AIMS Materials Science, 7(5): 583–595.
DOI: 10.3934/matersci.2020.5.583
Received: 26 August 2020
Accepted: 26 August 2020
Published: 15 September 2020

http://www.aimspress.com/journal/Materials

Research article

Effect of fiberglass form on the tensile and bending characteristic of epoxy composite material

Mohammed O. Atteaa Al-hassany[1,*], Ali Al-Dulaimy[2], Amir Al-Sammarraie[2] and Abed Fares Ali[2]

[1] Electro-mechanical Engineering Department, College of Engineering, University of Samarra, Iraq
[2] Mechanical Engineering Department, College of Engineering, Tikrit University, Iraq

* **Correspondence:** Email: mohammedattea@tu.edu.iq; Tel: +9647702951576.

Abstract: This search focuses on the tensile and bending characteristics of a composite material that reinforced by various forms of fiberglass. Two fiber forms are considered; the first is bi-directional of (0°–90°) fiber direction, the second is random. The fiber thickness of bi-directional form has been investigated by considering thick and thin mats. The composite has been developed by hand lay-up process with a fiber weight ratio of 10%. Three samples of the developed composited have been compared with a base case sample (pure matrix of epoxy resin). Also, a microscopic vision has been captured on the fracture zone of tensile specimens. The results reveal that the random-form composite had maximum tensile strength and transverse stiffness, also, the thin-fiber composite showed maximum ductility.

Keywords: epoxy-fiberglass composite; composite forms; composite tensile strength; composite bending; composite transverse stiffness

1. Introduction

Generally, the composite consists of two phases, matrix, and reinforcement, they bonded together in one unity to get specific proprieties. The first uses of that material back to the age of Mesopotamian and Egyptian civilizations where their people used a mixture of mud and straw to make strong and durable buildings. The straw appears in many ancient composites like pottery and boats. The second stage of progress in composite appeases by using natural resins from plants and animals. The modern era of composite did not begin until developing the plastics such as vinyl and polyester. The plastic alone could not provide enough strength for many applications, so reinforcement was needed to provide strength and rigidity. In the year of 1935 the fiberglass was introduced, which when combined with a plastic polymer creates a strong structure and has a light weight [1]. Fiber-reinforced composite materials are finding increasing applications in aerospace structures, military, naval and automotive industry, because of their good properties [2]. The aircraft and aerospace engineering are from the first fields that used composites and benefited from its lightweight which plays an important role in the structure of those vehicles [3]. Fibers such as glass and carbon have the potential to be used as a replacement for traditional reinforcement materials in composites for applications that requires further strength to weight ratio. The mechanical properties of composite materials relate with the interfacial bond strength, which has to be sufficient for transforming the load from the matrix to the fibers [4], beside that the homogeneity is an important characteristic.

The composite can be classified into three categories with respect to the reinforcement: Reinforced by fibers, reinforced by particles, laminated (Hybrid or not hybrid). With respect to the matrix type, the composite can be put into three groups: Polymer matrix, metal matrix, ceramic matrix. The polymer matrix contains two types, which defined as: Thermosets resin—The basic property of this type of resin is that, when it transforms to solid-state cannot be reshaped again, polyester and epoxy are some types of that resin; Thermoplastic resin—The main property of this resin is the ability to reshape by heat, polyamide and polypropylene are examples. Reinforcements differ among themselves by: The raw material that is used in manufacturing (carbon, glass, Kevlar, boron, natural fiber); The shape of meshing. With respect to the shape of meshing, reinforcements can classified into: Form of Mat; form of single fiber which exists in two shapes, woven fabric, randomly orientated fiber bundle, which may be chopped (chopped strand mat); continues and loosely held together with a binder (continues filament mat). Depending on aliening, the fiber can take these categories: Aligned fiber—they are all lying in the same direction; random—which they are randomly orientated [5].

Epoxy resins are polymeric or semi-polymeric materials, and it is rarely exist as pure substances, because of variable chain length results from the polymerization reaction that used to produce them. High purity grades can be produced for certain applications, e.g. using a distillation purification process. One of the side effects of high purity liquid grades, is their tendency to form crystalline solids due to their highly regular structure, which requires melting to enable processing [6].

