid on top of it. A dispersion net was placed to gain a rapid and uniform epoxy spread. A suction-bagging film was bonded from the sides by a sealant band to wrap the glass fabrics. A vacuum channel and an epoxy entry were bonded to the vacuum bags both across edges with airtight (Fig.2). The entrance of the resin system was allowed after checking that there was no leakage such as an air outlet from the whole system. The leakage was controlled from the vacuum bag that is the pump vacuum was kept constant as 0.12 MPa. Hence, the resin system spread into the composite homogenously. After the process of impregnating the resin with glass fabrics, all valves were closed to keep the pressure in the system constant. Next, the plates were let for curing for 2 h at 45°C temperature. Making sure the curing was finished, the plates were let for cooling at laboratory temperature for 12 hours. The glass fabric used in the study and production illustration is shown in Figure 1 and Figure 2, respectively.

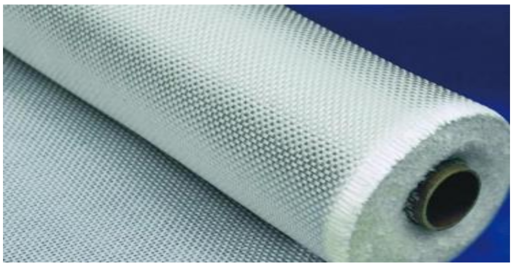


Figure 1. S-glass woven fabric

2.2. Specimen Preparation

Charpy impact test specimens were cut with the help of the CNC rooter according to ISO 179/92 [15] as can be seen in Figure 3. The samples that would be immersed in water before the test was not sandpapered due to the sandpapering process may prevent water absorption. Instead of sanding the samples, fringes of samples were cut by using an electronic cutter. After cutting of fringes, samples were numbered and before placing specimens into the environmental chambers all specimens were dried on the vacuum tables at 50°C until taking a constant weight to make samples completely dry. In this way, samples became moisture-free. Before immersed samples into sea water, samples were weighed to obtain the dry weight them. The thickness of samples was taken by a digital caliper and recorded.

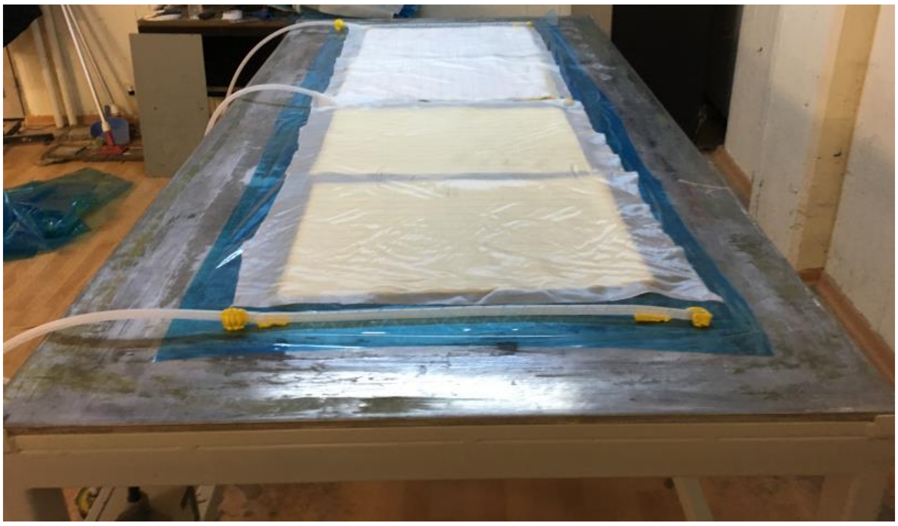


Figure 2. Production of glass fibre/epoxy composite plates by VARIM

Figure 3. Cutting process of glass/epoxy plates with CNC rooter

2.3. Hydrothermal Aging Process

Immersing process was done by cabins made of heat-resistant glass and silicon. 25°C temperature was used for room temperature, and 70°C temperature was used for hot conditions. The hydrothermal aging was carried out based on ASTM D5229/D5229M-14 [16]. According to standard, a conditioning chamber is required that shall be capable of maintaining the required temperature to within ±3°C. To be able to obtain constant heat inside of the whole cabins, adjustable resistance has been installed to the cabins. Due to the position of resistance in the cabins, there are different temperatures in the cabin at different points. To avoid this problem, a small circulation pump was placed in the cabin. In this way, the change of heat could be achieved as nearly zero. The change of heat inside of the cabin may lead to misinterpretation of water absorption of composite laminates due to it changes the density of the fluid and thus fluidity of water. All equipment of the cabin is shown in Figure 4. The temperature control was done every day by a digital thermometer.

