Experimental and Theoretical Studies of Mechanical Properties for Reinforcement Fiber Types of Composite Materials

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***Abstract*--- In this research, experimental and theoretical study of composite materials reinforcement fiber types are presented. The experimental work and the theoretical investigation covered the study of modulus of elasticity for long, short, woven, powder, and particle reinforcement of composite materials types with difference volume fraction of fiber. In addition the compare it the experimental results with theoretical results of modulus of elasticity for difference composite materials types.**

The results show that the effect of fiber and resin types on modulus of elasticity for composite materials are presented. In addition the effect of volume fraction of fiber and matrix materials on modulus of elasticity for composite materials shown a presented. The results show have good agreement between experimental and theoretical study for different types of composite materials. The results having that shown the best modulus of elasticity for reinforcement composite is unidirectional fiber types in longitudinal direction and the woven reinforcement fiber types for transverse direction.

***Index Term*--- Mechanical Properties, Composite Materials, Powder Composite Materials, Reinforcement Fiber.**

I. INTRODUCTION

The bonding between fibers and matrix is created during the manufacturing phase of the composite material. This has fundamental influence on the mechanical properties of the composite material. Fibers consist of thousands of filaments, each filament having a diameter of between 5 and 15 micrometers, allowing them to be producible using textile Machines These fibers are sold in the following forms, **[5]**:

1. Short fibers, with lengths of a few centimeters or fractions of millimeters are felts, mats, and short fibers used in injection molding.
2. Long fibers, which are cut during time of fabrication of the composite material, are used as its or woven.
    - Principal fiber materials are, **[5],**

1. Glass
2. Aramid or Kevlar (very light)
3. Carbon (high modulus or high strength)
4. Boron (high modulus or high strength)
5. Silicon carbide (high temperature resistant)

In forming fiber reinforcement, the assembly of fibers to make fiber forms for the fabrication of composite material can take the following forms:

1. Unidimensional: unidirectional tows, yarns, or tapes
2. Bidimensional: woven or nonwoven fabrics (felts or mats)
3. Tridimensional: fabrics (sometimes called multidimensional fabrics) with fibers oriented along many directions (>2)
    - The matrix materials include the following

1. Polymeric matrix: thermoplastic resins (polypropylene, polyphenylene sulfone, polyamide, polyetheretherketone, etc.) and thermoset resins (polyesters, phenolics, melamines, silicones, polyurethanes, epoxies).
2. Mineral matrix: silicon carbide, carbon.
3. Metallic matrix: aluminum alloys, titanium alloys, oriented eutectics.

II. THEORETICAL STUDY

Denote as ply the semi-product “reinforcement + resin” in a quasi-bidimensional form, [5].

- Fiber mass fraction is defined as,

$$M_f = \frac{Mass\ of\ Fibers}{Total\ Mass} \qquad (1)$$

- In consequence, the mass of matrix is,

$$M_m = \frac{Mass\ of\ Matrix}{Total\ Mass} \quad ,$$

With, $M_m = 1 - M_f$ (2)

- Fiber volume fraction is defined as,

$$\forall_f = \frac{Volume\ of\ Fiber}{Total\ Volume} \qquad (3)$$

- As a result, the volume of matrix is given as,

$$\forall_m = \frac{Volume\ of\ Matrix}{Total\ Volume},$$

With,

$$\forall_m = 1 - \forall_f \qquad (4)$$

Note that one can convert from mass fraction to volume fraction and vice versa. If ρ_f and ρ_m are the specific mass of the fiber and matrix, respectively, get,

$$\forall_f = \frac{\frac{M_f}{\rho_f}}{\frac{M_f}{\rho_f} + \frac{M_m}{\rho_m}} \quad ,$$

$$M_f = \frac{\forall_f . \rho_f}{\forall_f . \rho_f + \forall_m . \rho_m} \qquad (5)$$

- The mass density of a ply can be calculated as, $\rho = \frac{Total\ Mass}{Total\ Volume}$, equation can also be expanded as,

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$$\rho = \frac{Mass\ of\ Fiber}{Total\ Volume} + \frac{Mass\ of\ Matrix}{Total\ Volume} = \frac{Volume\ of\ Fiber}{Total\ Volume}\rho_f + \frac{Volume\ of\ Matrix}{Total\ Volume}\rho_m$$

$$\rho = \rho_f.\forall_f + \rho_m.\forall_m \qquad (6)$$

Unidirectional Ply

The mechanical characteristics of the fiber/matrix mixture can be obtained based on the characteristics of each of the constituents. With the definitions in the previous paragraph, one can use the following relations to characterize the unidirectional ply, [13]:

- Modulus of elasticity along the direction of the fiber E_1 is given by,

$$E_1 = E_f.\forall_f + E_m.\forall_m\ ,$$

Or,

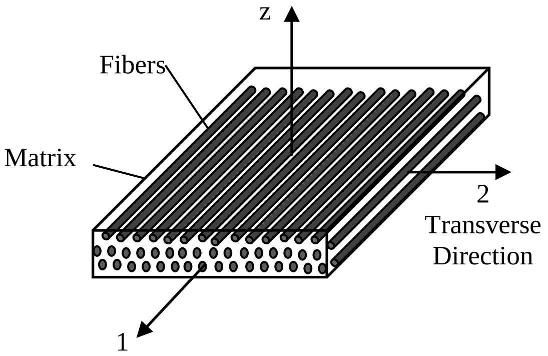
$$E_1 = E_f.\forall_f + E_m.\left(1 - \forall_f\right) \qquad (7)$$

- Modulus of elasticity in the transverse direction to the fiber axis, E_2 and Shear modulus G_{12},

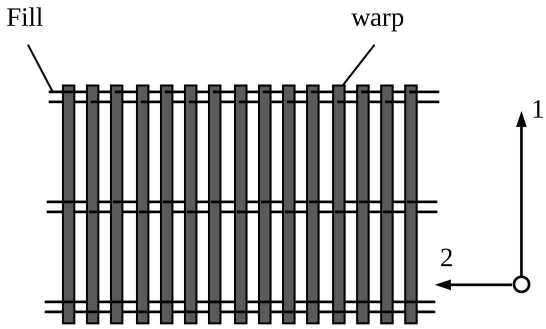
$$E_2 = E_m\left[\frac{1}{(1-\forall_f)+\frac{E_m}{E_f}\forall_f}\right]$$

$$G_{12} = G_m\left[\frac{1}{(1-\forall_f)+\frac{G_m}{G_f}\forall_f}\right] \qquad (8)$$

Note the directions of unidirectional ply shown in the Fig. 1.



Longitudinal Direction, Unidirectional Ply



Unidirectional Fabric

Fig. 1. Orientations in composite layers, [13].

Woven Fabrics

The fabrics are made of fibers oriented along two perpendicular directions,[5],

- one is called the warp and,
- the other is called the fill (or weft) direction.

The fibers are woven together, which means the fill yarns pass over and under the warp yarns, following a fixed pattern.

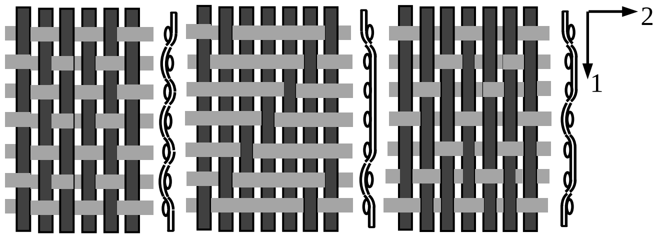
Fig. 2.a. shows a plain weave where each fill goes over a warp yarn then under a warp yarn and so on. In Fig. 2.b, each fill yarn goes over 4 warp yarns before going under the fifth one. For this reason, it is called a "5-harness satin." Fig. 2.c. shows a twill weave.

The fabric layer is replaced by one single anisotropic layer, x being along the warp direction and y along the fill direction (see Fig. 2). One can therefore obtain, [5],

$$E_{1_w} = k.E_1 + (1-k)E_2\ ,\quad E_{2_w} = (1-k)E_1 + k.E_2\ ,\quad G_{12_w} = G_{12} \qquad (9)$$

Where, $= \frac{n_1}{n_1+n_2}$, n_1 =number of warp yarns per meter, n_2 =number of fill yarns per meter.