Glass fiber is light in weight, extremely strong and robust. More for that, it has bulk strength, stiffness, and weight properties are also very favorable when compared to metals. Due to its light weight and high impact resistance it had used for aerospace, marine, and other industrial applications [7]. The characteristic of a composite can be affected by many factors, such as the form of fiber, the amount of fiber, the bond between the matrix and fiber, which appears in the stages of manufacturing the composite. The reinforcement materials in the composite have a principal rule that is raising mechanical properties. In fiber of mat many searches has done to study the effect of fiber form on prosperities of composite.

Wang, Ding &Sun used the variable type of fiber reinforcement (jute, carbon fiber & glass fiber) and studied some mechanical properties (tensile & bending) experimentally. The analysis appears that, jute felt reinforced polyurethane composite material has the properties of low cost, environmental protection, and light weight. Also, when the fiber content is 10% and 20%, jute felt enhanced the mechanical characteristics of the composite approaches close to the glass fiber reinforced composite materials and has a good development prospect [8].

Jweeg and others had done an experimental and theoretical study on the composite with different forms of reinforcement (short, long, woven fiber, powder, and particle).This study investigated the effect of fiber type on modulus of elasticity for composite. The results appear that the unidirectional composite materials give minimum modulus of elasticity in transverse direction comparing with other composite material types [9].

Jagannatha et al. studied the mechanical properties of hybrid composite that consist of epoxy matrix and (carbon/glass) fiber reinforcement with different weight ratios of glass fiber and certain ratio of carbon fiber. The result of this study shows that tensile strength and the ductility of carbon fiber mat composite are higher than the other types [10].

Fernandez et al. had focused on the development of composite structures fully based on natural materials. Natural fibers and cork acted as a core. The natural fibers used resulted from compounding flax fibers with bio-resin. The core material is agglomerated cork. The aim of this study is to compare these natural structures against similar synthetic sandwiches based on fiberglass and epoxy resin. Several laminates were produced and then subjected to static and dynamic mechanical testing, carried out via bending and impact tests respectively. After carefully analyzing the results, it was possible to conclude that the proposed materials show compatible mechanical properties and can even compete against the synthetic materials. Important property, these materials are friendly to environment [11].

The different things in present study are that, two fiber forms were considered; the first is bi-directional of (0°–90°) fiber direction, and the second random. The thickness of bi-directional fiber form has been investigated by considering thick and thin mats. The study focuses on composites of thermosets resin, and synthesis fiber of certain weight content (10%) of composite, to investigate the effect of this forms of fiber with this small ratio on specific mechanical properties, the ultimate stress, the ductility, and the transverse stiffness. The selection this type of resin as matrix, these forms of synthesis fiber and adept this weight ratio of fiber, as a reinforcement, as well as selection certain tests, all these give the difference to this search from the past searches in this field.

2. Materials and methods

2.1. The theoretical aspect

2.1.1. The normal stress and ultimate strength

The normal stress can get it from the tensile test, which gives a tabulated data for the applied load and the elongation in the experimental specimen. By using Eqs 1 and 2, we can get the stress and strain that corresponding to the force and the elongation. The ultimate strength is the maximum stress that appears in the stress-strain diagram.

$$\sigma = \frac{F}{A} \tag{1}$$

$$\varepsilon = \frac{L_f - L_i}{L_i} \tag{2}$$

where σ: the normal stress in (pas); F: the normal force in (N); A: cross section area (m^2); ε: the longitudinal stain; L_i: initial length (m); L_f: final length (m).

2.1.2. The ductility

Highly ductile material can exhibit a significant strain before fracturing whereas a brittle martial frequently displays very little strain. Ductility is an important property because it measures the ability of a material to absorb overloads and to be cold worked [12]. The percentage elongation (% EL) of a test piece after breaking is used as a masseur of ductility, this elongation can get it by Eq 3.

$$\%EL = \frac{L_f - L_i}{L_i} \times 100 \quad (3)$$

2.1.3. Transverse stiffness

Fiber-reinforced polymer composite material is widely used because of its high stiffness to the weight ratio as compared with much traditional material [13]. Bending stiffness is termed as the flexural rigidity of the member and also termed as the capacity of structural members to resist bending, Eq 4 describes this property.

$$\mathrm{k} = \frac{\mathrm{T}}{\delta} \quad (4)$$

where k: transverses stiffness in (N/m); T: transverse load in (N); δ: transverses deflection in (m).

2.2. Experimental aspect

2.2.1. Selection of the principal material of composite

In this study three forms of fiberglass as reinforcement for the composite are selected; because it's used in many engineering applications, low cost and good mechanical performance which enhances the mechanical characteristics of composite as tensile strength. The resin properties have explained as follows:

The resin: Its ability to adhere to the fiber so that forces applied to the composite are transmitted to the fiber and then the fibers can be the primary responsible for the strength of the composite; It protects the surfaces of the fibers from damage; It keeps the fibers apart to hide the crack propagation.