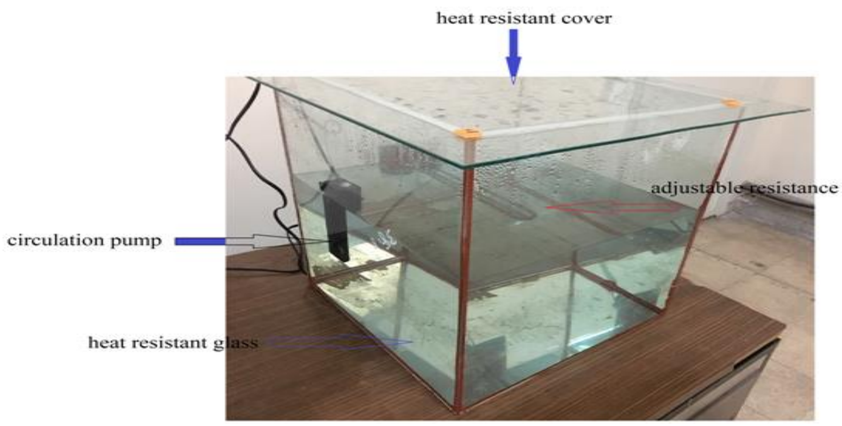


Figure 4. Aging Cabin

Because of the geographical position, there is not able to obtain sea water continuously from the sea, so sea water salt was bought and sea water has been prepared at a rate of 3.5%. Since this rate deteriorates due to heating, periodical rate control has been performed with a suitable densitometer, and water and salt have been added as needed. The portable refractometer and designation of measuring of salt ratio are shown in Figure 5.

Figure 5. Refractometer

The groups are named SW25 for specimens at 25°C, SW70 for specimens at 70°C. For each group of composite, fifteen specimens were prepared to immerse hydrothermal aging environments, five of them to saturate, and five of them for re-dried, and five of them for dry (non-immersed).

2.4. Impact Test

To be able to understand the low-velocity impact behavior of glass/epoxy composites immersed in sea water at a different temperature, a Charpy impact test was conducted. The test was done with three groups. The first group consists of wet samples. This group was immersed 1000 h in a seawater cabin at 25°C and 70°C. After saturation point, samples were taken out and conducted to Charpy impact test immediately. The second group consists of re-dried samples. Samples of this group were removed after waiting for 1000 h in a seawater cabin and heated until they reached constant weight on a heated table at 50°C. The last group is dry samples. These samples were not immersed in hydrothermal aging conditions. Tests were performed by ISO 179/92 standard [15]. Impact tester Köger 3/70 device with pendulum energy of 15 J shown in Fig.6 a) the schematic illustration and b) test machine was used to investigate the low-velocity impact behavior of composite samples. Test samples with dimensions of 55 x 10 mm as seen in Fig. 8 were subjected to impact loads flatwise. Charpy impact test device consists of a pendulum with a mass attached to a rotating arm connected to the device body. The pendulum falls from a certain height and strikes the test sample and the sample absorbs part of the pendulum's kinetic energy. The absorbed impact energy and impact strength of the material was calculated from Eq.1. The schematic illustration of the Charpy impact test and test machine is shown in Figure 6a and b, respectively.

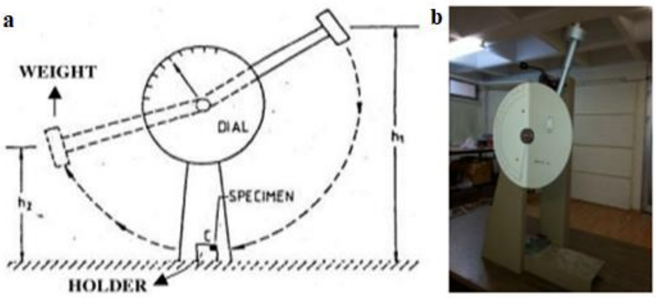


Figure 6. a) Schematic Illustration of Charpy Impact Test b) Test Machine

$$K = \frac{W}{A} \quad (1)$$

Where W is the absorbed energy(J), A is the area (m^2), and K is the impact resistance (J/m^2)

$$W = E_1 - E_2 \quad (2)$$

Where E_1 and E_2 are initial and final potential energies respectively.

