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Studying the Hygrothermal Effects on the Impact Responses of Composite Materials Under Various Environmental Conditions

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Abstract

The current study focuses on the effects of different weather conditions, including temperature and humidity, on the impact energy properties of composite materials tested using a Charpy impact tester connected to a special hygro-thermal device. This is a unique device, handcrafted and equipped with sensors and control panels. The composite materials, used in this study, combine polyester and reinforced with fiberglass in various shapes and loadings. Nanopowder materials including titanium oxide nanoparticles (TiO_2) and aluminum oxide nanoparticles (Al_2O_3) were also added to the composite materials and their effects were assessed. The obtained results showed that all the different factors studied in this research have a positive effect on the impact test, except the nanomaterials in both cases (Al_2O_3 and TiO_2 nanopowders) at 2 wt.% of the sample and at approximately 10 wt.%. Hence, at this percentage, there is not enough effect on the impact energy.

Keywords: Impact; composites materials; Nanocomposites; Hygro-thermal

1. Introduction

Georges Augustin Albert Charpy described the results of a steel impact resistance test using a pendulum. Charpy also found that including a notch in the test sample was critical to increasing the measurement's sensitivity and reproducibility [1], [2]. The resistance of a material to cracking due to suddenly applied force is determined by impact tests. During the impact test, the sample absorbs the energy until it yields, which is called impact energy. The sample will begin to show plastic deformation in the notch. In the plastic area at the notch, the test sample continues to absorb energy and work hard. When the sample is unable to withstand more energy, a fracture occurs. Hard materials absorb more energy, before fracture than brittle materials [3]. Nanomaterials have emerged as a class of materials that have at least one dimension at nano-size. The properties of nanomaterials can be tuned as desired through precise control of size, shape, and appropriate synthesis and functionalization conditions [4]-[8]. Baig et al [9] presented a brief history of nanomaterials and their use to stimulate progress in nanotechnology development. The unique features of nanomaterials are highlighted throughout the review. The review also described advances in nanomaterials, challenges, and future perspectives related to these nanomaterials are discussed.

Chlob and Fenjan [10] examined the effect of natural plant and animal additives in the form of fibers on the mechanical properties of epoxy and tested their properties at different weight ratios. It was discovered that the mechanical properties have different behavior according to the type of additive and its origins, and were also influenced by the weight ratios.

The effect of temperature on the strength of point-welded and high-strength steel fittings was investigated by Winkler et.al [11]. They found that A strength and ductility decreased with increasing temperature indicating a reduction in energy adsorption. Lebedev et al [12] reviewed and analyzed the changes in mechanical properties of composite materials under the influence of temperature and humidity by referring to the scientific literature. The findings showed that a reduction in the mechanical properties of polymeric composite materials was observed after exposure to an extremely cold environment. Composites cause internal stresses resulting from uneven thermal expansion of the reinforcing fibers and polymer matrices. Internal stresses cause micro-cracks and damage to the bulk of the material bonding to the fibers.

Composite materials are vulnerable to environmental threats associated with moisture absorption, which affects the bonding performance of the joints [13],[14]. Chen et al [15] studied the effect of moisture absorption drying of composite materials on the bonding performance of joints. The surfaces of the composite materials were treated in three different ways. The composite materials are subjected to a moisture absorption drying treatment at a certain temperature and relative humidity. The results showed that the bonding performance decreased significantly after moisture absorption. Airale et al. [16], investigated the moisture effects on composite materials to understand the mechanisms of moisture absorption and damage in fiber/polymer composite materials. Effects of cyclic humidity at constant temperature on the tensile, compressive, and fracture properties of graphite/epoxy composites were studied. Composite structures can provide a reasonably good response to impact loads and enhance weight savings and structural rigidity.

The use of a Charpy impact tester to better understand the principles behind impact testing has significantly increased. A study was conducted by Hussein to use the Charpy impact test [17]. It has been found that it must be realized that the strength of the material can only be increased at the expense of durability, and this means that it must be ensured that there is sufficient strength with maximum durability to avoid encountering cracks that may reach a critical defect, which in turn leads to failure. Thaddaeus and Ezeaku [18] investigated the effects of fiber composites on the environment in terms of composition, properties, and application. Overall, it was determined that balsawood could be considered the best alternative for the construction of this ship's superstructure. Costa et al. [19] investigated Izod impact energy against PALF fiber (pineapple leaf fiber) volumetric fraction of PALF-reinforced epoxy composites, which have excellent mechanical properties. The fibers are embedded in an epoxy matrix with a different volume fraction. The samples were analyzed with a macro image after fractionation. The Charpy Impact Test device can be used for a better understanding of the principles behind impact testing in order to further develop engineering skills in materials selection according to a study by Attallah [20]. It was found that the strength of a material can only be increased at the expense of toughness, which means there must be enough strength with maximum toughness to avoid encountering cracks that may reach a critical flaw size leading to material failure. Almeida et al [21] used the Charpy impact test for quick evaluations of various Polyether-ether-ketone (PEEK)-reinforced composites for impact protection. The effect of the weave pattern was first investigated by comparing the impact characteristics of three PEEK composites reinforced with plies of unidirectional (UD) tapes made of high-strength carbon fibers in the first part. In the second part, the effect of fiber nature was investigated for the same weave pattern. Two main failure modes were identified. A brittle behavior mode with high failure strength and a highly deformable behavior mode in which energy absorption is was identified. In the case of organic fibers, the Charpy impact led to a high level of energy absorption due to the highly deformable behavior of the specimen.