And, E_{1_w}, E_{2_w}, and G_{12_w} are mechanical properties of woven fabrics in 1 and 2-directions; and E_1, E_2, and G_{12} as in equations (7) to (8).



a) Plain b) Satin c) Twill

Fig. 2. Forms of woven fabrics, [5].

The stiffness obtained with a woven fabric is less than what is observed if one were to superpose two cross plies of unidirectionals. This is due to the curvature of the fibers during the weaving operation (see Fig. 3). This curvature makes the woven fabric more deformable than the two cross plies when subjected to the same loading. (There exist fabrics that are of "high modulus" where the unidirectional layers are not connected with each other by weaving. The unidirectional plies are held together by stitching fine threads of glass or polymer).

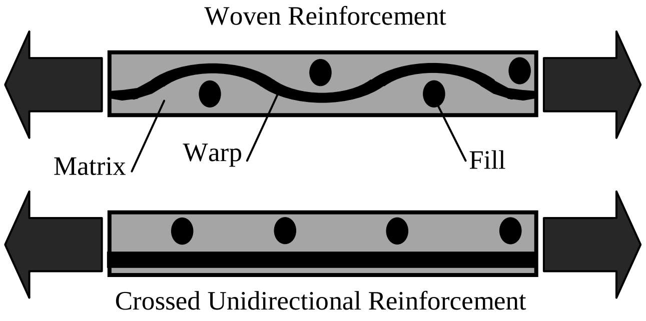


Fig. 3. Cross section of a layer with fibers crossed at 90°, [5].

Mats Materials

Mats are made of cut fibers (fiber lengths between 5 and 10 cm) or of continuous fibers making a bidimensional layer. Mats are isotropic within their plane (x, y). If E_1 and E_2 are the elastic module (along the longitudinal and transverse directions) of an unidirectional ply with the same volume fraction of V_f, one has, [5],

$$E_{mat} \approx \frac{3}{8}E_1 + \frac{5}{8}E_2 \,, \qquad G_{mat} \approx \frac{E_{mat}}{2.(1+\nu_{mat})} \qquad (10)$$

Spherical (Powder) Fillers

Spherical fillers are reinforcements associated with polymer matrices. They are in the form of microballs, either solid or hollow, with diameters between 10 and 150 μm. They are made of glass, carbon, or polystyrene. The composite (matrix + filler) is isotropic, with elastic properties E, G given by the following relations, [5]:

$$K = \frac{E_m}{3.(1-2.\nu_m)}\left[1 + 3.\left(\frac{1-\nu_m}{1+\nu_m}\right).\frac{\forall_f}{(1-\forall_f)}\right]$$

$$E \approx \frac{9.K.G}{3.K+G}$$

$$G = \frac{E_m}{2.(1+\nu_m)}.\left[1 + \frac{15}{2}.\left(\frac{1-\nu_m}{4-5.\nu_m}\right).\frac{\forall_f}{(1-\forall_f)}\right] \qquad (11)$$

Discontinuous (Short) Fiber-Matrix Composite Materials

For unidirectional fiber matrix shown in Fig. 4.a. the following Halpin-Tsai relation are used to determine the elastic properties, [6],

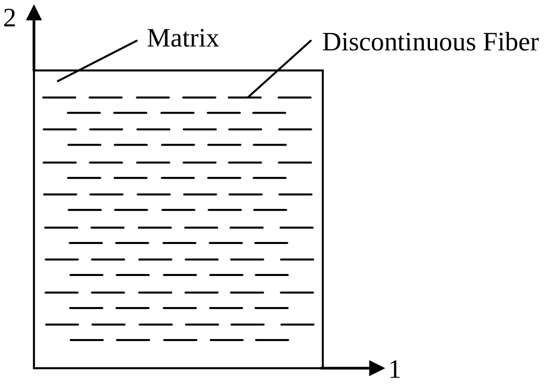
$$E_{1m} = \frac{1+2.a_f.\eta_l.\forall_{sf}}{1-\eta_l.\forall_{sf}}.E_m \,, \quad E_{2m} = \frac{1+2.\eta_T.\forall_{sf}}{1-\eta_T.\forall_{sf}}.E_m \,, \quad G_{12m} = G_{21m} = \frac{1+\eta_G.\forall_{sf}}{1-\eta_G.\forall_{sf}}.G_m \qquad (12)$$

Where,

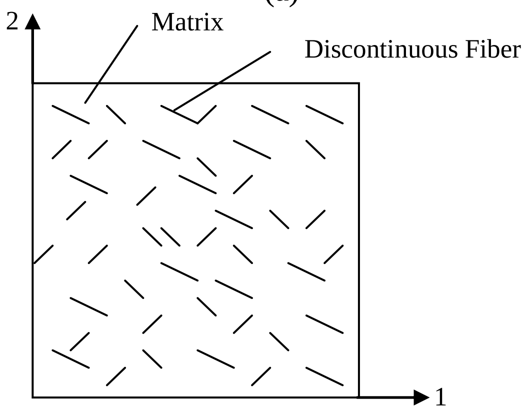
$$\eta_l = \frac{\frac{E_{sf}}{E_m}-1}{\frac{E_{sf}}{E_m}+2.a_f} \,, \quad \eta_T = \frac{\frac{E_{sf}}{E_m}-1}{\frac{E_{sf}}{E_m}+2} \,, \quad \eta_G = \frac{\frac{G_{sf}}{G_m}-1}{\frac{G_{sf}}{G_m}+1}$$

let E_{1m} and E_{2m} be the longitudinal and transverse module defined by eq. (12) for a unidirectional discontinuous fiber 0^0 composite matrix of the same fiber aspect ratio and fiber volume fraction as the randomly oriented discontinuous fiber matrix shown in Fig. 4.b. Since the fiber is randomly oriented, the matrix exhibits isotropic behavior. The Young's modulus and shear modulus of such a composite matrix are given by, [6],

$$E_{cm} = \frac{3}{8}E_{1m} + \frac{5}{8}E_{2m}, \; G_{cm} = \frac{1}{8}E_{1m} + \frac{1}{4}E_{2m} \qquad (13)$$



(a)



(b)

Fig. 4. Unidirectional and randomly oriented discontinuous fiber matrix, [6].

III. EXPERIMENTAL STUDY

The experimental study of composite materials included study of mechanical properties of difference types of composite materials with various volume fraction of reinforcement fiber as powder, particle, long, woven, and short reinforcement glass fiber, as shown in Fig. 5.

a- Short fiber b- Woven fiber

c- Long fiber d- Particle fiber e- Powder fiber

Fig. 5. Over view pictures for types of composites fiber.

The density of fiber used can be evaluated, as shown in Fig. 6, as,

$$\rho = \frac{weight\ of\ fiber}{\Delta\forall} \qquad (14)$$

Where, $\Delta\forall$ change of water volume after case the weight of fiber.

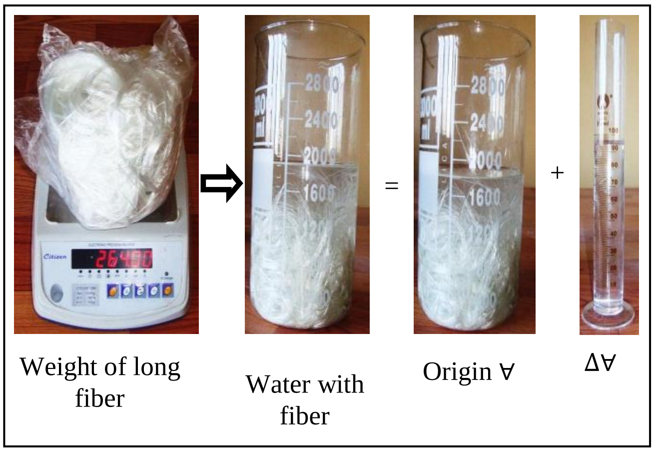
Then, the density of fiber types are,

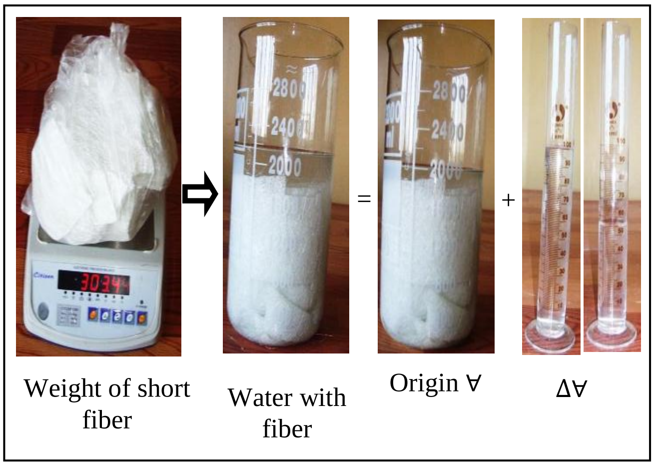
Polyester Resin Materials $\rho = 1000\ \mathrm{kg/m^3}$
Powder Fiber $\rho = 3000\ \mathrm{kg/m^3}$,
Particle Fiber $\rho = 2400\ \mathrm{kg/m^3}$,
Long Fiber $\rho = 2750\ \mathrm{kg/m^3}$,
Short Fiber $\rho = 1960\ \mathrm{kg/m^3}$,
Woven Fiber $\rho = 2400\ \mathrm{kg/m^3}$ (15)