Figure 7. Test Samples

3. Results and Discussion

Five specimens of the glass/epoxy composite materials were conducted to Charpy impact test as the dry state at room temperature to obtain the control impact properties which include impact strength and absorbed energy at failure. Replicas of five specimens for each condition of the conditioned samples that are saturated and re-dried groups were tested to determine the combined effects on the impact properties. An average of five samples was evaluated finally for each condition. The schematic illustration of the impact test of glass/epoxy composites is shown in Figure 8.

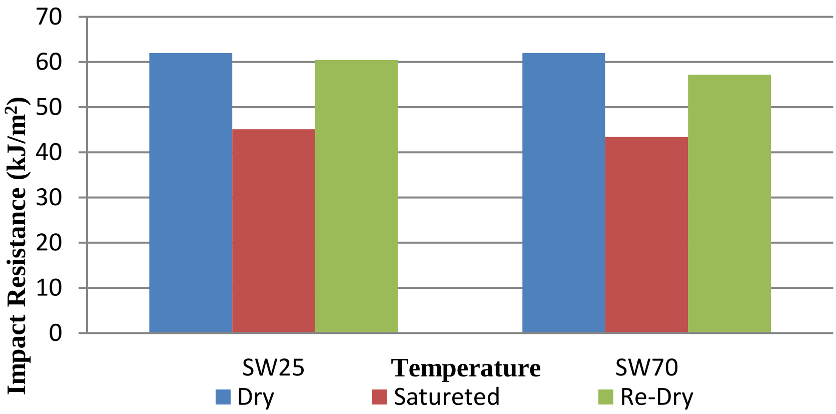


Figure 8. Impact Resistance of Glass/Epoxy Composites

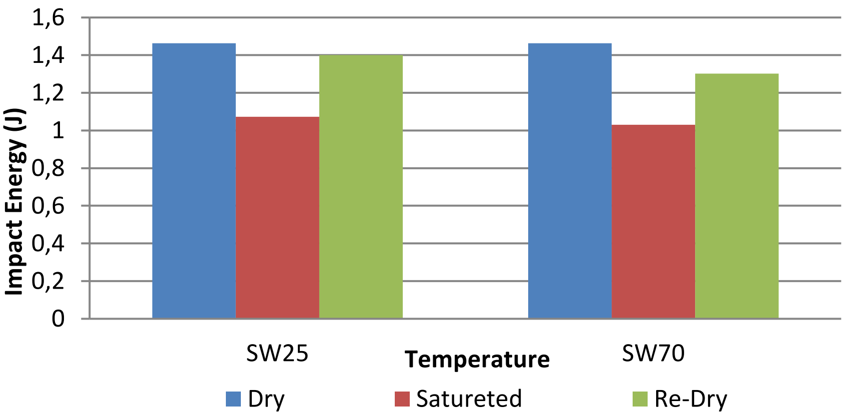


Figure 9. Absorbed Energy Values for Glass/Epoxy Composites

It can be observed from Figure 8 impact strength of samples that were immersed until saturation (wet state) in seawater and re-dried after saturation point at 25°C and 70°C decreased when compared to the control specimen. Impact strength is considerably influenced by temperatures. This decrease is also valid for the absorbed energy that can be seen in Figure 9.

The Charpy impact test results showed that both absorbed energy values and impact strength values are much lower in the wet state compared to their dry state for both temperatures. This changeable tendency is associable with a few reasons occurring at the same time. The extended sea water aging causes deteriorations in the composites because of plasticization and swelling that impress the stress and strain degree at failure and the tolerance capability of the composite is seriously affected [17,18]. The results in this article are consistent with our study in the literature [22].