The resin that is used in this search is Sikadur-52 which is consists of two-component, epoxy resins and the hardener. The epoxy resins has a high-mechanical and adhesive strength, low-viscosity injection liquid, applicable at low temperature and Shrinkage free hardening. The epoxy resin and the hardener are shown in Figure 1a while its properties are listed in Table 1 [14].

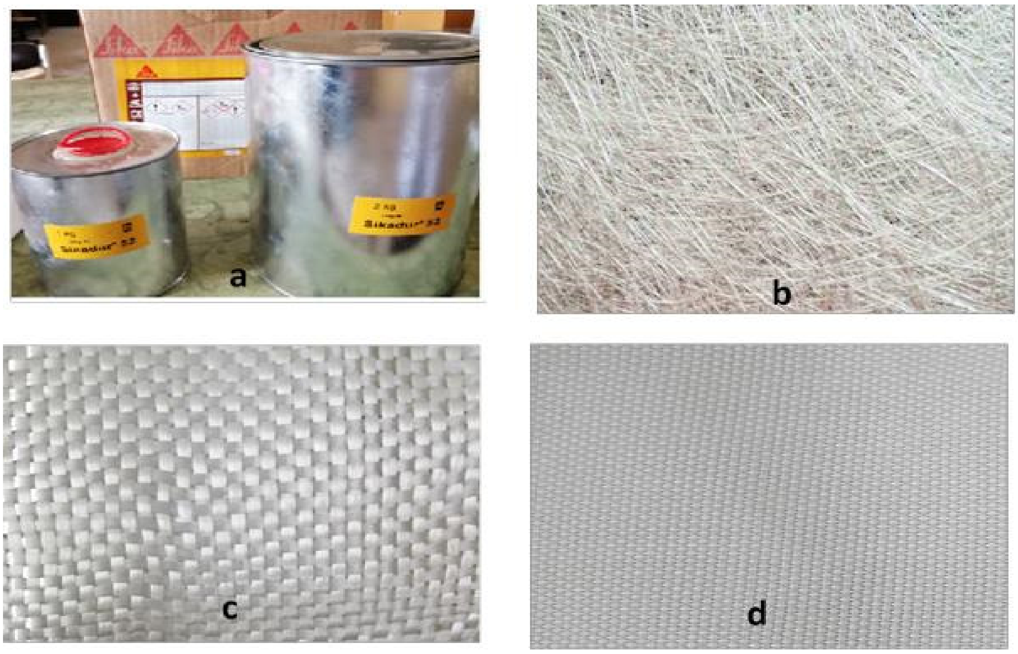

Figure 1. (a) Sikadur-52 epoxy resin and hardener containers, (b) Random fiber, (c) Thin fiber, and (d) fiber.

Table 1. The specifications of the Resin that has used in this research and technical data are specified at 20 °C**.**

Properties	Value	Unit
Flexural strength	50	N/mm^2
Compressive strength	53	N/mm^2
Tensile strength	25	N/mm^2
Modulus of elasticity	1060	N/mm^2
Density	1.1	kg/L
Resin to hardener ratio	3:1	-

The fibers: In this search the fibers that used are: fiberglass of randomly orientated fiber bundle as shown in Figure 1b and fiber mat of woven fabric forms (thick & thin) with two orientations direction (0º–90º) of fiber as shown in Figure 1c,d. The properties of these fibers have listed in Table 2.

Table 2. Properties of polymer and fiberglass.

Sl. No.	Fiberglass type	The thickness of the fiber (mm)	Weight of fibre (W.f.) (g)	Weight of polymer (W.p.) (gram)	Weight of hardener (g)	Density (kg/m^3)
1	Thick	0.6	52	313.3	165.6	783.6
2	Thin	0.4	52	313.3	165.6	1175.4
3	Random	0.2	52	313.3	165.6	1175.4

2.2.2. Manufacturing the composite sheets

Many sheets have prepared of composite by adapting the weight ratio of (10%) of fiber from composite weight for three forms of it, as shown in Table 2, as well as one sheet of pure epoxy (without fiber) for comparison purposes has prepared, but for random-fiber sample has used two fiber plates (this type of fiber has light weight in comparison with other fibers) to maintain the same weight ratio of fiber in composite that had fixed in the manufacture process. The resin mixed with the hardener by mix ratio that had advised by the manufacturing company (Sika) which supplies this production.