Demircan, et. al. [22] used glass fibers with epoxy resin and multi-walled carbon nanotubes to fabricate hybrid composites with biaxial nonwoven fabrics. The samples were subjected to Charpy impact and then pressure tests. The hybrid composites showed greater post-impact strength and force modulus compared to the samples without nanotubes. The samples showed an increase in the strength of the Charpy effect compared to the samples without carbon nanotubes. According to the results, an improvement was observed in the mechanical properties of the hybrid composites, and that is possibly due to the addition of carbon nanotubes to the interfacial adhesion. The impact energy of natural fiber composites (linen, cannabis plant fiber, jute, and wood fiber composites) that were tested with various methods have been compared and discussed by Navaranjan and Neitzert [23]. It was found that the test results cannot be compared with the results from other test methods because each test method has its own advantages and limitations. Also, during impact testing the natural fiber composite cannot be compared to minerals in failure mode and energy absorption properties. Klak et al. [24] provide an overview of how different structural elements of reinforced concrete (as composite materials) behave when exposed to high temperatures. It has been found that both concrete and reinforcing bars are adversely affected by fire. Moreover, it has been discovered that elasticity and toughness decrease with increasing stress or fire exposure period. Also, elasticity and rigidity increase with increasing cross-section of structural elements. They also presented a review of a set of experimental and theoretical results on the thermal behavior of reinforced concrete slabs and beams and other structural parts under different conditions as a historical review. Go et al. [25] used a drop weight impact test to determine the mechanical and thermal properties caused by the changes in the ratio of carbon fiber reinforced plastic (CFRP) to ethylene vinyl acetate (EVA) laminations. by assembling five different types of sample, the ratios of carbon fiber reinforced plastic to ethylene vinyl acetate were increased from pure CFRP to different ratios reach to five by manufacturing 5 various types of specimens, and at the same time, the thermos-mechanical characteristics were measured using thermographic measurements. All values of observation decreased with increasing ethylene vinyl acetate lamination relative to carbon fiber reinforced plastic lamination, accordingly. Thus, it was found that the effect of ethylene vinyl acetate lamination plays an important role in reducing the effect. However, strain and temperature were inversely related.

Al Daraje et al. [26] tested the composite pipes made of woven fibers glass and carbon, with the addition of a percentage of Nano carbon/epoxy powder with a certain volumetric ratio. Composite pipes were manufactured in the traditional form with a certain inner diameter and thickness. ANSYS software was used to demonstrate the effect of internal pressure on composite pipes. As well as the design and construction of the test system. To study the effect of internal pressure and bending load on composite pipes, tensile tests were carried out. A formula was found to indicate the effect of compound stresses resulting from the pressure procedure and bending bore together on the composite pipe. Najm et al. [27] investigated the shear behavior of hollow Ferro-cement beams reinforced with different types of metallic and non-metallic reinforcements (steel wire mesh and fiberglass mesh). The results showed that the final load of the beams reinforced with several layers of fiberglass mesh decreased compared to the beams reinforced with layers of steel wire mesh. The propagation of cracks was reduced, and their number and width decreased by using steel wire mesh and fiberglass wire mesh instead of stirrups. The results also showed that the use of fiberglass or welded wire mesh in reinforcing hollow beams instead of steel stirrups significantly affected the failure load, deflection patterns cracks, and shear stresses.

The most important reason for using composite materials is their superior properties and lightweight. Composite materials are often lighter than traditional materials such as steel and aluminum. This means that they can be used to design lighter parts and components, reducing the overall weight of products and improving their performance [28]. Composite materials often have high strength, hardness, and resistance to corrosion. This makes them ideal for use in harsh environments such as in marine applications and chemical industries. In general, the use of composite materials in mechanical engineering provides opportunities to develop more innovative products with superior performance thanks to the variety of properties offered by these materials. The benefits of using nanomaterials include improving manufacturing methods, and nanomedicine, improving large-scale production methods and infrastructure for the automotive industry, and learning about the possibility of using them as composite materials. Products made with nanotechnology are high in yield, low in cost, and have modest material and energy requirements. After determining the composite materials and nanomaterials, composite materials are cast and manufactured with the standard dimensional measurements of impact test samples for the Charpy device, using the weight ratio equation, and then exposing these samples to weather conditions of different temperatures and humidity and for a different exposure period, thus reaching different readings, and then the results and their effects are compared and that is the aim of the current study.

2. Experimental work

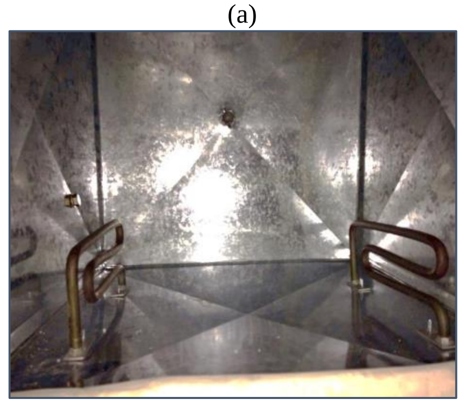
This section contains the experimental work, through the buildup of the Hygro-thermal chamber, casting the samples, and then testing it by using a CHARPY impact device after exposure to an accelerated weathering chamber.