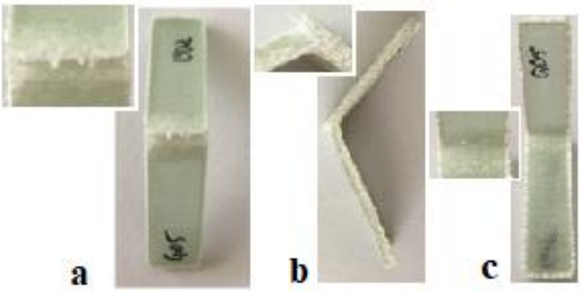


Figure 10. Dry Impact Sample a) tension side b) lateral side c) compression side

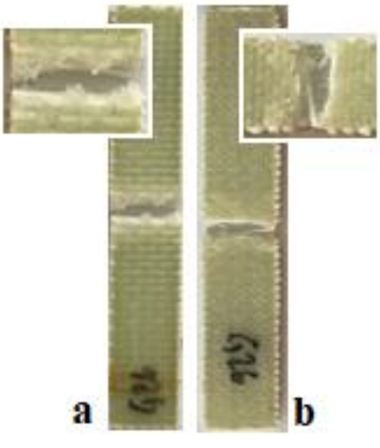


Figure 11. Wet Impact Samples Immersed at 70°C a) tension side b) compression side

It can be seen from Figure 10, there is no complete break for control samples, however, there is a separation between the laminates on the tension side of samples. The wet and re-dried groups of samples that were immersed at 25°C indicate a similar fracture type with a control group.

In contrast to control samples and samples aged 25°C, samples subjected to aging at 70°C either completely or almost completely fracture occurred. This type of fracture is valid in both the wet state and re-dried state of glass/epoxy composites that can be seen in Figures 11 and 12.

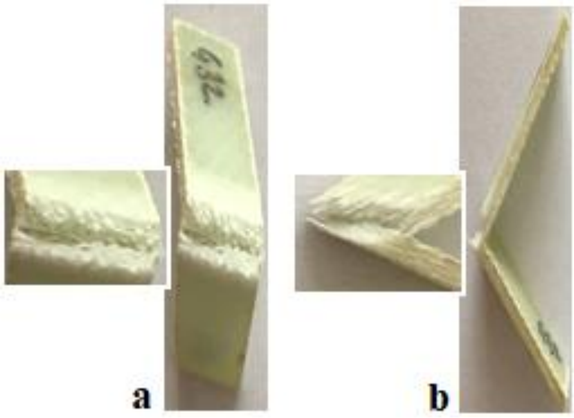


Figure 12. Re-dried Impact Samples Immersed at 70°C a) tension side b) lateral side

4. Conclusion

By this study, the effect of seawater aging conditions on the tensile properties of glass-epoxy composites was investigated experimentally. Results have shown that;

- The mechanical properties of glass/epoxy composites exposed to hydrothermal aging decrease generally due to material degradation. Impact strength decreases are higher the for wet state of samples. The decrease of impact properties is higher in the wet samples that are immersed at 70°C seawater. That is impact strength decrease is 30.03% at 70°C and 27.3% at 25°C.
- Furthermore, the decrease of impact strength for re-dried groups is 2.60% and 7.73% for 70°C and 25°C respectively.
- While there is no complete breakage at control samples and samples immersed at 25°C, complete breakage occurred in aged samples at 70°C for both wet and re-dried groups.

- From the Charpy impact test results it can be said that regardless of temperature, immersion in seawater causes mechanical deterioration when compared to their dry state in glass/epoxy composites. Also, as temperature increase, a decrease of impact resistances increase for both wet and re-dried state of samples. In the case of submerged samples, the wet state samples have higher mechanical degeneration.

Acknowledgements
This work was supported by the Gaziantep University Scientific Research Project Governing Unit (BAPYB) with an MF.DT.19.08 project number. The authors would like to express their deepest appreciation to organizing committee of TICMET19 in the selection of this study which was presented in the conference organized on 10-12 October, 2019 in Gaziantep University.