The base of mold has prepared for casting procedure by coating its surface with a film of wax for isolation the composite from the mold and to be easy in the extraction process for the production after solidification stage. The hand layup method used to get a composite at room temperature and atmospheric pressure.

2.2.3. Preparing the specimens

The sheets of composite have left for a suitable time period at (38 °C) temperature, and atmosphere pressure, to get a solid-state, and then they have cut by electrical saw to get specimens within the ASTM D3039. In this stage, many specimens from each sheet of the composite are prepared as shown in Figure 2a–c, in addition to the specimens of pure epoxy.

(a) (b) (c)

Figure 2. (a)Thick composite, (b) thin composite, and (c) random composite.

2.2.4. Mechanical tests

The mechanical tests have made on the specimens, which were of two categories; tensile and bending tests. Figure 3b shows the dimensions of tensile spacemen, and Figure 3a shows the one specimen of tensile in the tensile apparatus within the test period, the apparatus has a maximum load of (200 KN) with a constant rate of the applied load of (10 mm/min). Figure 4a–c shows different specimens after the tensile test.

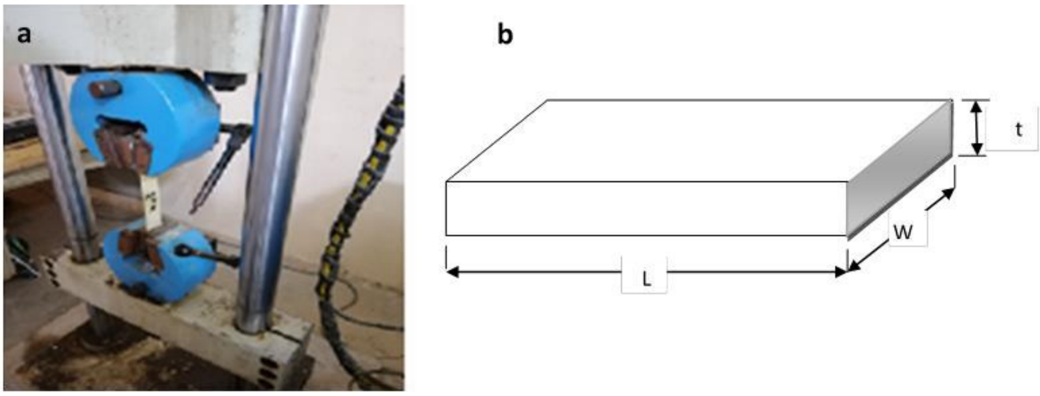

Figure 3. (a) Specimen in the tensile test, and (b) the dimension of tensile specimen.

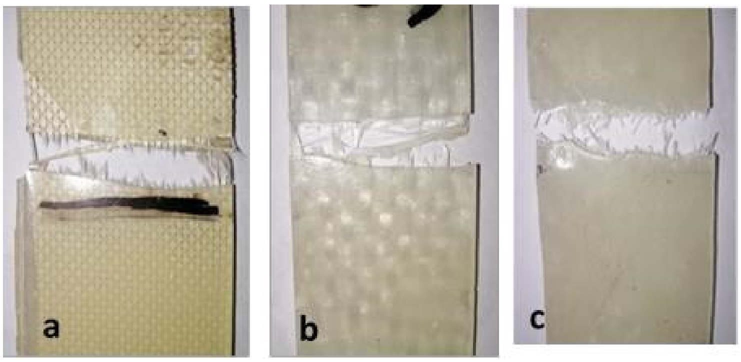

Figure 4. (a) Thick composite, (b) thin composite, and (c) random composite.

3. Results and discussion

3.1. Stress-strain curves of pure matrix

Figure 5 shows the behavior of the matrix under tensile stress. The curve of strain up to (0.02) is related as linear with stress and represent the elastic region, point 0.0218 of strain can be represent the region of start yield with (2.428 MPa) stress, while the strain point of 0.0437 represent the ending yield region with (2.428 MPa) stress. After that, up to ultimate strength point which is equal (23.5 MPa), the strain hardening of plastic region appears and finally the curve decrees to reach the rupture point. This curve generally shows the characteristics of ductile material that appears the low elastic behavior and large plastic characteristic with low strength. These results of mechanical strength are approximately equal to the magnitude of SIKADUR 52 properties represented in construction product data-sheet Eds. (22015) Version no. 12.2014 which gives the ultimate tensile strength of this material.

