EasyChair Preprint

№ 8426

The Physical-Mechanical Properties in Aggressive Media of Epoxy Composite Reinforced with Waste Glass Materials

Hadeel I. Kadhim, Besma M. Fahad and Awham M. Hameed

July 10, 2022

The Physical-Mechanical Properties in Aggressive Media of Epoxy Composite Reinforced with Waste Glass Materials

Hadeel I. Kadhim[1, a*], Besma M. Fahad [2,b], and Awham M. Hameed[1,c]

[1]Applied Sciences Department, University of Technology–Iraq, Baghdad, Iraq.

[2]Materials Engineering Department, Mustansiriayah University, Baghdad, Iraq.

[a]as.20.04@grad.uotechnology.edu.iq

[b]besma.m.alazzawi@uomustansiriyah.edu.iq

[c]awham.m.hameed@uotechnology.edu.iq
*Corresponding author: Hadeel I. Kadhim

Abstract. The world is evolving toward extending the life of commodities and decreasing waste by recycling. The purpose of this study is to improve resistance of epoxy against the corrosive conditions by reinforcing it with available chemically resistant and low cost materials. Glass wastes was selected to reinforce epoxy with 50% by weight. Four sets of samples were prepared, two sets of samples were made and cured at room temperature, while the others were cured at 50°C for two hours. Each set was made up of both reinforced and unreinforced epoxy. These samples were immersed in different environment (Water, NaOH, HCl, Benzene and Kerosene) to find out the resistance of the epoxy after reinforcing. After immersion for six months, it is found that the composite seems more resistance compared to matrix material alone. Composites reinforced by glass particles show an increase in mechanical properties when compared to elegant epoxy resin. Density, Vickers hardness and Modulus of elasticity values increased by (31%, 67% and 62%) respectively for composite at room temperature. The resistance was improved after the post curing of unreinforced and reinforced epoxy. The solutions that had highest effect for unreinforced samples at room temperature are (HCl and Water). This indicates that epoxy acquire resistance after reinforcing with glass waste which enables it to be utilize in different applications.

Keywords: Aggressive Conditions; Post-Curing; Polymer Composites; Recycling

1. INTRODUCTION

The rapid rise of industrialization has resulted in a considerable volume of solid garbage being generated, causing serious environmental issues and resource waste [1]. With the increasing of population and the lack of proper attention to waste leads to waste becoming a serious problem that harms people and the environment. This waste should be recycle as much as possible, either as nutrients, material, humus and energy. As a result, garbage can be a valuable resource [2,3]. Glass is a common material made from natural resources like sand,for many years, glass has been employed in a variety of applications, including optics, building and transportation.Although much of the waste glass is recycled to make new glass products. Glass is a practical non-biodegradable resource, occupying valuable landfill space. Glass garbage accounts for 7-10% of total waste dumped in landfills (among other things, packaging materials such as broken, mugs, damaged plates and crystal items). Recycling glass resulted in a 50% reduction in the consumption of sand, soda, limestone, water and energy (up to 30 percent) and reduces greenhouse gas emissions, mostly methane and carbon dioxide, and aids in reducing the harmful effects of air pollution on public health [4,5] , with the development of composites due to their excellent

strength to weight ratio, composite materials, specially epoxy particularly polymer matrix composites, are in highly demand in different industries such as marine, electrical , aerospace, automobile, electronics, and construction. weight ratio composites have advantages if they are well designed[6,7] .They frequently show out the greatest characteristics of its component. Stiffness, wear strength, life fatigue, corrosion resistance, thermal insulation, strength, electrical conductivity and durability are just a few of the attributes that can be improved by constructing a composite. Composite materials are made up of two or more different components. Matrix and reinforcement are examples of phases. The purpose of the matrix function is to keep the reinforcement, receive the entire load, and transfer it to another location. Reinforcement, which is utilized to strengthen the purpose of the second phase[8,9] .

Many studies had been carried out on the polymers and polymeric complexes for use in thermal, electrical, mechanical and optical applications such as Jagdev et al.[10] powdered waste glass materials were used to reinforce the epoxy , where the epoxy was supported with glass waste powder, which was added to the base material (epoxy) with a weight fraction of 70, 60 and 50%. Tensile and compression tests were carried out and the results showed that the samples reinforced with 50% glass powder had the highest value of tensile and compressive strength, and thus increased mechanical bearing capacity for the load generated by the composite. Sahu et al . [11] fabricated hybrid polymer composites of inorganic stone waste powder with various filler concentrations of 10, 20, 30, and 50 wt% in epoxy resin matrix system. Mineral composition of stone waste powder was determined by using X-Ray diffraction (XRD) analysis. Scanning electron microscopy (SEM) technique was performed to measure the morphology surface of stone powder, dimension and polymer hybrid composite. Ultra-low water absorption of 0.08 % and high flexural strength up to 39 MPa were achieved with 50 wt % stone. Such as high dielectric constant, low water absorption and flexural strength make it suitable of durable, sustainable electrical insulting and advanced construction materials applications by eco-friendly process. Agrawala et al. [12] analyzed the performance of epoxy-based composites filled with small-format solid glass pellets (SGM), the densities of all manufactured samples were calculated. The results of mechanical and physical tests showed that the reinforced samples have less porosity and improve flexural and impact strength , microhardness, though tensile strength is compromised marginally. With improved physical and mechanical wear and slip wear, currently manufactured composites can be used in applications where predominated wear. Bharadwaja et al.[13] in his work, the Epoxy composite association presented a study of effect of the epoxy composites of SiO2 particles (volumetric fracture 1,2,3,4,5%) on the epoxy composites gum. The results showed improvement in general mechanical and wear resistance such as Charpy's test, bending (three (3) points), impact test, mechanical properties and for use SiO2 epoxy composites.