2.1. Hygro-Thermal Chamber

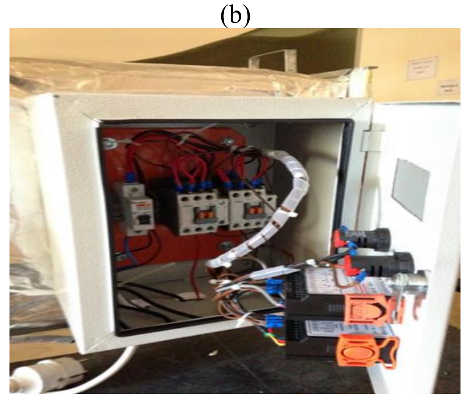
It's a special chamber buildup to accelerate the environmental conditions of temperature and relative humidity. Help to investigate the effect of this acceleration on impact energy for composite and nanocomposite materials through the test. The hygrothermal chamber consists of the following (Fig. 1):

1. Thermally isolated chamber with fibers glass with dimensions of 40 cm*40 cm*40cm.
2. Control panel and measurements (temperature controller and humidity controller) which include humidity circuit control with a reading range of 0%-99.9% RH and temperature circuit control with a heating range of 19.9 – 99.9 ^{o}C.
3. The device is equipped with moisture.
4. Heaters of the type KR37157 with power of 400w and 220v inside the chamber.

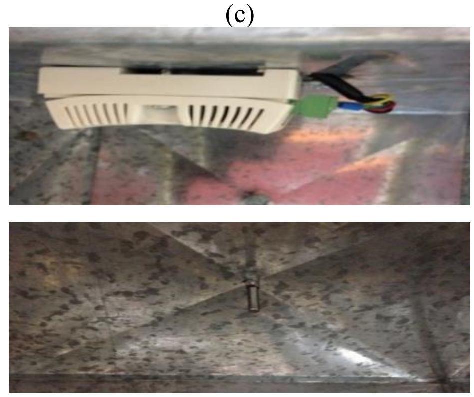
(a)



(b)



(c)



(d)

Figure 1. Parts of the Hygrothermal chamber, a view of the chamber, the internal part with Heaters, c- Control panel & measurements, and d- Humidity and Temperature sensors

2.2. Dimensions of mold and samples

The different molds with different dimensions of the whole glass manufacturing to obtain a good surface finish of the cast. A mold of 200mm × 55mm × 10mm was used for composite materials, and a mold of 80 mm × 55 mm ×10 mm was used for nanocomposite material. Then cut the cast to the dimensions of the same molded impact testing. The test sample which shall be machined all over should be 55 mm long and in the center of the length of one face, a "V" notch of depth 2 mm, and root radius of 0.25 mm with an angle of 45 degrees, and a width of the sample is 10 mm as shown in Fig. 2.

For molding composite material polyester material has been used with adhesive hardening and fiber with two types of random times and the uniform (mat) is once to give some diversification in composite materials shown in Fig. 3 and 4.

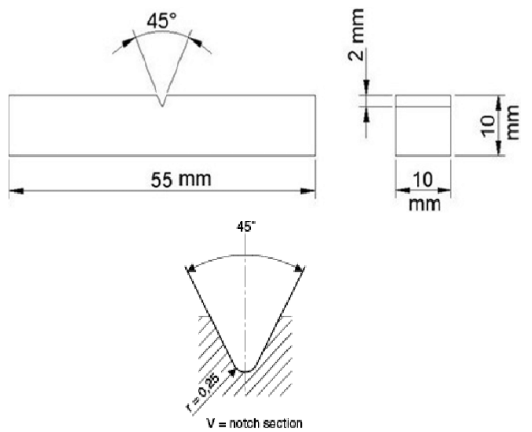


Figure 2. ASTM Sample dimensions

Figure 3. Uniform fiber (Mat)

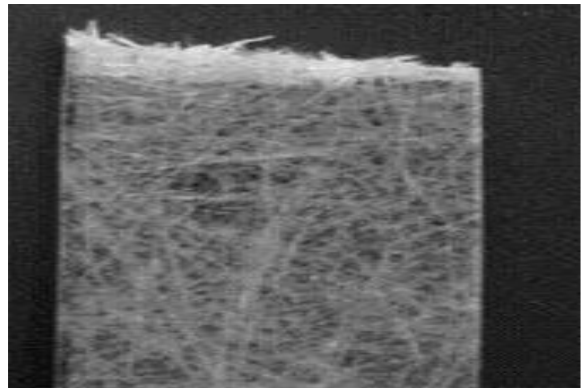


Figure 4. Random fiber

2.3. Weight fraction calculation

For composite materials, different weight fractions have been used which are 0%, 10%, 20%, and 30%. These values represent the percentage of the weight of fiber layers to the weight of the cast completed.