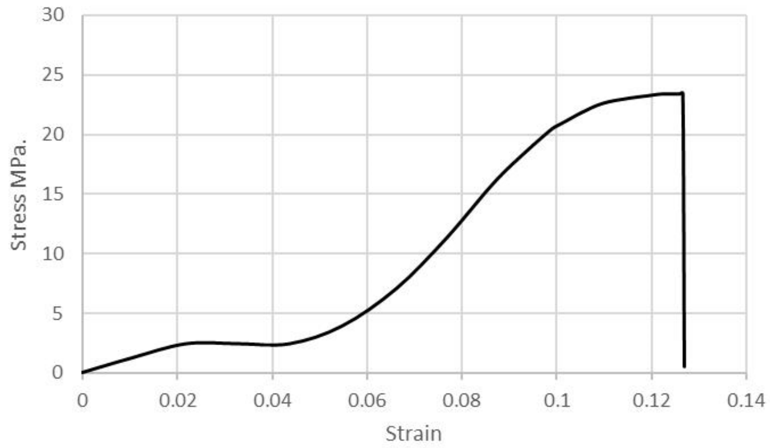

Figure 5. Stress-strain curve of pure resin specimen.

3.2. Stress-strain curve of the composite

The stress-strain curves shown in Figures 6–8, appear relatively a ductile behavior with a significant difference between them and that of epoxy, especially in elastic and plastic regions, at yielding points and tensile strengths. The difference between the curve of stress-strain for pure epoxy and the composite material in this search belongs to existence of fiber in the composite which decrease the ductility, and increase the strength of composite material. In another side, the curves of composites are differencing between them because of using different forms of fiber in each one, so that there are many differences can be seen between the shapes of curves and specific properties like as tensile strength which will discuss with detail in the article 3.3.

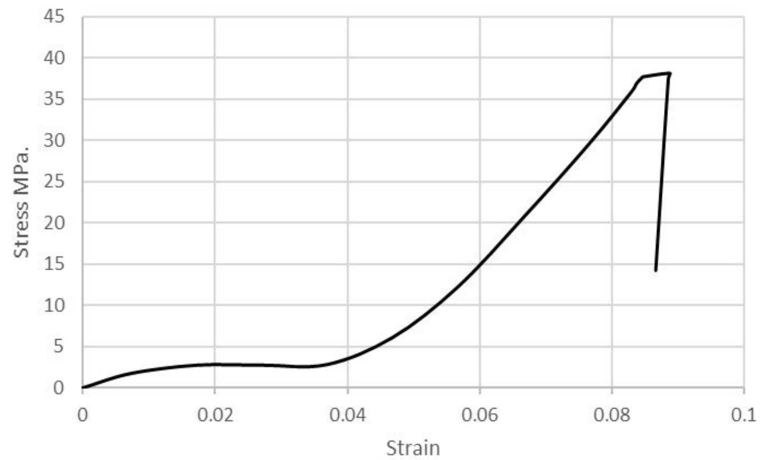

Figure 6. Stress-strain curve of thin mat specimen (SPC.).

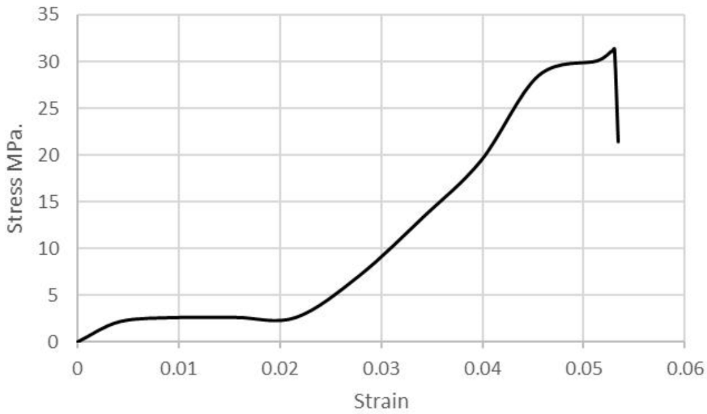

Figure 7. Stress-strain curve of thick mat specimen (SPF.).