The aim of this study are to improve resistance of epoxy against the corrosive media by reinforcing it with available, chemically resistant and low cost materials and study the influence of post curing on the epoxy- powdered waste glass composites to resemble the elevated temperatures of Iraqi climate.

2. MATERIALS AND METHODS

2-1.Powdered waste glass

Waste glass was sorted, separated into forming bodies, and cleaned to remove any impurities. Glass powder was obtained after crushing window glass with an electric ceramic crusher and grinding with a special ball mill for ceramic materials. A vibrator (sifting) / shaker was used to sieve the glass powder, resulting in particle sizes of (0.212-0.075 μm), as illustrated in Figure (1).

Fig. 1: Powdered waste glass.

2-2.Epoxy

Sikadur®-52 epoxy resin, which may be ordered from SikaTM, has a high mechanical, low viscosity injection-liquid, and adhesive strength. Epoxy is two parts liquid solution, that consists of resin and hardener. When these two parts are mixed in a 2:1 ratio, they react over time to form a solid cast in about 24 hours. Some of the casts were allowed to solidify at ambient temperature, while others were post-cured for two hours at 50°C. Epoxy was used as the composite's matrix material.

2-3.Preparation of Samples

According to the American Society for Testing and Materials Standard (ASTM), the samples necessary for the research were utilized the manual method (Hand lay-up) with a ready-to-cast silicon mold. Pure and composite samples were made by combining epoxy and glass particles in a weight fraction of (50%), and choosing this percentage to make the glass properties be the dominant more than epoxy, so less than this percentage the epoxy may be the dominant and more than this percentage may have lack of adhesion and more aggregates, then mixing them thoroughly for (8-12) minutes to achieve a homogeneous dispersion. The mixture was then put into the mold, which ensured that it flowed evenly and constantly. After 24 hours at room temperature from the time of casting, the samples were demolded. Two groups of specimens were prepared at room temperature, while the other two were cured at 50°C for two hours. Each group is made up of epoxy that is both reinforced and unreinforced. As shown in Figure (2), the reinforced and unreinforced materials were cut into small cubic samples with dimension of (1) cm and weighed weekly for six months using a sensitive electronic scale.

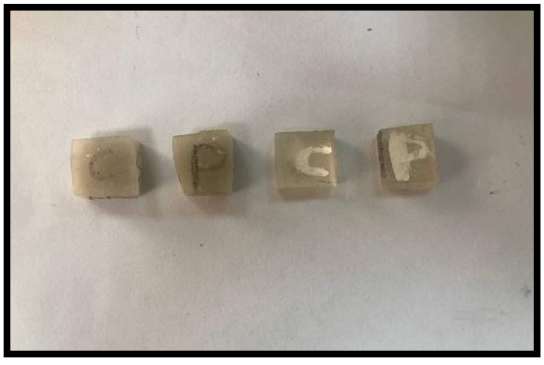


Fig. 2: Cubic samples**.**

2-4. Preparation of solutions

There were corrosive solutions (water,0.5 N sodium hydroxide,0.5 N hydrochloric acid, benzene and kerosene). The samples were placed in glass containers containing the solutions, with the tops tightly closed to avoid evaporation, and their weights were measured before and after they were placed in these solutions. The composition, chemistry, and crosslinking agent of the resin, as well as the bonding and adhesion strength of the reinforcing phase to the resin utilized, all influence the composite material's ability to absorb water and chemical solutions [14].

2-5.Physical properties

Physical properties are those features that can be perceived without altering the individuality of the matter. The assets of the material such as (Optical microscope and density) are cases of physical characteristics.

2-5-1. Weight Changes Test

The chemical resistance of a polymeric material is its ability to withstand chemical attack with minimal change in appearance, dimensions, mechanical properties and weight over a period of time[15].

2-5-2. Density Test

Density enters in many engineering design and quality control calculations and its value is a determining factor for several applications. Density test is the mass of material per volume. Mass was calculated using a sensitive electronic balance. Volume is calculated by measuring the dimension (length * width * thickness) . Density can be calculated as in Eq [16]:

$$\text{Density} = \text{Mass}/\text{Volume} \quad (1)$$

2-5-3. Optical Microscope

This test was carried out utilizing an optical microscope (MEIJI/Japan) to examine the surface of the prepared samples.

2-6. Mechanical Properties

The mechanical qualities of a material are those that influence how it responds to a load. Mechanical properties used to determine a material's usability and predicted service life assist categorize and recognize the material.

2-6-1. Hardness Test

Surface resistance to abrasion and penetration from an applied force is a solid material attribute. Precision hardness tool made in China, model LARYEE HVS-1000, performs hardness resistance to international criteria (according to tool specifications). The specimens prepared according to ASTM (D-2240 standard) .