Thus, Weight fraction (W.F) = (weight of fibers/weight of total cast) *100%

Weight fraction calculation for composite material

In this study, 10 % W.F was cast with 5 layers of random fibers, the weight of cast complete =190g, the Weight of each fiber layer = 3.8g, the Volume of cast complete = 110cu.cm, and the thickness of one layer = 0.2mm.

Hence: Weight fraction = (3.8*5/190) *100%=10 %

The other weight fractions results for composite material with mold (200mm*55mm*10mm) are shown in Table (1).

Weight fraction calculation for the nanocomposite material used 2% of nanocomposite of Al_2O_3 and TiO_2 from the Weight of polyester that was used, these have two weight fractions:

Nano weight fraction = (weight of Nanopowder)/(polyester weight)*100% For Al_2O_3 and TiO_2.

2.4. Casting the samples

Preparing molds made of glass for the casting process is used to give a good surface finish and for ease of making molds and extracting the sample, layers of fibers of all kinds are used, and Nano-powders as well. Cut off the fiber class for dimensions equal to mold dimensions (200×55). Weighing of one layer of fiberglass uses an electronic scale for random type {W=3.8g at (200×55) and W=1.3g for (80×55)} and for Mat (uniform) type {W=5g for (200×55) and W=2.2g for (80×55)}.

Table 1. Weight fraction for samples:

Type of fiberglass	Number of layers	Weight of each layer (gram)	The total weight (gram)	Weight of used polyester (gram)	Weight fraction (%)
Mat	4	5	200	180	
Random	5	3.8	190	171	10
Mat	8	5	200	160	
Random	10	3.8	190	167	20
Mat	12	5	200	140	30
Random	15	3.8	190	133	

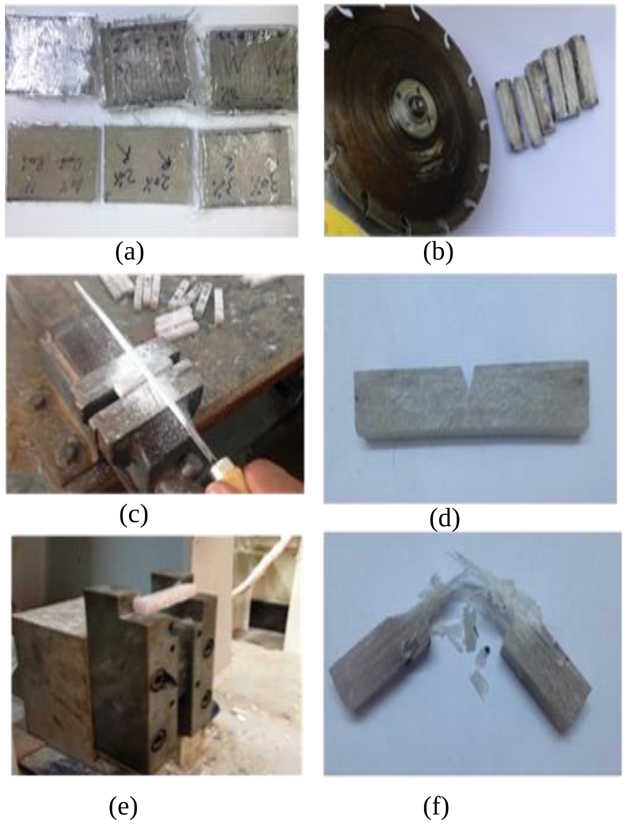


Figure 5. Casting the samples, a- Taking the casting out of the mold,b- Cut it according to the dimensions of the test model, c- Make the V- V-notch manually, d- Charpy impact test sample, e- Put the sample in impact device, f- Show sample after test.

Coated the mold with oil to prevent adhesion and facilitate removing the cast from the mold. After coating the mold with oil, the mixture homogenized (polyester, hardener, and Nano Al_2O_3 or TiO_2.) was poured into the mold and started in single layers Consequently, after pressing each layer using the brush time and time again using a thin timber to eject the air bubbles, that generated during the casting, then put the other layer of fiberglass and pour above it the mixture, after that pressed by brush and timber again. After completing the layers of fiber class pour the mixture to cover all layers; the samples cast as shown in Fig. 5.

2.5. Charpy impact test device

The Charpy test consists of measuring the energy absorbed in breaking placed horizontally on the anvil and supported at each end, the striker is mounted within the hammer with its edge in a vertical plane on impact (as shown in Fig. 6). The temperature and moisture conditions and the number of tested specimens in each condition are shown in Table 2.

3. Results and Discussions

The results of the Charpy impact tests for composite material at different conditions are discussed in this section.