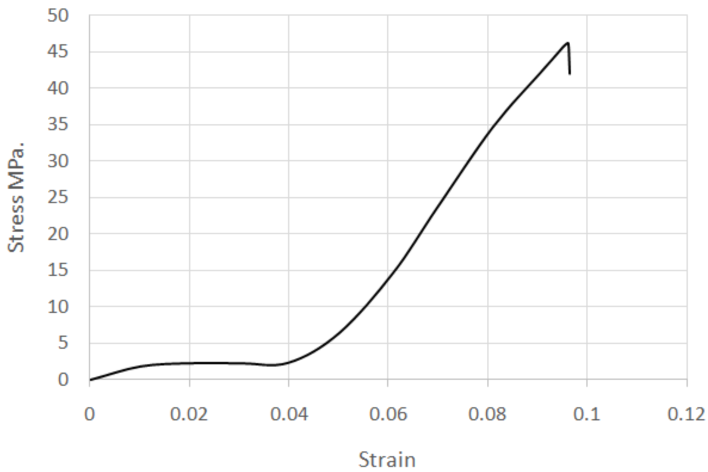

Figure 8. Stress-strain curve of random mat specimen (SPR.).

3.3. Ultimate strength

Figure 9 shows the results of ultimate strength for composite specimens. It appears that minimum value is (23.5 MPa) for the pure epoxy specimen, because it did not have reinforcement in these specimens. The magnitude of ultimate strength for thick woven mat is (31.357 MPa) which is greater than the ultimate strength of pure epoxy, because of the fiber existence, that makes it more resist to external load.

In the third stage, the thin woven mat has magnitude (38.21428 MPa) of ultimate strength which is greater than the magnitude of thick woven mat, because of the difference in microscopic structure between them. The cross-section in thin fiber consists of collected bands of filaments as shown in Figure 10b, while the thick fiber consists of scattered bands that contain some filaments in the cross-section as shown in Figure 10a, this difference gives good strength to the thin fiber composite and in another side weakens the thick fiber composite.

Finally, the randomly orientated fiber bundle takes the greatest value of (46.14285 MPa) because of two reasons, first one, it has collected bands of filaments along the cross-section of specimen, these filaments are more dense in that area as well as more overlap as shown in Figure 10c, the second reason is using two fiber reinforcement sheets for random-fiber specimens (this type of fiber has light weight in comparison with the other fibers for same surface area) to maintain the same weight ratio of fiber in composite that had fixed in the manufacture process. For all these reasons, the randomly orientated fiber mat composite takes the greatest ultimate strength than others.

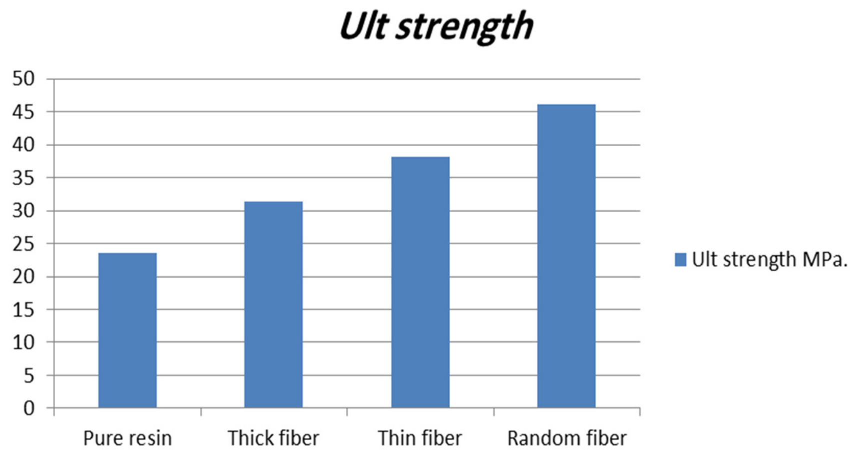

Figure 9. Ultimate strength-fiber form.

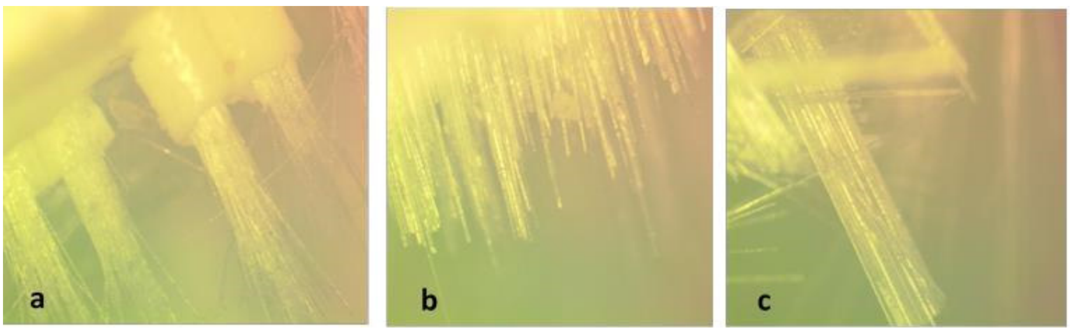

Figure 10. Microscopic vision for fracture region of (a) thick fiber specimen, (b) thin fiber specimen, and (c) random fiber specimen.