Then, the weight required of tensile samples for difference volume fraction of difference types of fiber and resin can be evaluated from,

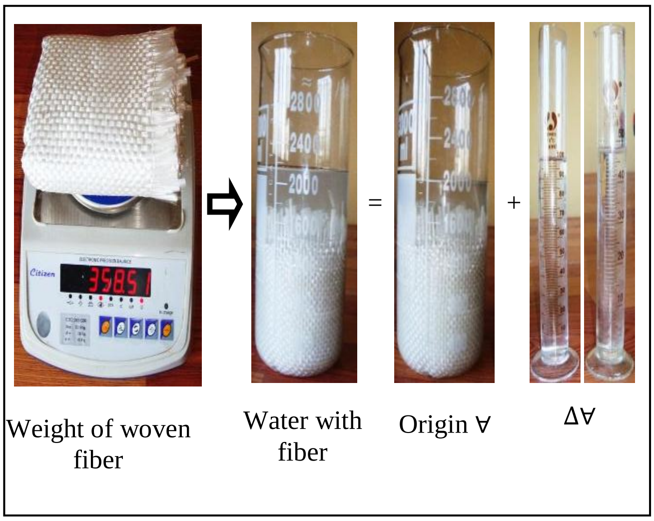
$$Weight\ of\ Fiber = \rho_f * \forall_t * \forall_f$$
$$Weight\ of\ Resin = \rho_m * \forall_t * \forall_m \qquad (16)$$

Where, $\forall_t$ total volume of tensile sample, depended on as ASTM Number (D3039/D03039M), [3], selected the shape and dimensions of tensile test sample, as shown in Fig. 7, as, $Width\ of\ Sample = 3\ cm$, $Length\ of\ Sample = 20\ cm$, $Thickness\ of\ Sample = 5\ mm$

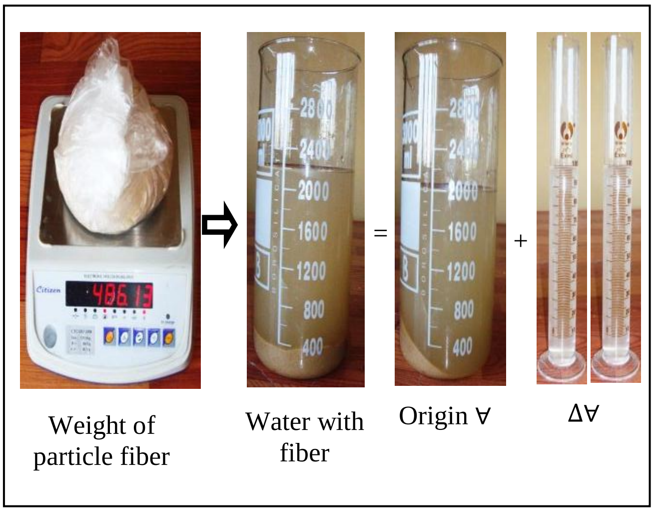




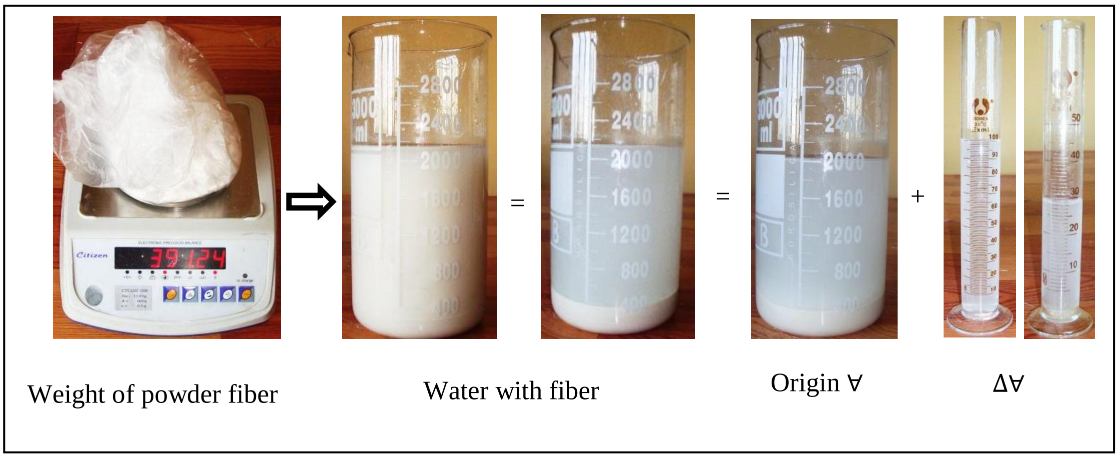
b- Short fiber



c- Woven fiber



d- Particle fiber



e- Powder fiber

Fig. 6. Evaluation of density for difference types of reinforcement glass fiber

Then, the weight of difference volume fraction of fiber and resin can be calculated as shown in Tables 1. to 3.

TABLE I
Weight required of short, powder, and particle fiber and polyester resin of composite materials for difference volume fraction of fiber and resin.

Sample	$\forall_m$	$\forall_f$	Weight of Fiber Materials (g)			Weight of Resin Materials (g)
			short fiber	particle fiber	powder fiber	polyester
S_1	0.9	0.1	5.88	7.2	9	27
S_2	0.8	0.2	11.76	14.4	18	24
S_3	0.7	0.3	17.64	21.6	27	21
S_4	0.6	0.4	23.52	28.8	36	18
S_5	0.5	0.5	29.4	36	45	15

TABLE II
Weight required of woven fiber and polyester resin of composite materials for difference volume fraction of fiber and resin.

Sample	Thickness of Sample (mm)	$\forall_m$	$\forall_f$	Weight of Woven Fiber Materials (g)	Weight of Resin Materials (polyester) (g)
S1	1	0.75	0.25	3.6	4.5
S2	2.5	0.9	0.1	3.6	13.5
S3	5	0.95	0.05	3.6	28.5
S4	7.5	0.967	0.033	3.6	43.515

TABLE III
Weight required of long fiber and polyester resin of composite materials for difference volume fraction of fiber and resin.

Sample	$\forall_m$	$\forall_f$	Number of Fiber Wire	Weight of Long Fiber Materials (g)	Weight of Resin Materials (polyester) (g)
S1	0.95	0.05	9	4.125	28.5
S2	0.90	0.1	18	8.25	27
S3	0.85	0.15	26	12.375	25.5
S4	0.80	0.20	35	16.5	24
S5	0.75	0.25	43	20.625	22.5

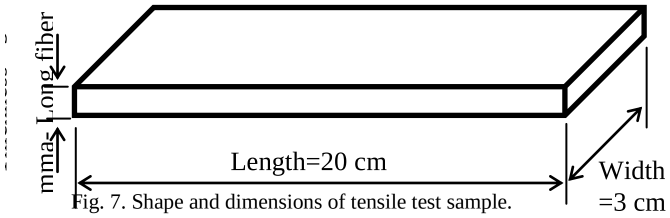
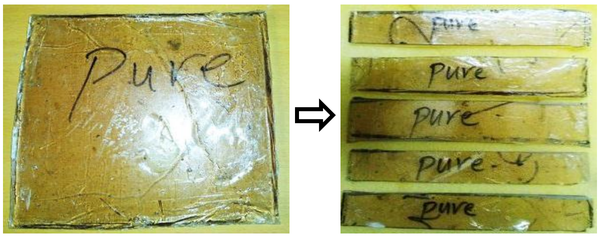


Fig. 7. Shape and dimensions of tensile test sample.