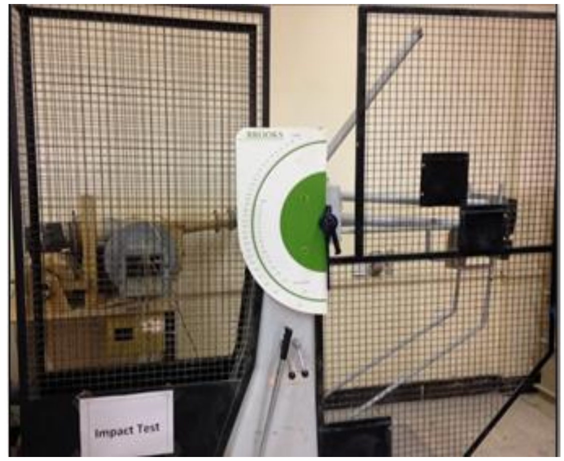


Figure 6. Charpy impact test

Table 2. The influencing variables and climatic conditions used during the test

Type of fiber	Nano-comp. added	Temp.	R. humidity	Exposure interval
Mat	Al_2O_3 nano.c	-10 ºC	45%	1 Hour
Random	TiO_2 nano.c	0 ºC	50%	2 Hours
		21 ºC	65%	3 Hours

3.1 Effect of temperature

The effect of temperature on impact energy with set the exposure time of samples and relative humidity (with Relative humidity = 48 % and Time = 1 hour) and the relationship between the weight fraction and impact energy in different temperatures to mat composite material are shown in Fig. 7.

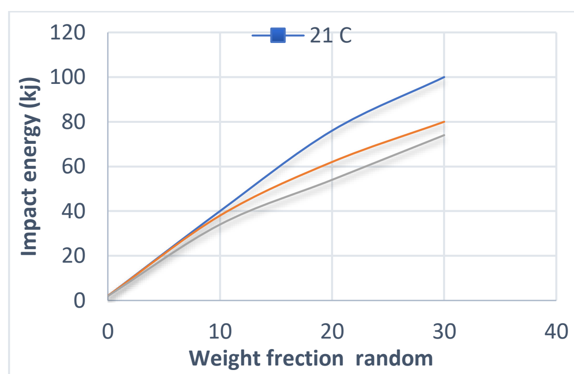


Figure 7. Temperature effects on Mat composite material.

The figure shows that the increase in the percentage of the weight fraction, which results in an increase in the amount of fiberglass for Mat, leads to an increase in the amount of impact energy, which is therefore direct, as a result of the increase in the amount of material, which leads to more ductility. At different temperatures, note that the decrease in temperature results in a reduction in impact energy for Mat composite materials because the strength of cohesion between polyester particles and the strength of adhesion between them and fiberglass molecules will be reduced as a result of the decrease in temperatures as shown in Fig. 8.

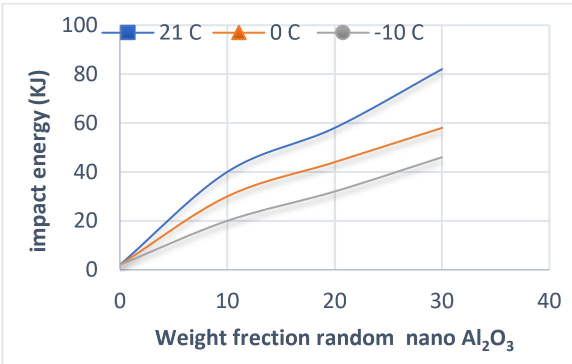


Figure 8. Temperature effect on Random composite material.

From Fig. 9, the increase in the percentage of the specific weight for mat composite materials results in an increase in the amount of impact energy due to an increase in the amount of material. Note that the decrease in temperature also reduced the impact energy for mat composite materials, which is the same as the decrease in temperature.

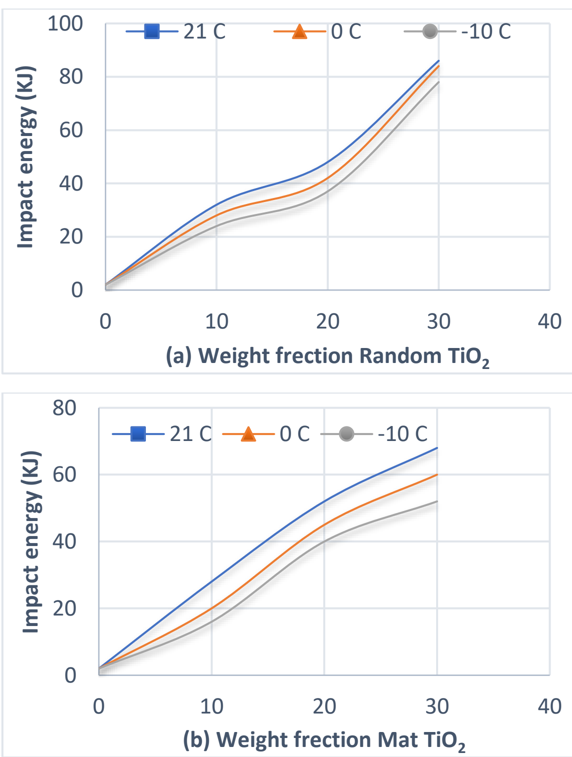


Figure 9. Shows the relationship between the weight fraction and impact energy in different temperatures to (a) random and (b) mat Tio2 nanocomposite material.

A decrease in temperature causes the weakening of the bonds, lowering the impact energy for the material, which means this additional TiO_2 with 2% percentage from polyester weight does not have the desired effect with these temperatures for both types of fiberglass. Fig.10 shows the relationship between the weight fraction and impact energy at different temperatures to the mat and random Al_2O_3 nanocomposite material.