3.4. Ductility

From Figure 11 of ductility results, the pure matrix (without fiber) gives the highest value of ductility as (13.58%), because its more effect by external load (where no reinforcement), while the thin composite gets second grade for ductility with value of (9.8%) because of fiber existence. The random composite appears the value (9.197%) of ductility, which is less than thin fiber composite because of the strength of this fiber form. The thick fiber composite has ductility value of (8.6%), which is represent the smallest value of ductility, the thickness of this form and fine knitting , make this type of composite has low ductility than other Mats.

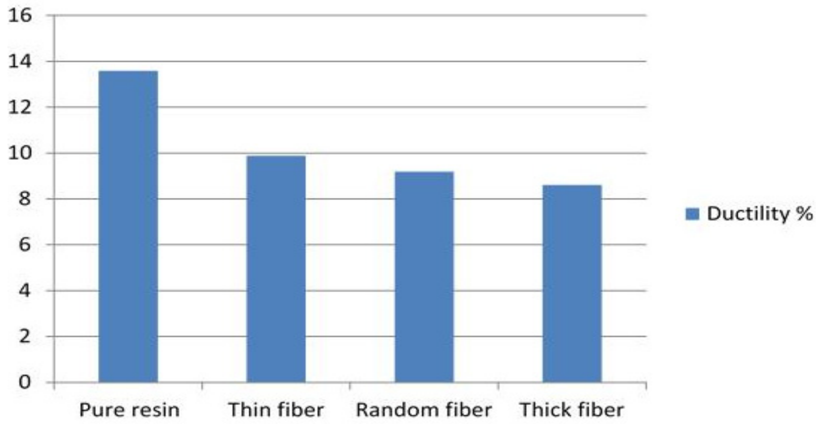

Figure 11. Ductility diagram-fiber form.

3.5. Transverse rigidity

To get the transverse rigidity, the bending tests for three composites types and one pure matrix specimens have done. Figure 12 shows the results of transverse rigidity which appears that, the pure matrix has the lowest value of (0.39 MN/m) and this belongs to the absence of reinforcement which supports the material rigidity. The thick composite has value of (0.403 MN/m), the increase in this value caused by reinforcement existence, while the thin composite has the value of (0.532 MN/m), and the random composite gets the highest value of (0.935 MN/m), this behavior can be said that it belongs to the same reason for ultimate strength, it is clear this property has same behavior of ultimate strength with variation of fiber form.

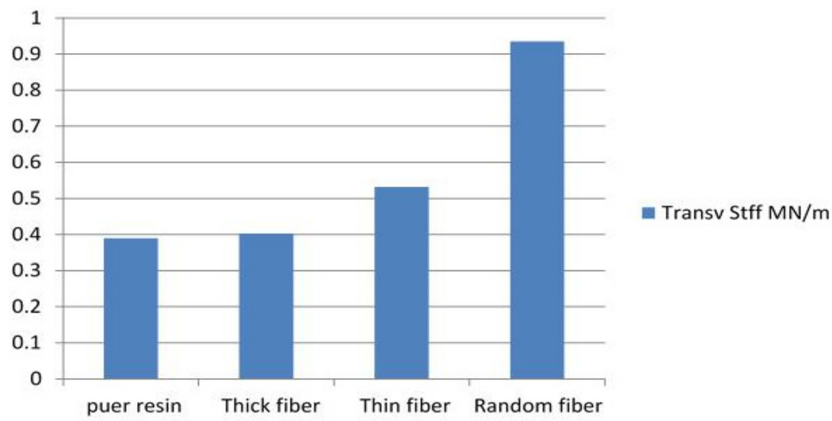

Figure 12. Transverse stiffness diagram-fiber form.