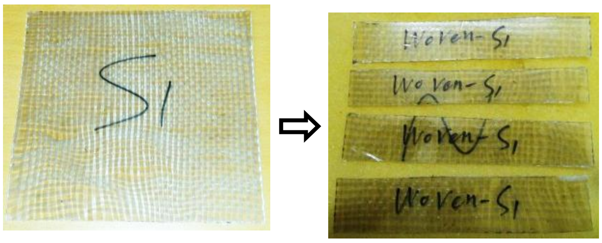
Then, made five samples for each volume fraction composite materials and testing the samples and taking the average results of modulus of elasticity, as shown in Fig. 8 for difference composite materials and polyester resin.

Then, the tensile test properties of composite materials are defined by testing the samples by tensile machine shown in Fig.9.

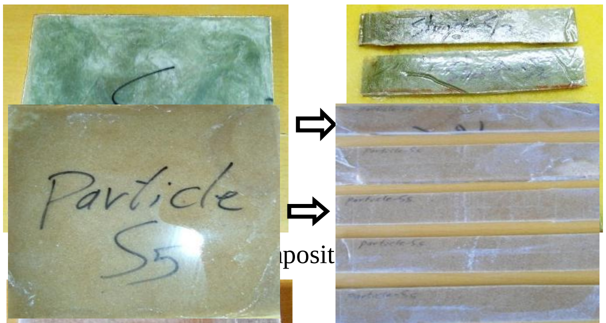
Then, the fracture of composite materials types due to tensile testing are shown in Fig. 10.



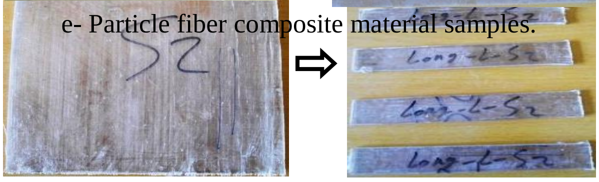
a- Pure polyester resin material samples.



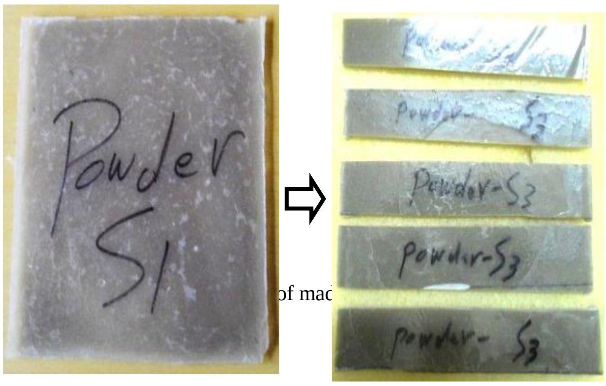
b- Woven fiber composite material samples.



e- Particle fiber composite material samples.



f- Long fiber composite material samples.



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d- Powder fiber composite material samples.

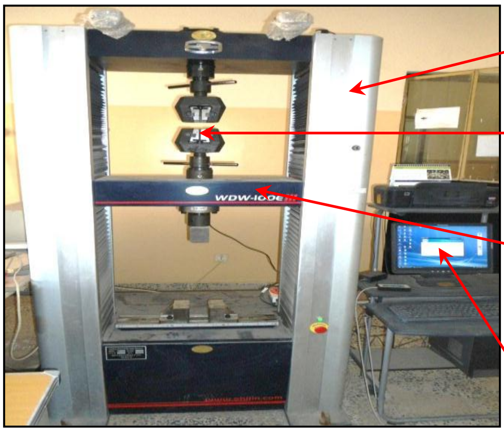
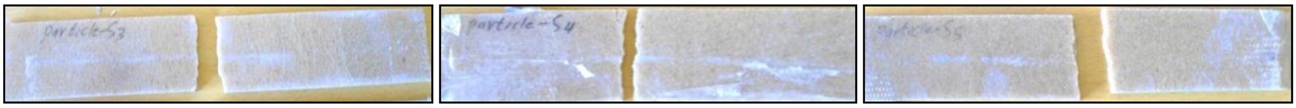


Fig. 9. Tensile test machine.

a- Pure polyester resin material.

b.1. Particle composite, S_1.

b.2. Particle composite, S_2.



b.3. Particle composite, S_3.

b.4. Particle composite, S_4.

b.5. Particle composite, S_5.

c.1. Powder composite, S_1.

c.2. Powder composite, S_2.

c.3. Powder composite, S_3.

c.4. Powder composite, S_4.

c.5. Powder composite, S_5.

d.1. Woven composite, S_1.

d.2. Woven composite, S_2.

d.3. Woven composite, S_3.

d.4. Woven composite, S_4.

e.1. Long composite, S_1.

e.2. Long composite, S_2.

e.3. Long composite, S_3.

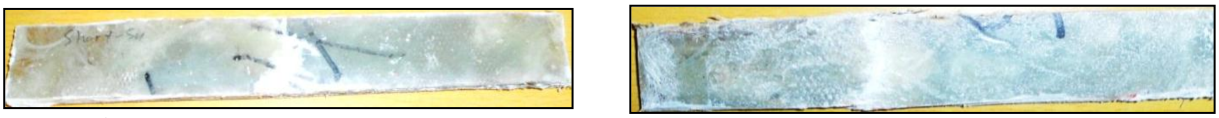
e.4. Long composite, S_4.

e.5. Long composite, S_5.

f.1. Short composite, S_1.

f.2. Short composite, S_2.

f.3. Short composite, S_3.



f.4. Short composite, S_4.

f.5. Short composite, S_5.

Fig. 10. Fracture of composite materials due to tensile loading (by tensile testing).

IV. RESULT AND DISCUSSIONS

The results get by experimental and theoretical study presented the modulus of elasticity for differences composite materials. The experimental work included the study of long, short, powder, particle and woven reinforcement fiber of composite materials for difference volume fraction of fiber. Figs. 11 to 16. show the modulus of elasticity of difference composite materials testing for five sample for each composite materials types with volume fraction fiber. And, the average modulus of elasticity for composite materials are shown in Table 4.

TABLE IV
Modulus of elasticity (Gpa) of different types of composite materials.

$\forall_f$	Reinforcement Fiber Types				
	Woven	Long	Short	Particle	Powder
3.3%	4.77	/	/	/	/
5%	6.02	8.62	/	/	/
10%	10.80	12.64	7.56	3.878	4.68
15%	/	15.87	/	/	/
20%	/	20.32	11.85	4.24	6.18
25%	18.76	22.80	/	/	/
30%	/	/	14.78	4.66	7.18
40%	/	/	18.51	5.82	9.14
50%	/	/	24.70	6.48	10.62

Fig. 11. To 16. Show the various of modulus of elasticity for composite materials types testing of five samples for each volume fraction of fiber sample. Fig. 17. Shows the modulus of elasticity for difference composite materials with difference volume fraction. Form Figures shown the modulus of elasticity increasing with increasing the volume fraction of fiber. And, the modulus of elasticity for long fiber composite more than for other reinforcement fiber. In addition to, the modulus for powder composite more than for particle composite.

The experimental study compares with theoretical study for woven, long, powder and short fiber, as shown in Figs. 18. to 21. for woven, long, short and powder reinforcement fiber, respectively. Figures show a good agreement between experimental and theoretical results.

The theoretical study of composite materials types included study of different composite materials types, as shown in Tables 5.

TABLE V
Types of reinforcement for composite materials.