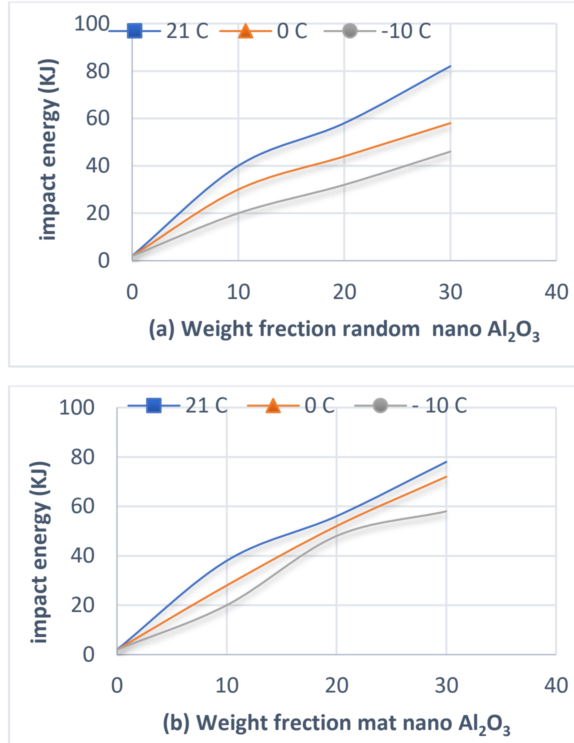


Figure 10. The effect of temperature at (a) random and (b) mat Al2O3 nanocomposite material

From this figure, the increase in the percentage of the specific weight for fiberglass in addition to adding nanocomposite material Al2O3 with a percentage of 2% from polyester weight increases the amount of impact energy due to an increase in the number of molecules and thus resistance more and more ductility. Fig. 11 shows the relationship between the weight fraction and impact energy at different temperatures of composite material to know the effect of increased temperature on impact energy.

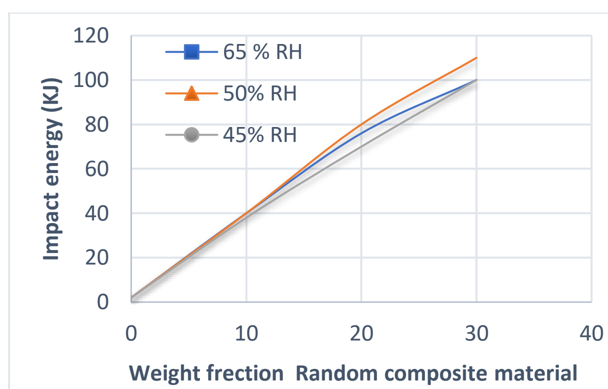


Figure 11. increase temperature effect on random composite material

3.2 Effect of humidity

The effect of relative humidity on impact energy with the set of the exposure time of samples and temperature at Time = 1 hour and Temperature=21 ºC. The relationship between the weight fraction and impact energy at different relative humidity for random and mat composite materials is shown in Fig. 12.

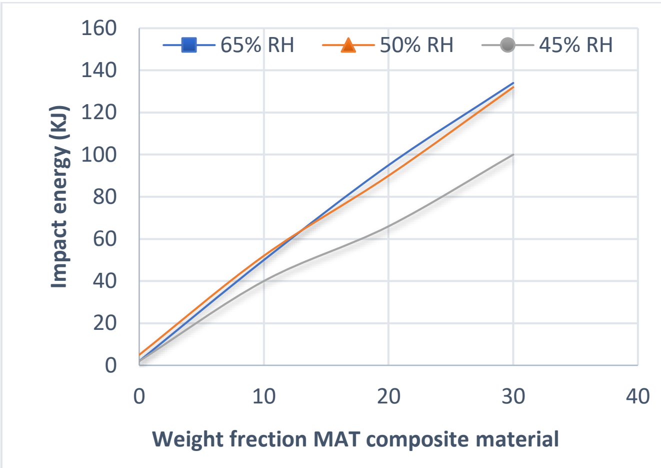


Figure 12. The effect of humidity on normal composite material.

The increase in the percentage of the specific weight in composite materials has resulted in an increase in the amount of impact energy, this is due to the increase in the amount of substance and thus impact resistance. Note the increasing relative humidity for composite materials, it will be able to absorb some of the water vapor particles, increasing the material's strength and thus increasing the material's strength, as well as a decrease in impact energy. Fig.13 shows the relationship between the weight fraction and impact energy in different relative humidity for TiO_2 nanocomposite material.