2-6-2. Bending Strength Test (3- Point test)

The bending test is used to determine the material's maximum bending resistance and to measure Modulus of elasticity , which is defined as the material's resistance to external bending stresses when applied to various central loads until fracture occurs. The bending strength test was carried out on a Universal testing machine type "PHYWE" from Germany in accordance with (ASTM-D790). A three-point bending test was performed on standard parameters of thickness (5mm), width (55mm) and length (100mm). The Modulus of elasticity was calculated from this equation [17] :

$$E = MgL\ 3\ 48Is\ (MPa) \quad (2)$$

M: mass (gm) g: 9.8 m/s2
L: the distance between two supports (mm)
S: the deflection (mm)
I: geometrical bending moment (mm4)

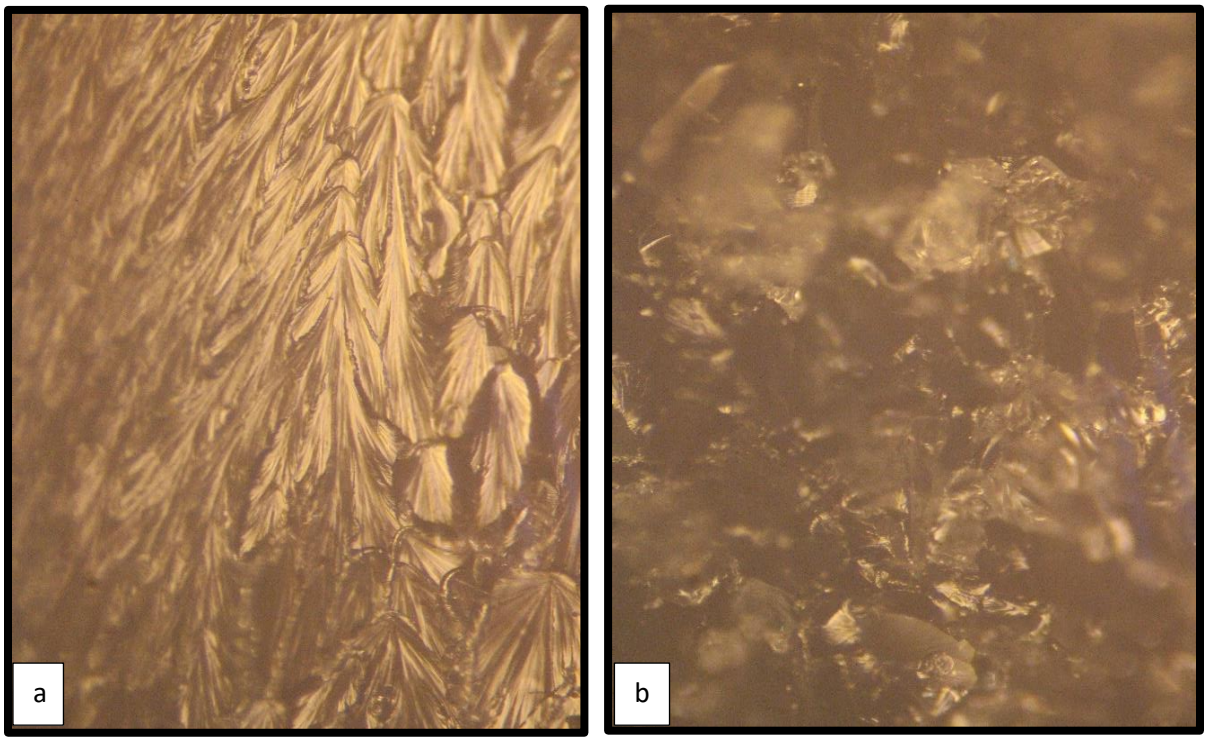
$$I = bd\,3\,12 \text{ (mm4)} \qquad (3)$$

where: b: sample width (m), d: sample thickness (m).

3. RESULTS AND DISCUSSION

3-1 . Optical Microscope

Figure (3) shows the before and after immersion micrographs of the prepared reinforced and unreinforced samples cured at room temperature . It can be seen the good bonding nature at the interface between the matrix and the reinforcement there is no separation between the two phases within composite materials. This micro-structure gives a good idea of the adhesion between the epoxy resin and the reinforcement used in this work. It was evident following immersion after six months that there was no phase separation inside the composite materials. the bonding at the matrix-reinforcement interface was constant,Unlike unreinforced samples, where all solutions were affected, and the most effective solution was in (HCl ,Water) it resulted in some crack and the material's interior structure deteriorating.