Composite Materials Combine				
Resin Matrix				Fiber Reinforcement
Epoxy	Polyester	Nylon	Polyester (PC)	Glass
				Carbon-High-strength
				Carbon-High-modulus
				Boron

Figs. 22. to 25. show the relation-ship between modulus of elasticity and volume fraction of unidirectional composite materials for difference fiber types, for epoxy, polyester, nylon, and polyester (PC) matrix, respectively. Figs. 26. to 29. show the relation-ship between modulus of elasticity and volume fraction of Woven composite materials for different fiber types, for epoxy, polyester, nylon, and (PC) polyester matrix, respectively. And, Figs. 30. to 33. show the relation-ship between modulus of elasticity and volume fraction of Mats composite materials for difference fiber types, for epoxy, polyester, nylon, and polyester (PC) matrix, respectively. From the figures it is seen that the modulus of elasticity increasing with increasing of volume fraction of fiber and increase with increasing the strength of fiber reinforcement and matrix materials.

Figs. 34. to 37. show the relation-ship between modulus of elasticity and volume fraction of Spherical (Powder) composite materials for difference fiber types, for epoxy, polyester, nylon, and polyester (PC) matrix, respectively. From the figures it is seen that the modulus of elasticity increasing with increasing of volume fraction of fiber and un-difference with increasing or decreasing the strength of fiber reinforcement increasing with increasing strength of matrix materials.

Figs. 38. to 41. show the relation between modulus of elasticity and volume fraction of Discontinuous (Short) composite materials for difference fiber types, for epoxy, polyester, nylon, and (PC) polyester matrix, respectively. From the figures it is seen that the increasing of volume fraction of fiber increase the modulus of elasticity. In addition to the modulus of elasticity increasing with increasing the strength of fiber reinforcement and matrix materials.

Fig. 42. to 46. show the relationship between modulus of elasticity and volume fraction for unidirectional, woven, mats, powder, and short Carbon-High-Modulus reinforcements fiber composite materials, respectively, for differences resin matrix. Form Figures it is seen that the modulus of elasticity for unidirectional, woven, and mats reinforcements fiber composite materials not effect with change of matrix materials. And the modulus of elasticity for short and powder reinforcement fiber composite materials increasing with increasing of modulus of matrix materials. In addition to, the change for modulus of elasticity for powder reinforcement more than for short reinforcement composite materials.

Figs. 47. and 48. show the comparison of modulus of elasticity for different composite materials types with E_1 and E_2, respectively, for unidirectional. From figures it is seen the best modulus of elasticity composite types are unidirectional composite types in longitudinal direction and woven fiber composite to given modulus in transformation direction.

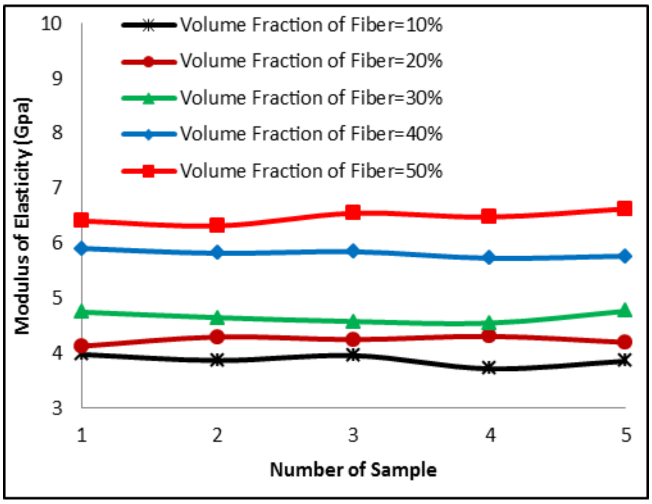


Fig. 11. Experimental testing of five samples for particle composite materials with difference volume fraction fiber.

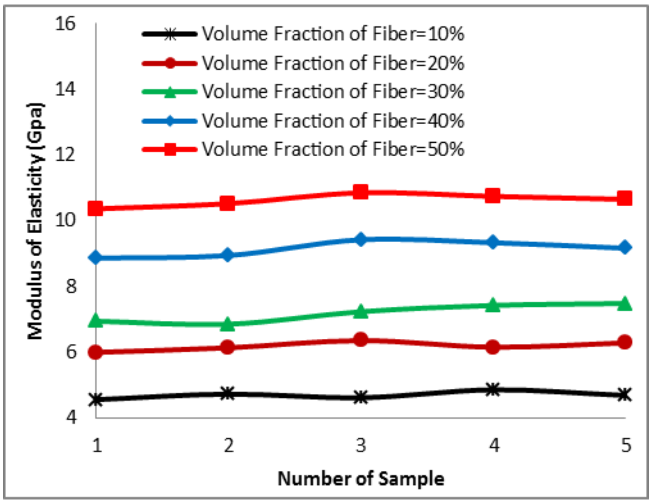


Fig. 12. Experimental testing of five samples for powder composite materials with difference volume fraction fiber.

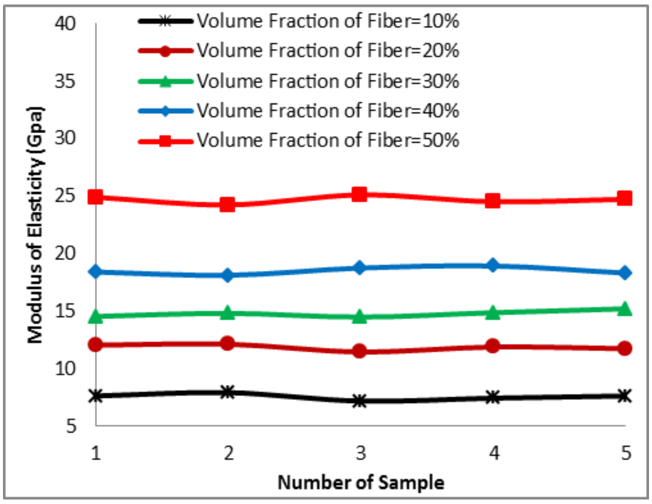


Fig. 13. Experimental testing of five samples for short composite materials with difference volume fraction fiber.

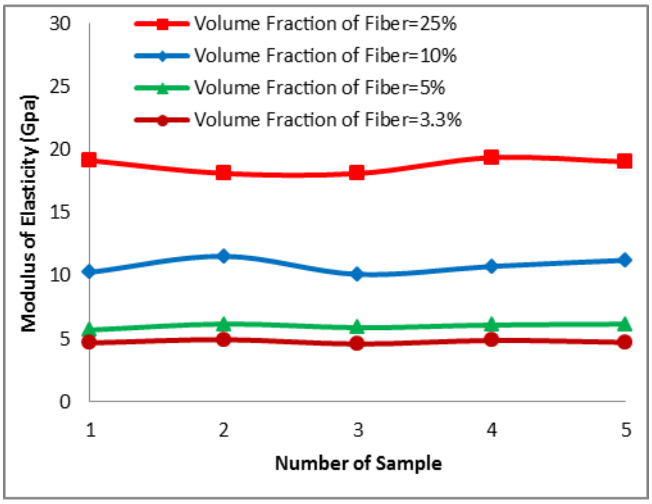


Fig. 14. Experimental testing of five samples for woven composite materials with difference volume fraction fiber.

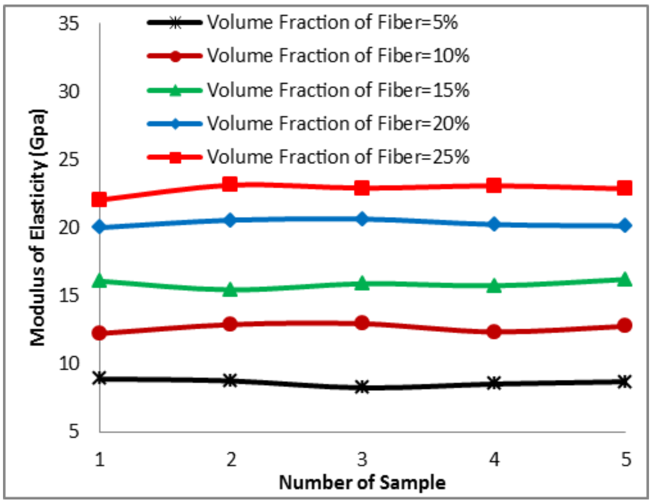


Fig. 15. Experimental testing of five samples for long composite materials with difference volume fraction fiber.