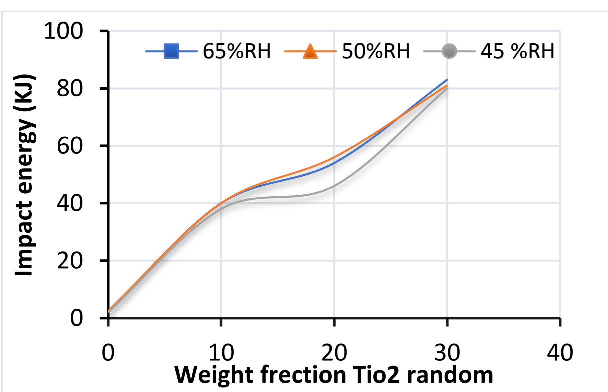


Figure 13. The effect of humidity at random TIO2 nanocomposite material

The impact energy is increased due to the increase in the amount of fiberglass and added 2% of Tio2 nanocomposite as shown in the figure. The strength of the material can be increased by absorbing some of the water vapor by the Tio2 particles and fiber because of an increase in relative humidity, so the impact energy can be increased. The relationship between the weight fractions and impact energy in different relative humidity at random AL2O3 nanocomposite material is shown in Fig.14.

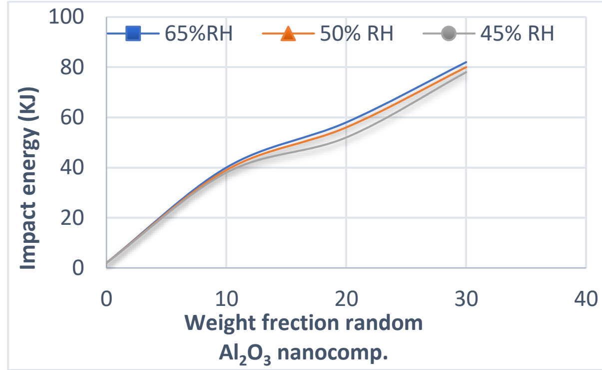


Figure 14. Humidity effects at Random AL2O3 nanocomposite material.

As shown in the figure for nanocomposite material with type aluminum oxide Nanopowder has the same effect as Tio2, the increase in Weight fraction increases impact energy too. Because the result of the normal composite material is almost identical to the nanocomposite material in each case (Al2O3 and TiO_2 Nanopowder), adding 2% Nanopowder from polyester weight hasn't sufficient effect.

3.3 Effect of time

Time period effect on impact energy in constant temperature and humidity. At: temperature = 50 º C and Relative humidity (RH) = 50 %. The relationship between the weight fraction and impact energy in the different time periods at the mat and random composite material is shown in Fig. 15.

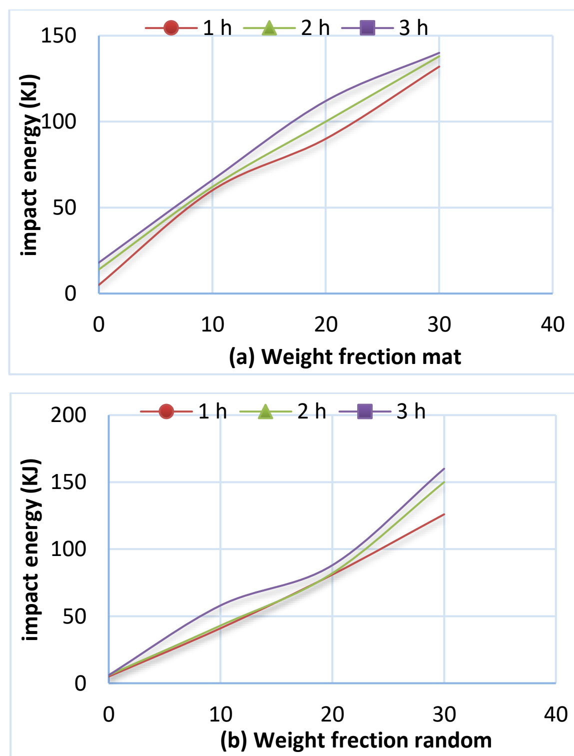


Figure 15. the effect of time at (a) mat and (b) random composite material

From the figures above the relationship between the weight fraction of composite materials and impact energy is still directly correlated with an increase in the exposure time of composite material to temperature and humidity, impact energy increased. The relationship between the weight fraction and impact energy in different periods of time at random AL2O3 nanocomposite material is shown in Fig. 16.

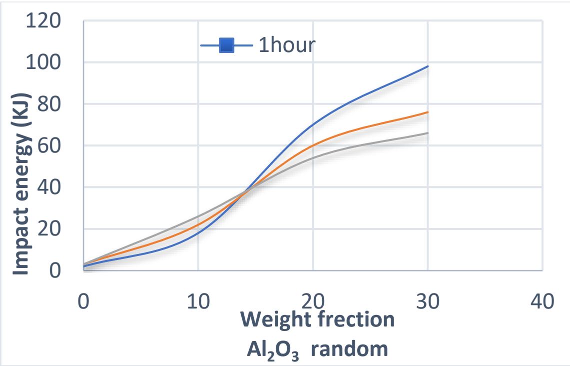


Figure 16. the effect of time at random AL2O3 nanocomposite material

It can be noted that the relationship between the weight fraction of Al_2O_3 nanocomposite material and impact energy is a direct correlation. When the time period of exposure of the material to this temperature and humidity at 10%, it's effect like effect on normal composite but when the amount of fiberglass increased with the presence of Al_2O_3 Nanopowder (at 20% and up) this exposure with this period will be the effect on material properties include impact resistance as shown with 3hour period the impact energy decreased.

Fig. 17 shows the relationship between the weight fraction and impact energy in different time periods at mat TiO_2 nanocomposite material.