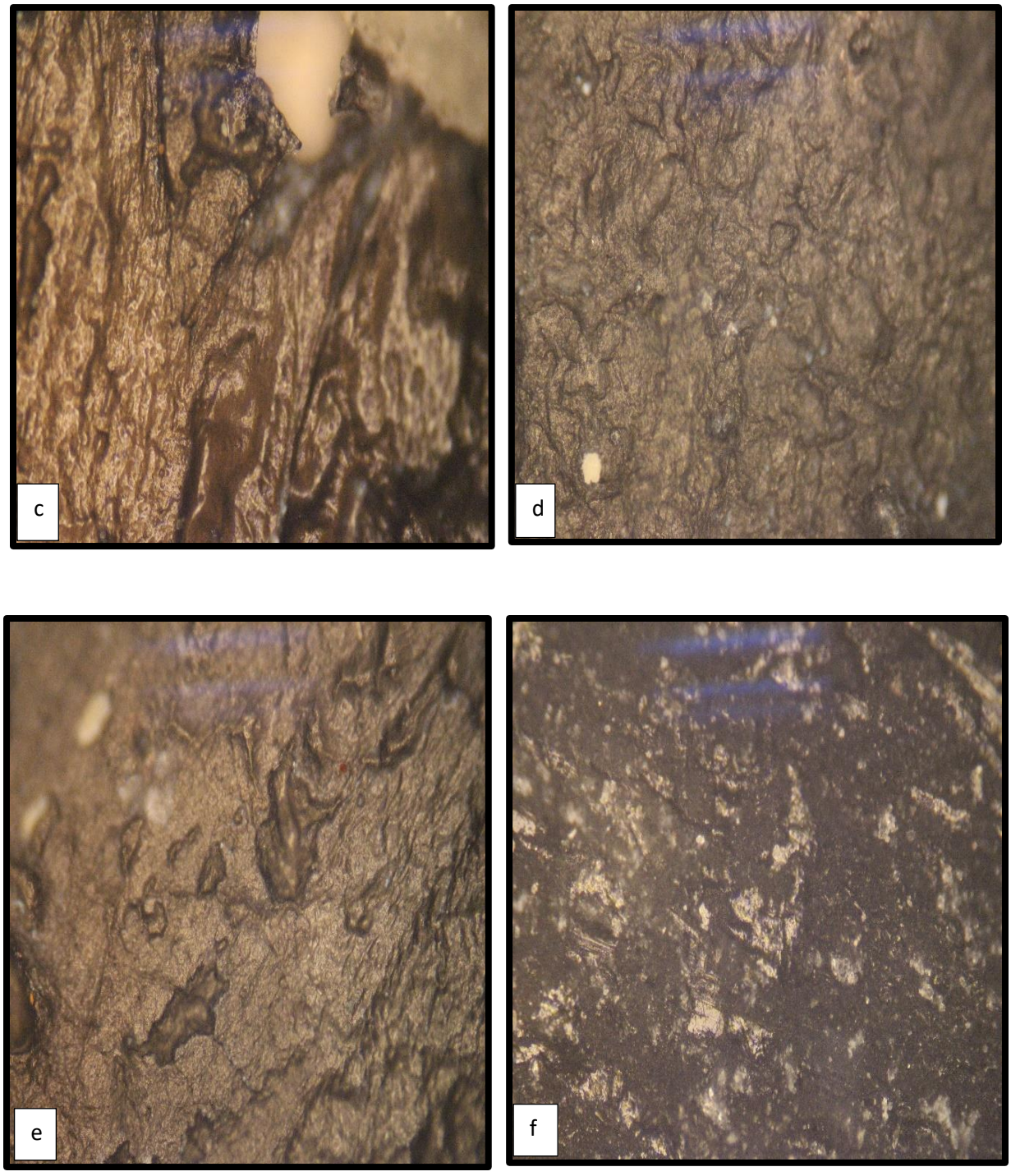


Fig. 3 (a) Pure Epoxy before immersion, (b) Composite before immersion, (c) Pure Epoxy after immersion for six months into HCl (d) Composite after immersion for six months into HCl,(e) Pure Epoxy after immersion for six months into Water,(f) Composite after immersion for six months into Water.

3-2. Weight Changes Test

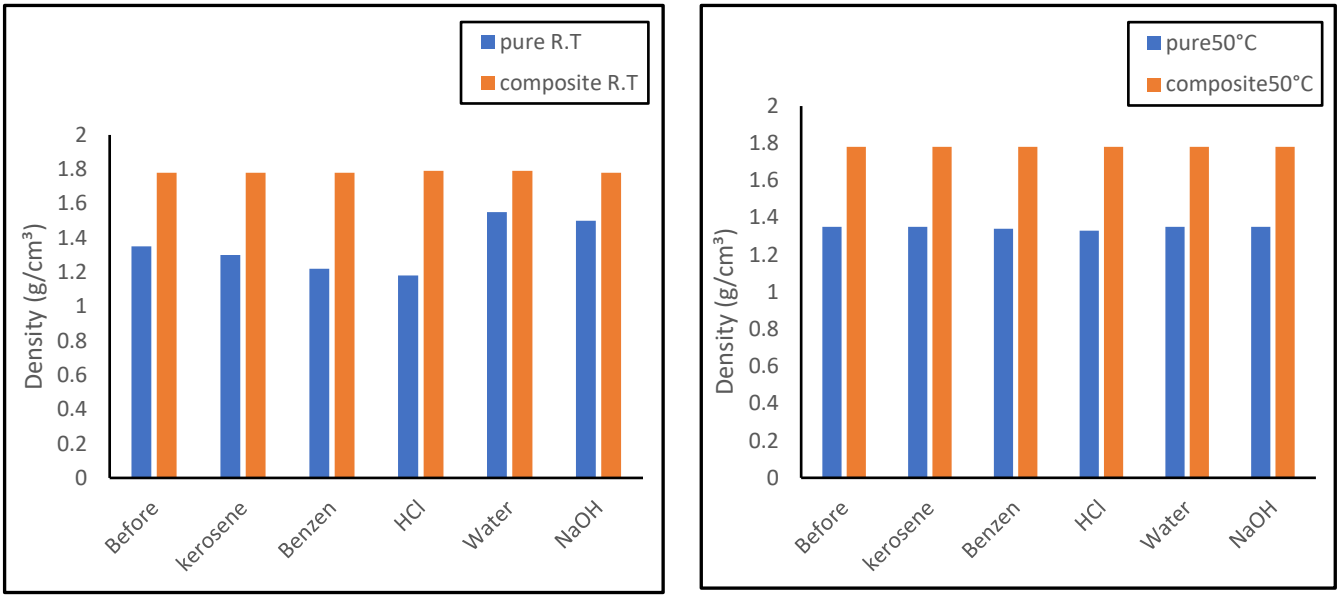
The physical and mechanical qualities of a composite can be harmed by short and long-term exposure to environmental elements such as moisture and solutions, temperature changes, and biological attack[18]. Table (1) shows the change in weight with time for samples at room temperature and at cured for two hours at 50°C for six months immersed into ((a) Water, (b) NaOH, (c) HCL, (d) Benzene, (e) Kerosene). The weight of the unreinforced samples at room temperature increases with the increase in the immersion time and this was due to the fact that the polymer upon contact with the liquid will pass quickly to fill the voids and gaps in material that will break the chains which leads to decomposition.The higher change in weight was in the water due the diffusion of water molecules in the polymeric material, as most polymers do not dissolve in water, but rather absorb with a certain percentage of and depending on the degree of absorption, the properties of the polymer may be affected to a greater or lesser extent,which is agree with the Suad [14]. The rise in weight was caused by the factors (as a result of physical variables such as surface adsorption or adsorption and osmosis through the polymer , as a result of the occurrence of certain chemical processes that produce weight gain and Via secondary forces that result in specific intermolecular bonds[19]. Water was the solution with the greatest influence on the unreinforced samples at room temperature, while the solution with the least effect was (sodium hydroxide) of unreinforced samples at room temperature. Sodium hydroxide had the reverse impact of hydrochloric acid in that it raises the weight, whereas the acid causes a drop in the weight of unreinforced samples at room temperature. In addition, the composite was unaffected by any of the corrosive solutions that clarified by microscopic images. The weight of the reinforced and unreinforced epoxy samples at cured for two hours at 50°C unchanged which may attribute to cross linking had been completed and reduction of internal stresses formed during the solidification process which lead absence of internal defects in the material.