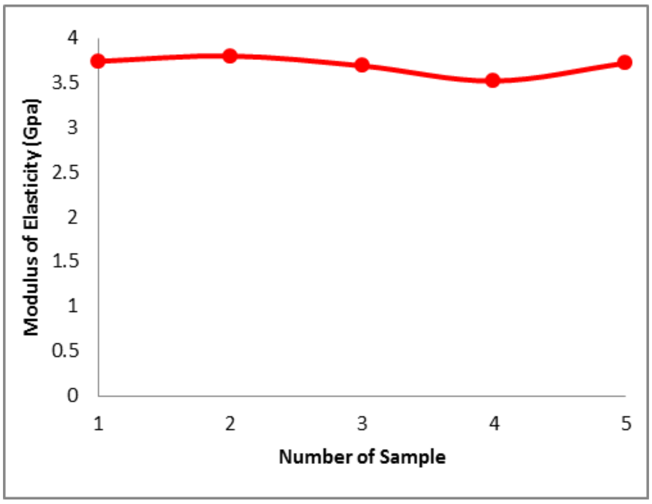


Fig. 16. Experimental testing of five samples for polyester materials.

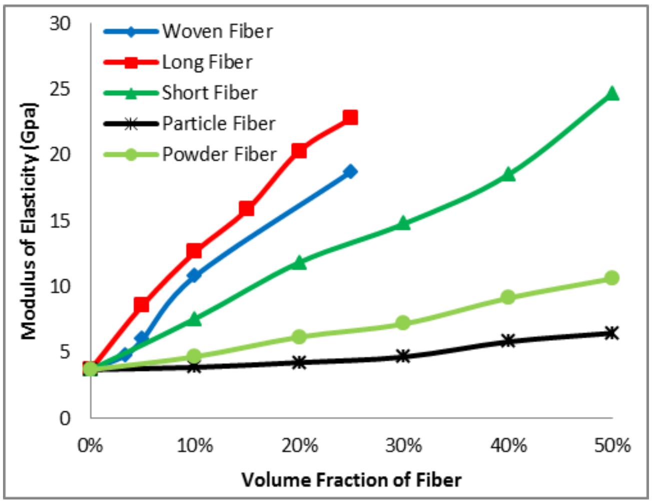


Fig. 17. Modulus of elasticity for different composite materials types with various volume fraction of fiber.

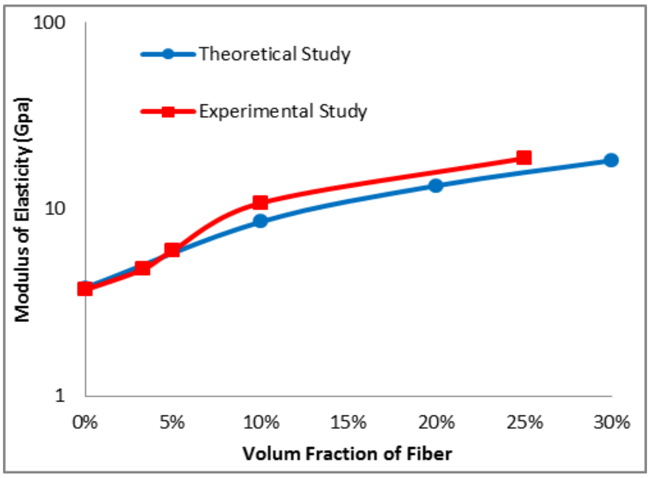


Fig. 18. Compare between theoretical and experimental study of woven fiber composite materials with difference volume fraction fiber

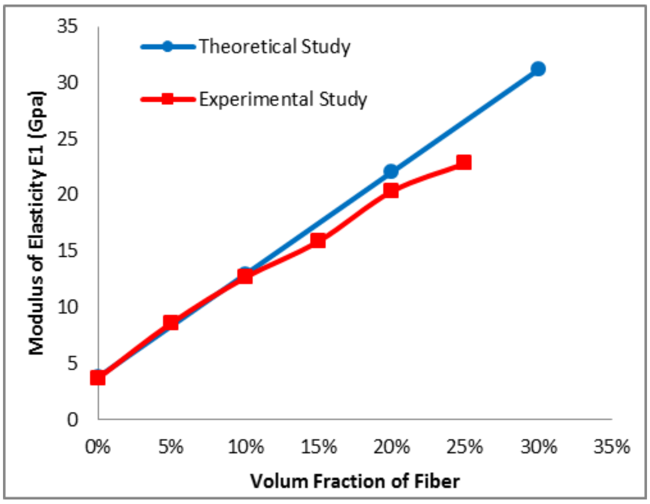


Fig. 19. Compare between theoretical and experimental study of long fiber composite materials with difference volume fraction fiber

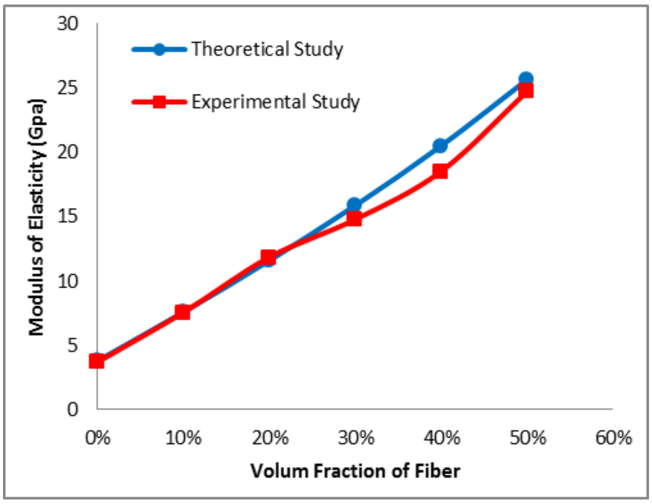


Fig. 20. Comparison between theoretical and experimental study of short fiber composite materials with different volume fraction fiber

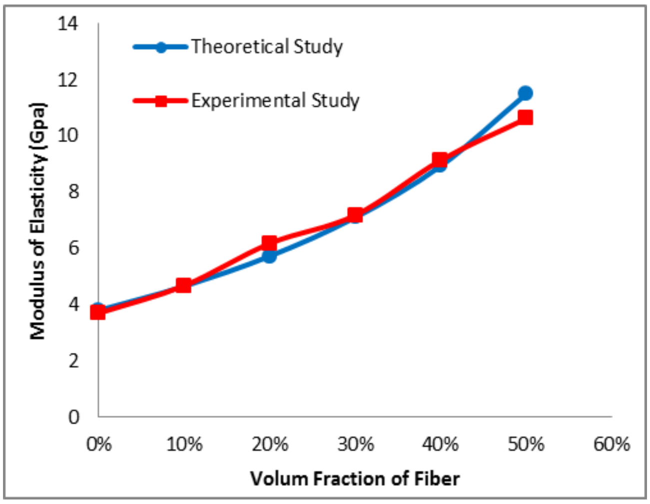


Fig. 21. Compare between theoretical and experimental study of powder fiber composite materials with difference volume fraction fiber

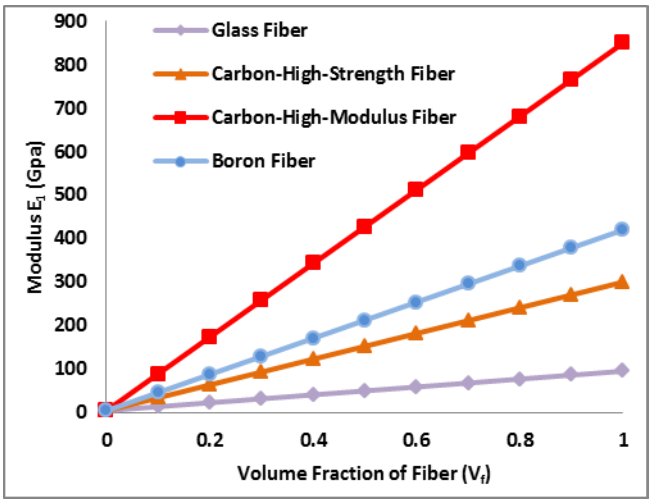


Fig. 22 Modulus of elasticity for unidirectional composite material-epoxy matrix with different reinforcement fibers.