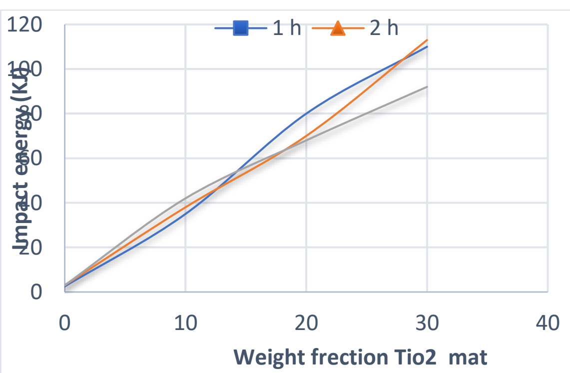


Figure 17. The effect of time at mat TIO2nanocomposite material

From the figure the increase in the weight fraction of TiO_2 nanocomposite material, it increases impact energy. The time period of exposure to the material nanocomposite TiO_2 has the same effect as the time period in Al_2O_3 and for the same reason.

3.4 Effect of type of composite material

The effect of the type of composite used on impact energy at Temperature = 21 C° and R.H (Relative humidity) = 48%

The relationship between the weight fraction and impact energy in different types of composite material at random fiberglass is shown in Fig.18.

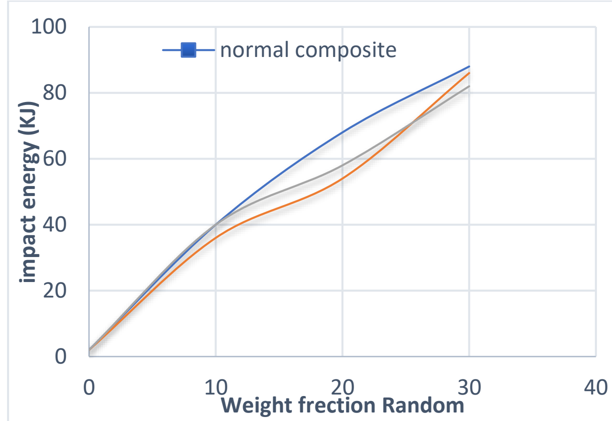


Figure 18. Effect of type of composite material at random fiberglass

From the figure, the increase in weight fraction for any type of random composite material increased the impact energy. Note also the presence of nanocomposite material in each case (Al_2O_3 and TiO_2 Nanopowder) with a percentage 2% from the weight of polyester that used at 10% W.F approximately have not the sufficient effect on impact energy but at 20%W.F and up note from the figure the normal type have energy greater than the type that contain Al_2O_3 and TiO_2 Nanopowder because decreased the strength of adhesion between the polyester and fiberglass due to decrease in amount of polyester used. The relationship between the weight fraction and impact energy in different types of composite material at mat fiberglass glass are shown in Fig. 19, note also the effect of mat composite material has the same effect as random type.

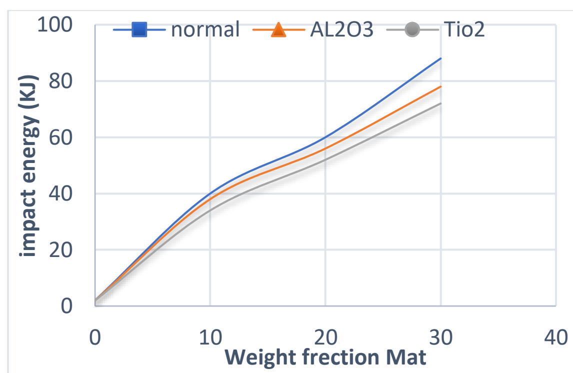


Figure 19. Effect of type of composite material on mat fiberglass

4. Conclusions

that the current study demonstrated that, the increase in weight fraction (W. F percentage) of composite material (0% - 30 % increase in the amount of fiberglass) has caused an increase in the impact energy. The increase in temperature to a higher value than room temperature (24°C) has caused a decrease in the impact energy. As shown at 50 °C and 75 °C. Also, when the temperature is less than room temperature it causes decreasing impact resistance. As shown in 0 ºC and -10 ºC. Increasing relative humidity RH% (45%-65%) causes an increase in the impact energy for all types of composite material that are used. Increased the exposure time period of normal composite material increased impact energy. As shown in 1, 2, and 3 hours. Note for nanocomposite material for both cases (Al_2O_3 and Tio_2 Nanopowder) with 2% of the weight of sample at 10% W.F approximately have no sufficient effect on impact energy but at (20%W.F and up) noted greater impact energy.

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Conflict of Interests

The authors declare that there is no conflict of interest.

Authors Contribution

Fadhel Abbas: - The basic idea of the research, the selection of materials used, and the type and number of experiments that lead to achieving the research objectives, in addition to participating in analyzing and discussing the results and reaching conclusions for the research.

Hasan Abbas: - Completing the practical aspect of casting samples and adding nanomaterials in different proportions, as well as conducting tests related to the research and discussing the results, in addition to completing the entire research (writing, drawings, etc)

Alaa Almansoori: Methodology, Analyzing and evaluation results.

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