References

1. Atas, C., Dogan, A., An experimental investigation on the repeated impact response of glass/epoxy composites subjected to thermal ageing. Composites Part B, **2015**, 75:127-134.
2. Bradley, W.L., Grant, T.S., The effect of the moisture absorption on the interfacial strength of polymeric matrix composites. Journal of Materials Science, **1995**, 30:5537-5542.
3. Ellyin, F., Rohrbacher, F., Effect of aqueous environment and temperature on glass-fibre epoxy resin composites. Journal of Reinforced plastics and composites, **2000**, 19(17):1405-1427.
4. Aktas A., Uzun I., Sea water effect on pinned-joint glass fibre composite materials, Composite Structures, **2008**, 85(1): 59-63.
5. Catherine, A., Bradley, W.L., Determination of the effect of seawater on the interfacial strength of an interlayer E- glass/graphite/epoxy composite by in situ observation of transverse cracking in an environmental SEM. Composite Science and Technology, **1997**, 57(8):1033-1043.
6. Ray, B.C., Temperature effect during humid ageing on interfaces of glass and carbon fibres reinforced epoxy composites. Journal of Colloid and Interface Science, **2006**, 298(1):111-117.
7. Chakraverty, A.P., Mohanty, U.K., Biswal, B.B., Thermal shock behaviour of hydrothermally conditioned e-glass fiber/epoxy composite. Material Research, **2012**, 1(5):263-270.
8. Rutowska, M., Krasowska, K., Heimwoska, A., Steinka, E. and Janik, H. Degradation of polyurethanes in sea water. Polym. Degrad. Stab., **2002**, 76:233-239.
9. Mourad, A.I., Abdel-Magid, B.M., EI-Maaddawy, T. and Grami, M.E., Effect of Seawater and Warm Environment on Glass/Epoxy and Glass/polyurethane Composites. Applied Composite Material, **2010**, 17(5):557-573.
10. Hawa, A., Abdul Majid, M.S., Afendi, M., Marzuki, H.F.A., Amin, N.A.M., Mat, F., Gibson, A.G., Burst strength and impact behaviour of hydrothermally aged glass fibre/epoxy composite pipes. Mater Des **2015**, 89(5):455–464.
11. Deniz, M.E., Ozen, M., Ozdemir, O., Karakuzu, R., Icten, B.M., Environmental effect on fatigue life of glass-epoxy composite pipes subjected to impact loading. Composites Part B, **2013**, 44(1):304-312.
12. Deniz, M.E., Karakuzu, R., Seawater effect on impact behaviour of glass-epoxy composite pipes. Composites Part B, **2012**, 43:1130-1138.
13. Strait, L.H., Karasek, M.L., Amateau, M.F., Effects of Seawater Immersion on the Impact Resistance of Glass Fiber Reinforced Epoxy Composites. Journal of Composıte Materıals, **1992**, 26(14):2118-2133.

14. Vijay, R.B., Shivdarshan, B., Effect of moisture absorption on tensile properties of SiCp filled glass fiber reinforced epoxy composite material. International Journal of Scientific and Engineering Research, **2018**, 9(11):1347-1350.
15. ISO 179–181 Plastics – Determination of Charpy impact properties – Part 1: non-instrumented impact test, **2010**.
16. ASTM D5229 Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials, **2014**.
17. Erkliğ A., Oğuz Z.A., Doğan N.F., Effect of Seawater Aging Condition on Tensile Properties of Glass-Epoxy Composites. 6th International Multidiciplinary Studies Congress, **2019**, 121-129.
18. Chakraverty A.P., Mohanty U.K., Mishra S.C., Satapathy A., Sea Water Ageing of GFRP Composites and the Dissolved salts. Materials Science and Engineering, **2015**, 75.
19. Abd El-baky M.A., Experimental investigation on impact performance of glass-polypropylene hybrid composites: Effect of water aging. Journal of Thermoplastic Composite Materials, **2019**.
20. Lulu L., Zhenhua Z., Wei C., Chao S., Gang L., An experimental investigation on high velocity impact behavior of hygrothermal aged CFRP composites. Composite Structure, **2018**, 204:645-657.
21. Jesthi D.K., Nayak R.K., Improvement of mechanical properties of hybrid composites through interply rearrangement of glass and carbon woven fabrics for marine application. Composites Part B, **2019**, 168:467-475.
22. Oğuz Z.A., Erkliğ A., Bozkurt Ö.Y., Degradation of hybrid aramid/ glass/ epoxy composites hydrothermally aged in distilled water. Journal of Composite Materials, **2020**.