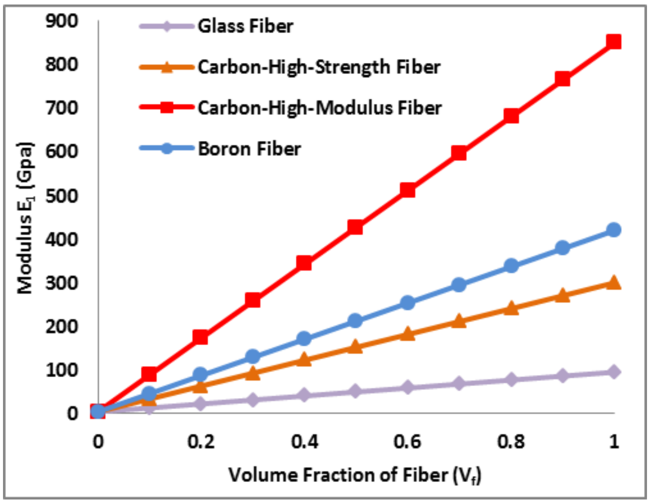


Fig. 23. Modulus of elasticity for unidirectional composite material-polyester matrix with different reinforcement fibers.

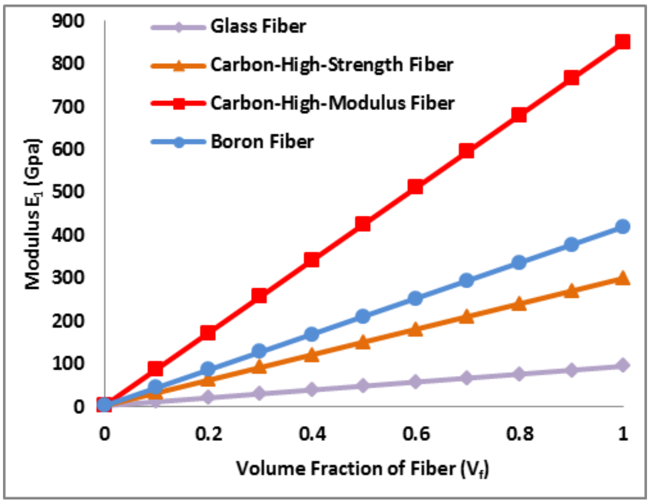


Fig. 24. Modulus of elasticity for unidirectional composite material-nylon matrix with different reinforcement fibers.

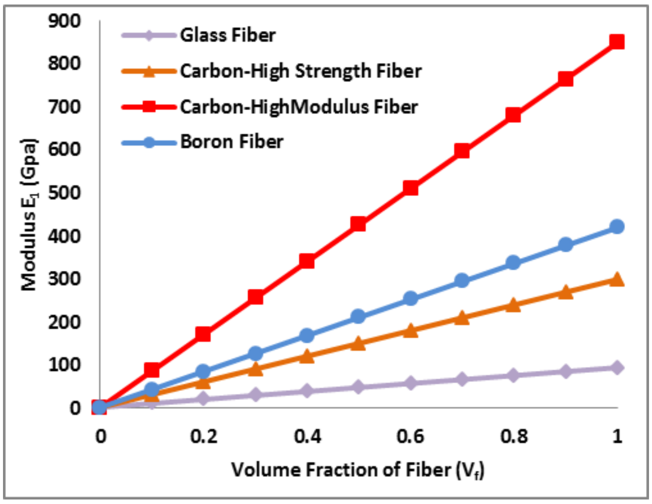


Fig. 25. Modulus of elasticity for unidirectional composite material-polyester (PC) matrix with different reinforcement fibers.

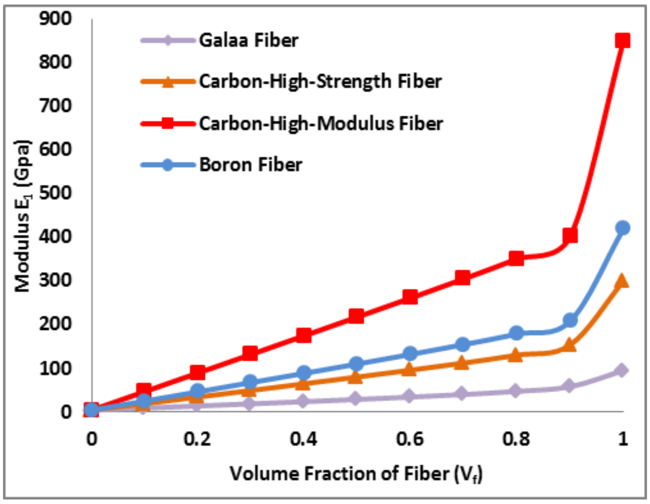


Fig. 26. Modulus of elasticity for woven composite material-epoxy matrix with different reinforcement fibers.

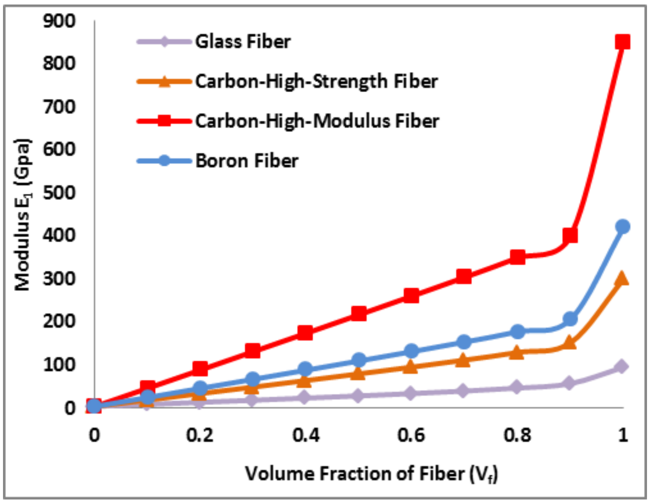


Fig. 27. Modulus of elasticity for woven composite material-polyester matrix with different reinforcement fibers.

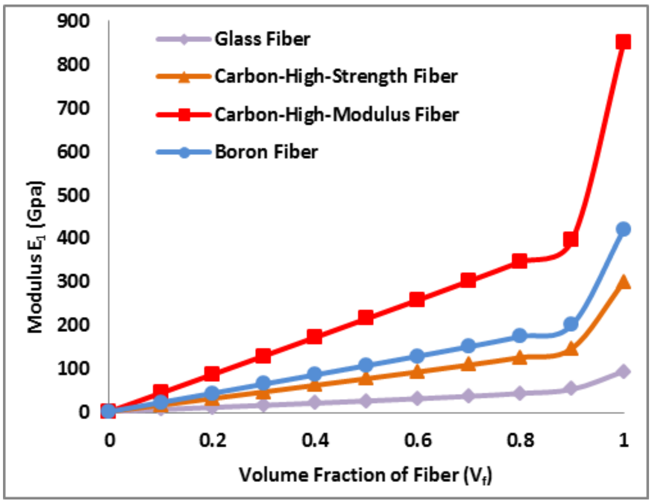


Fig. 28. Modulus of elasticity for woven composite material-nylon matrix with different reinforcement fibers.

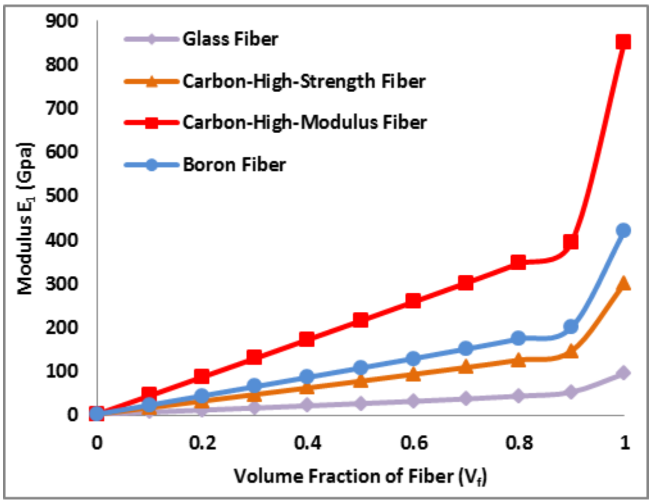


Fig. 29. Modulus of elasticity for woven composite material-polyester (PC) matrix with different reinforcement fibers.