3.6. The microscopic vision

In this article the discussion will be about the microscopic vision which is taken in the fracture region in all types of composites with accuracy of 50 μm. Figure 10a of the thick fiber specimen shows a fracture region with thick fibers which appears as scattered bands that contain some filaments in the cross-section, this makes it to some degree stronger than of the specimens of epoxy but by comparison, it is weaker than other types of composites. On the other hand, the fracture region of thin fiber specimens shows as a collected band of filaments along its cross-section as shown in Figure 10b, this type of composite will be stronger than the thick type, and will be ductile more than the other composites and the value of transverse stiffness has intermediate between other composites. In random specimens, the collected band of filaments is along the cross-section of the specimen, denser in that area as well as more overlap between them as shown in Figure 10c, so that this type of composite is the strongest between the other types of composites.

4. Conclusions

In this study, three composite samples have been investigated based on different fiber form and thickness. The mechanical properties of considered materials have been tested. Generally, it can be concluded that the reinforcement by fiberglass enhances the ultimate strength and the transverse stiffness while the ductility is reduced. In particular, the following conclusions have been deduced:

- The thick fiber enhances the ultimate strength and transverse stiffness slightly but makes the composites has smallest ductility.
- The thin fiber significantly improves these all properties in this study and has optimum case in its properties (strength, stiffness and ductility) between other composites.
- The random fiber exhibits maximum ultimate strength and transverse stiffness but small ductility in comparison with pure matrix and thin composite.
- The tests appear that; the strength of composites begins from the greatest value to smaller as follows: random composite, thin composites, thick composite and finally the resin, respectively.
- The transverse stiffness has same trends of ultimate strength.
- The ductility has other trends, such that the sequence from greatest to smaller as that; the resin, thin composite, random and thick composites respectively.
- The microscopic vision appears that; The composite of thick fiber has the fracture region of scattered bands of filaments, the composite of thin fiber has collected a band of filaments, and in random type, the collected band of filaments are denser in that area as well as more overlap between them. All above have principal role to give that properties which is mentioned previously.

Conflict of interests

All authors declare no conflicts of interest.

References

1. Nagavally RR (2017) Composite material history, types, fabrication, techniques advantage, and applications. *Int J Mech Prod Eng* 5: 82–87.
2. Kulkarni PV, Sawant PJ, Kulkarni VV (2018) Fatigue life prediction and modal analysis of carbon fiber reinforced composite. *Adv Mater Proc Technol* 4: 651–659.

3. Nahas MN (2005) New development in composite materials-recyclable and environment friendly composite materials. *Eng Sci* 16: 77–102.
4. Elanchezhian C, Ramnath BV, Hemalatha J (2014) Mechanical behavior of glass and carbon fiber reinforced composites at varying strain rates and temperatures. *Procedia Mater Sci* 6: 1405–1418.
5. Bolton W (1998) Composites, *Engineering Materials Technology*, 3 Eds., Butterworth-Heinemann, 303–306.
6. Ganugapenta R, Madhusudan S, Balaji K, et al. (2018) Study on mechanical and tribological properties of glass fiber reinforced epoxy composites with Sic & flyash as fillers. *IJESI* 7: 25–38.
7. EL-Wazery MS, EL-Alamy MI, Zoalfakar SH (2017) Mechanical properties of glass fiber reinforced polyester composites. *IJAS* 14: 121–131.
8. Wang L, Ding WX, Sun Y (2015) Effect of different fiber materials on mechanical properties of polyurethane composites. *2015 2nd International Workshop on Materials Engineering and Computer Sciences* 406–411.
9. Jweeg MJ, Hammond AS, Al-Waily M (2012) Experimental and theoretical studies of mechanical properties for reinforcement fiber types of composite materials. *IJMME-IJENS* 12: 62–75.
10. Jagannatha TD, Harish G (2015) Mechanical properties of carbon glass fiber reinforced epoxy hybrid polymers composites. *IJMERR* 4:131–137.
11. Fernandes FAO, Tavares JP, de Sousa RJA, et al. (2017) Manufacturing and testing composite based on natural materials. *Procedia Manuf* 13:227–234.
12. Budynas RG, Nisbett JK (1976) *Shigley's Mechanical Engineering Design*, 8 Eds., McGraw-Hill, 39–41.
13. Ghasemnejad H, Hadavinia H, Aboutorabi A (2010) Effect of delamination failure in the crashworthy analysis of hybrid composite box structure. *Mater Design* 31: 1105–1116.
14. Sika, Egypt for Construction Chemicals, Sikadur-52 Construction, Product Datasheet, 2003. 2 Eds., 1–2. Avaliable from: www.sika.com.eg.