Table (1): Weight changes of samples after the immersion in different solutions for six months.

Sample	Before	Water	NaOH	HCl	Benzene	Kerosene
pure R.T	0.6	0.64	0.63	0.57	0.59	0.59
composite R.T	0.92	0.92	0.92	0.92	0.92	0.92
pure50°C	0.6	0.6	0.61	0.6	0.6	0.6
composite50°C	0.92	0.92	0.92	0.92	0.92	0.92

3-3.Density Results

The dimensional stability of the composites created is mostly determined by density [16]. Figure (4) shows the density valuesbefore and after the immersion of samples in different solutions for six months, the density were increased after adding glass powder to it due to fact that powdered waste glass particles are heavier, more dense and also occupied a substantial amount of free space regards to epoxy resin which is agree with the Alok [12]. After immersion density fluctuate in epoxy pure as well as after post cured at 50 ° C, one of the initial strategies for improving the dimensional stability of composites was to attribute it to heat or thermal treatment[16]. The value of measured density for composite is obtained about 1.78 g/cm3, and remains constant during the immersion period at room temperature and 50°C .



(a) (b)

Fig. 4: Density of samples immersed in different solutions for six months, (a) cured at room temperature (b) cured at 50°C .

Figure (5) shows that the composite density cured at room temperature and at 50° C, before and after the immersion remain constant without any change after immersion in five solutions .

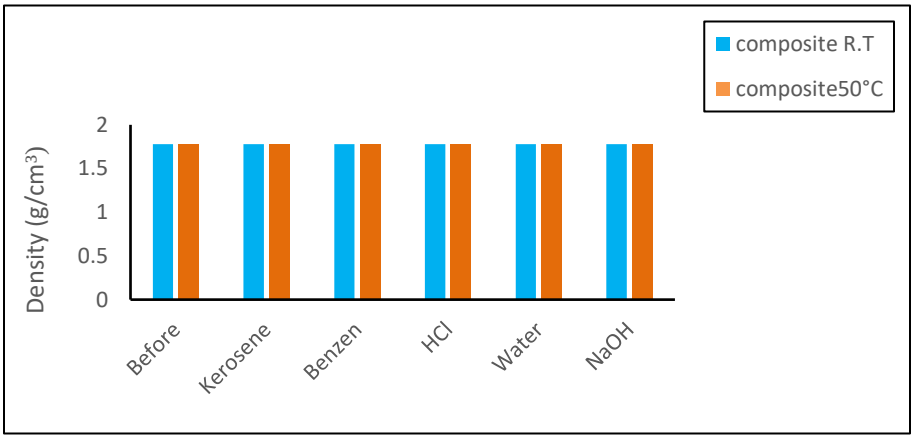
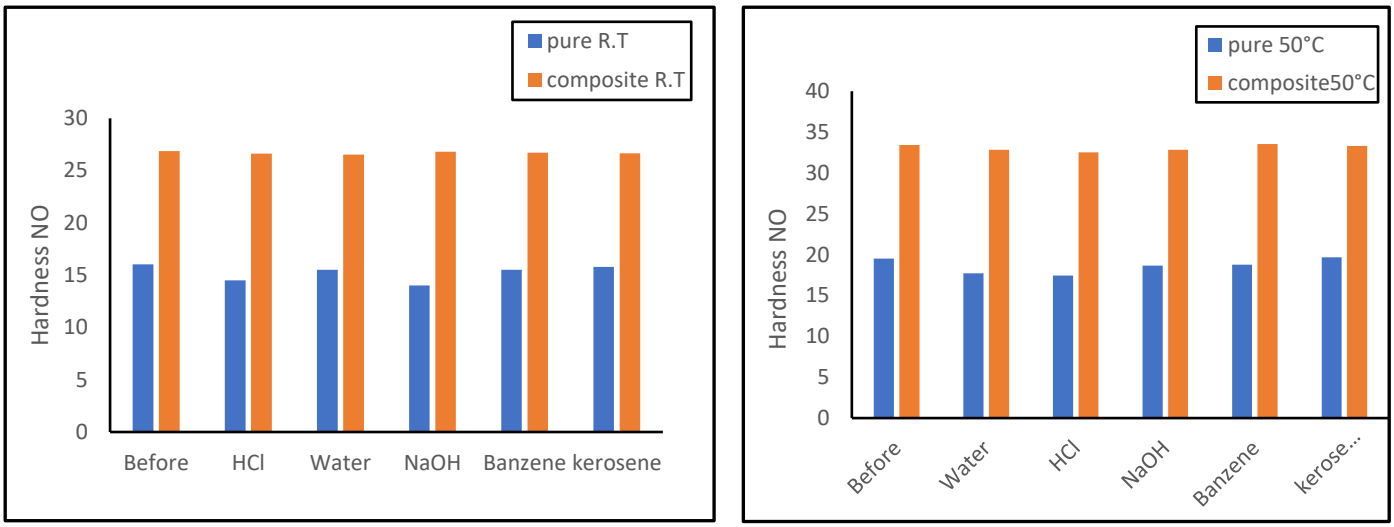


Fig. 5: Comparison of density before and after the immersion of reinforced samples cured at room temperature and at 50°C.

3-4. Hardness Results

The material's hardness might be a good indicator of its overall mechanical performance. Surface resistance to abrasion and penetration from an applied force is a property of a solid substance [20]. Hardness behavior is showed in Figure (6) before and after immersion for all sample surfaces. The unreinforced epoxy sample had lowest value at room temperature and higher at 50°C, adding powdered glass waste to the epoxy improved the hardness of the surface layer significantly aLnd that agree with Mohammed[21]. This Attribute to the glass remnants are high-hardness materials the chemical structure of the atoms that make up glass in the form of a tetrahedra of four oxygen

atoms linked to one silicon atom almost hierarchically is responsible for the glass's hardness and resistance to surface distortions. Found that hardness increased about (33 %) for reinforced and remain slightly constant during the immersion period in solutions at room temperature. Unlike epoxy pure , the hardness decreased by (13%, 9%, 14%, 4%, and 3%) in HCl, NaOH,Water, Benzene and Kerosene respectively. While at 50 °C the reinforced and unreinforced samples had higher value compared at room temperature and uneffected by solutions , the hardness value increased by (53%) for reinforced samples.



(a) (b)

Fig. 6: Hardness of samples after the immersion in different solutions for six months, (a) cured at room temperature, (b) cured at 50°C.

Figure (7) it shows the hardness values of the reinforced samples before and after immersion. It was clear for the hardness heighst values of the reinforced after post cured at 50 ° C, This may be attributed which helped to improve the correlation between the matrix and particles and reduce the gaps between the composite components and weaknesses of the composite. This result agree with Hashim study [22] Furthermore, reinforced samples in both cases do not change during the immersion period.

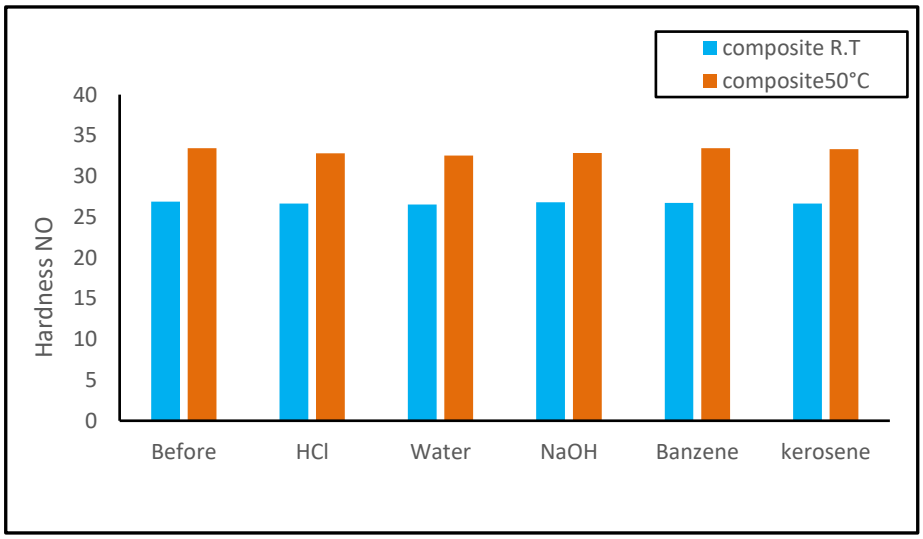


Fig. 7: Comparison of Hardness before and after the immersion in different solutions for reinforced samples cured at room temperature and at 50°C.

3-5. Bending Results

Figure (8) demonstrates the behavior of the Modulus of elasticity values obtained by three-point bending tests before and after immersion for six months, it was found that the modulus of elasticity of bending increases with the addition of glass powder compared to pure epoxy at room temperature and at 50° C by (62%,68%) respectively, attributed to high Modulus of elasticity of the glass and the strong bonding strength of the composite material between the matrix and the reinforcing material and that agree with Metin [23], in addition to the crosslinking that occurred at 50° C, lead to improve the mechanical properties and chemical resistance[24],this noted in high values of the Modulus of elasticity for pure epoxy when it compared at room temperature. The results showed that during the immersion period, the modulus of elasticity for reinforced samples remained constant without any change, in contrast to the unreinforced samples changed , the most influential solutions were (HCl,Water).

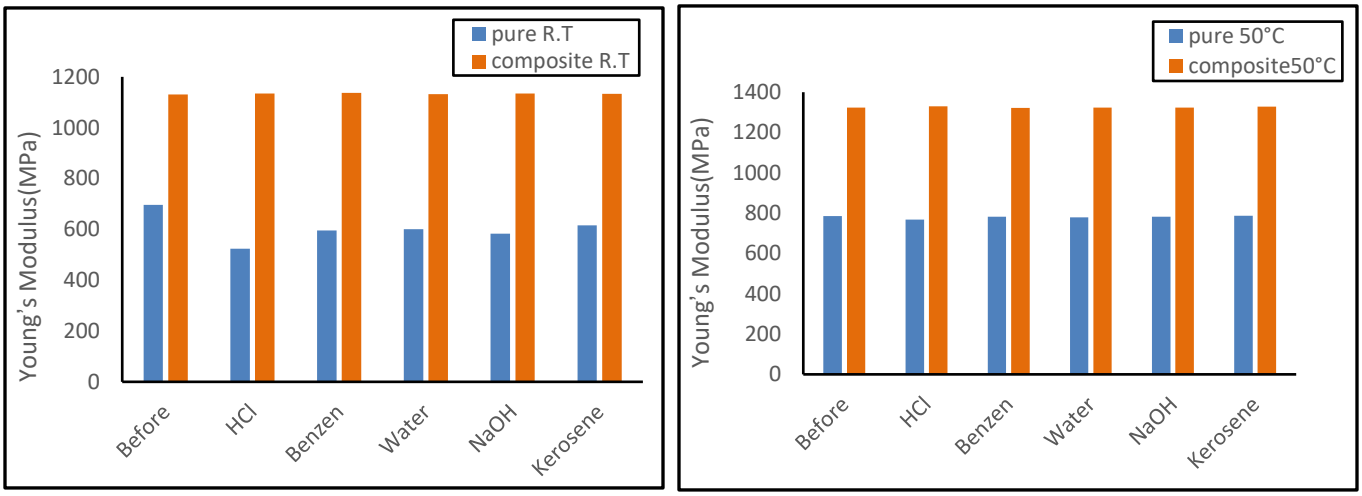


Fig. 8: Modulus of elasticityof samples after immersion in different solutions for six months, (a) cured at room temperature, (b) cured at 50°C.

From Figure (9) it is obvious the Modulus of elasticity values of the composite which treated at 50°C are higher than that of composite which cured at R.T. This increasing of Modulus of elasticity may be attributed to the effect of heat curing for increasing the crosslinking between the polymer chains and then the rigidity and stiffness will be increased [24]. Additionally, the results demonstrated that the reinforced samples' values of the modulus of elasticity did not change before and after immersion at room temperature and at 50° C.

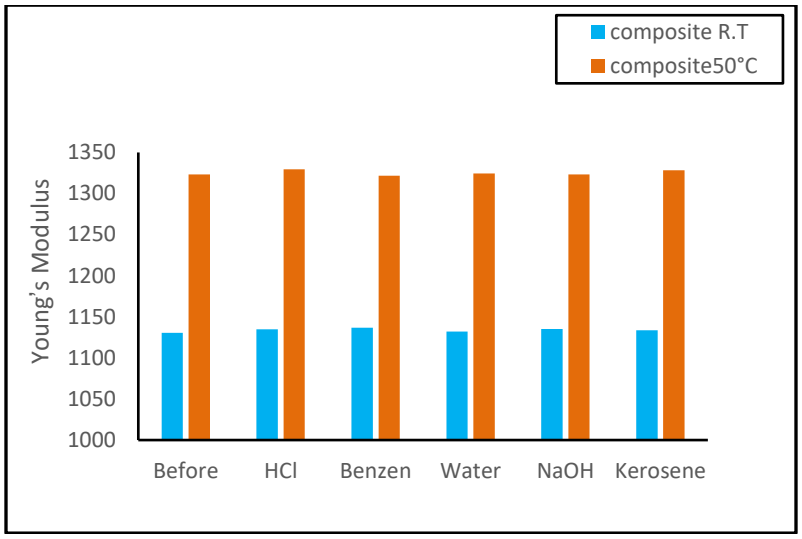


Fig. 9: Comparison of the Modulus of elasticitybefore and after the immersion in different solution for reinforced samples cured at room temperature and at 50°.

4. CONCLUSIONS

The current study encourages the recycle of glass waste and using it to prepare composites which used for different applications. This study found the resistance of (glass/epoxy) samples was remain constant without any change after the immersion in the corrosive conditions.Composites reinforced by glass particles show an increase in some physical and mechanical properties when compared to elegant epoxy resin. The value of measured density for composite is obtained about 1.78 g/cm3. Modulus of elasticity and Vickers hardness value highest increased by (62%, 33%) respectively for composite at room temperature. while at 50 °C increased by (68%, 53%) respectively. Also this study proved that the pure epoxy and composites samples cured for two hours at 50°C gave the better resistance to aggressive conditions,The unreinforced samples at room temperature the most afflicted,the solution that had highest effect increas weight was (water), unlike the acid which leads to decrease weight .while the composite was unaffected by any of the corrosive solutions that clarified by microscopic images.

References

[1] L. Zeng, H. Sun, T. Peng, and T. Hui, “Effect of glass content on sintering kinetics, microstructure and mechanical properties of glass-ceramics from coal fly ash and waste glass,” *Mater. Chem. Phys.*, vol. 260, Feb. 2021, doi: 10.1016/j.matchemphys.2020.124120.

[2] K. Johansson, “Understanding recycling behavior: a study of motivational factors behind waste recycling,” in *Waste Management and The Environment VIII*, Jun. 2016, vol. 1, pp. 401–414, doi: 10.2495/wm160361.

[3] M. Y. F. Esraa Q. Shehab a*, Zainab B. Mohammed b, “Estimation of the Components of Residential Solid Waste in Baqubah City and their Generation Rate.” 2021.

[4] A. Powęzka, P. Ogrodnik, J. Szulej, and M. Pecio, “Glass cullet as additive to new sustainable composites based on alumina binder,” *Energies*, vol. 14, no. 12, Jun. 2021, doi: 10.3390/en14123423.

[5] B. Jaiswal, V. K. Singh, S. Mishra, and R. K. Verma, “Study on polymer (epoxy) composite

using carpet waste for lightweight structural applications: A new approach for waste management," *Mater. Today Proc.*, vol. 44, pp. 2678–2684, 2021, doi: 10.1016/j.matpr.2020.12.681.
[6] H. S. Fadhil, "Flexural and Impact Properties of Epoxy Composites Reinforced with Peanut Shell Particles." 2020.
[7] F. A. H. M. Engineering, I. hashembsb@yahoo. co. Department, University of Technology, Baghdad, and I. M.S. Hamza Materials Engineering Department, University of Technology, Baghdad, "Effect of Silica Powder Addition on Mechanical Properties of Polymer Laminate Composite." 2017.
[8] G. Vara Prasad, S. Nagappa, Y. Ravi Kanth, I. Gopi Lakshmi, and J. Babu Rao, "Effect of brachyura shell particles on glass fibre reinforced epoxy polymer composite," *Mater. Today Proc.*, vol. 42, no. xxxx, pp. 555–562, 2020, doi: 10.1016/j.matpr.2020.10.521.
[9] and M. K. Heru Sukanto*, Wijang Wisnu Raharjo, Dody Ariawan, Joko Triyono, "Epoxy resins thermosetting for mechanical engineering." 2021.
[10] S. S. Asmeeta Jagdeva,*, Bidyut Prava Jenab, Bijaya Bijeta Nayakc, "Preparation and characterization of Mechanical Properties of Epoxy Resin Composites reinforced with Non Bio-degradable Wastes." Materials Today: Proceedings 5 (2018) 19723–19727 www.materialstoday.com/proceedings, 2018.
[11] A. P. Riya Sahu, Manoj Kumar Gupta, Ranjan Chaturvedi, Sandhya Singh Tripaliya, "Moisture resistant stones waste based polymer composites with enhanced dielectric constant and flexural strength." 2019.
[12] A. Agrawal, S. Chandraker, and A. Sharma, "Physical, mechanical and sliding wear behavior of solid glass microsphere filled epoxy composites," *Mater. Today Proc.*, vol. 29, pp. 420–426, 2018, doi: 10.1016/j.matpr.2020.07.295.
[13] K. Bharadwaja, S. S. Rao, and T. B. Rao, "Investigation of tensile and flexural behavior of epoxy and SiO2 composite: An experimental study," *Mater. Today Proc.*, vol. 45, pp. 2649–2652, 2021, doi: 10.1016/j.matpr.2020.11.514.
[14] U. of B. S.H. Aleabi Ibn AL- Haitham College, Department of Physics, University of Baghdad. Email;Suad_hammed@yahoo.com H.G. Attiya Ibn AL- Haitham College, Department of chemistry, "Study of the Diffusion Coefficient and Hardness for a Composite Material when Immersed in Different Solutions Polymer." 2017.
[15] A. M. Hameed and R. H. Helal, "The Diffusion Coefficients of Different Types of Liquid Environments Into Binary Polymer Blend," *Journal of Al-Nahrain University Science*, vol. 16, no. 3. pp. 148–158, 2013, doi: 10.22401/jnus.16.3.21.
[16] M. N. A. M. Taib and N. M. Julkapli, "Dimensional stability of natural fiber-based and hybrid composites," *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*. pp. 61–79, 2018, doi: 10.1016/B978-0-08-102292-4.00004-7.
[17] Baraa Khalil Ibrahim and Faik Hammad Antar, "The study of the bending property of the epoxy (Ep / MgO) and (Ep/SiO2) composites in natural conditions and after immersion in chemical solution." Iraqi Journal of Physics, p. Vol.16, No.39, PP. 93-102, 2018.
[18] 2 Ummu Raihanah Hashim 1, Aidah Jumahat 1, and S. A. 5, R. D. 4 , Mohammad Jawaid 3,*, and 1, "Effects of Accelerated Weathering on Degradation Behavior of Basalt Fiber Reinforced Polymer Nanocomposites." 2020.
[19] A. L. AL-Yaour and A. A. Mohamed, "The Abnormal Behaviour of Epoxy Resin in Acidic and Basic Organic Media," *Rafidain J. Sci.*, vol. 20, no. 5, pp. 79–94, 2009, doi: 10.33899/rjs.2009.40066.
[20] Q. A. H. c aMaterials Noor K. Faheeda*, Jawad K. Oleiwib, "Effect of Different Fiber Reinforcements on Some Properties of Prosthetic Socket." 2021.
[21] H. M. K. and L. M. H. Mohammed J. Kadhim and Departmentarukazu, "The wear characteristics

of thermoset polymers composites filled with ceramic particles.” .
[22] H. S. H. Assistant, “Effect of Glass Addition and Heat Tretment on Mechanical Properties and Wear Rate of Aluminum - 2% Graphite.” 2017.
[23] M. Sayer, “Elastic properties and buckling load evaluation of ceramic particles filled glass/epoxy composites.” journal homepage: www.elsevier.com/locate/compositesb Elastic, 2014.
[24] R. A.-K. Abbas, “Study of the thermal effect on the mechanical properties of a hybrid composite,” vol. 1. 2007.