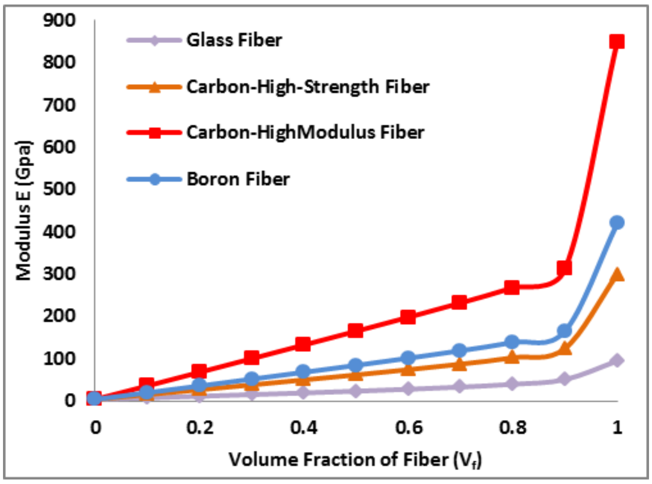


Fig. 30. Modulus of elasticity for mats composite material-epoxy matrix with different reinforcement fibers.

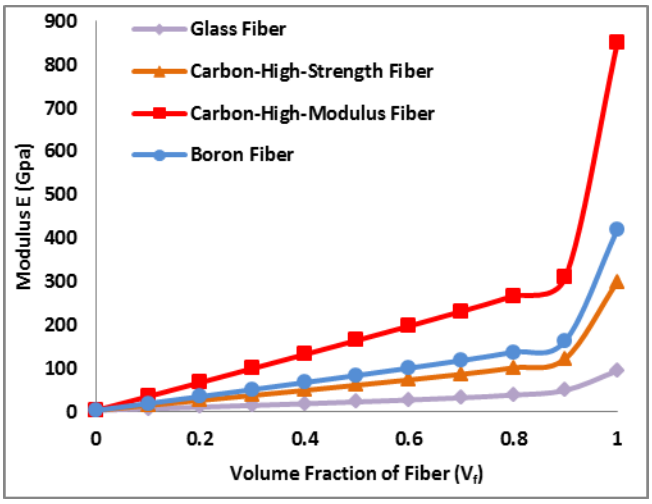


Fig. 31. Modulus of elasticity for mats composite material-polyester matrix with different reinforcement fibers.

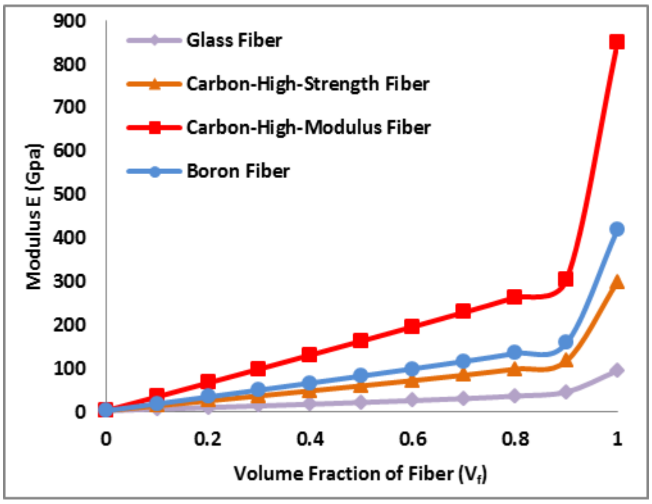


Fig. 32. Modulus of elasticity for mats composite material-nylon matrix with different reinforcement fibers.

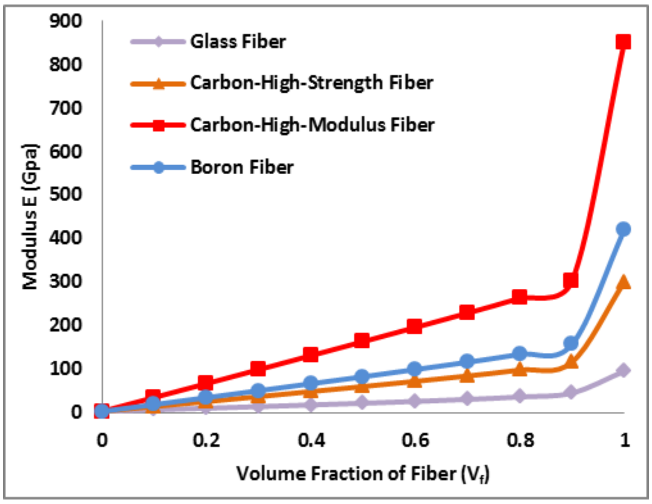


Fig. 33. Modulus of elasticity for mats composite material-polyester (PC) matrix with different reinforcement fibers.

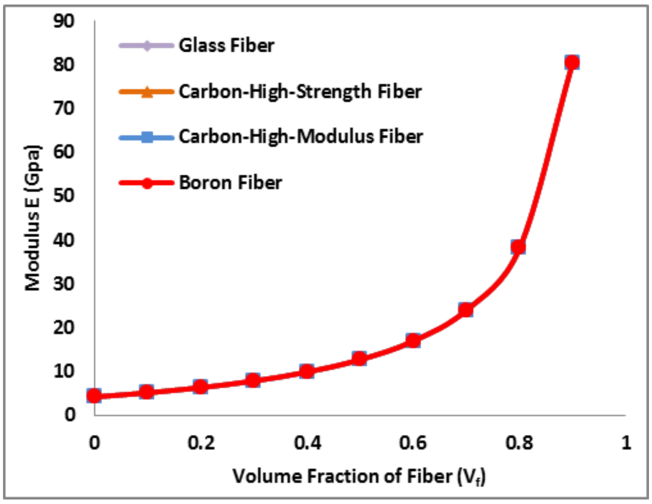


Fig. 34. Modulus of elasticity for spherical fillers composite material-epoxy matrix with different reinforcement fibers.

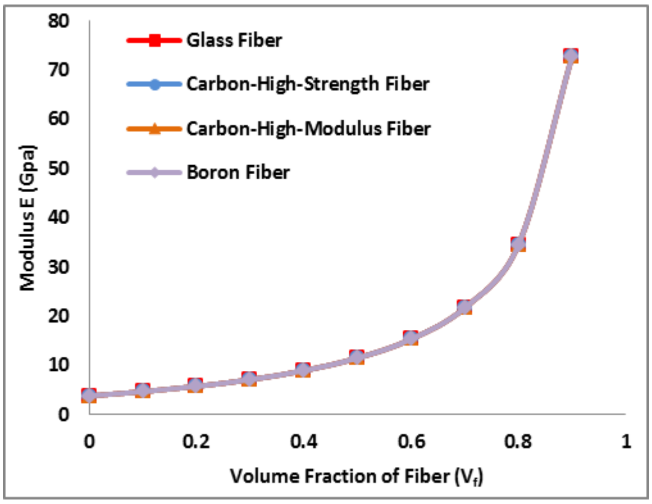


Fig. 35. Modulus of elasticity for spherical fillers composite material-polyester matrix with different reinforcement fibers.

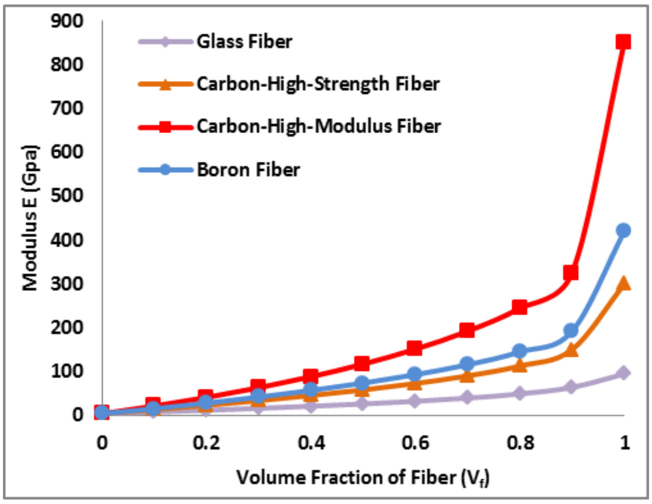


Fig. 38. Modulus of elasticity for discontinuous (short) composite material-epoxy matrix with different reinforcement fibers.

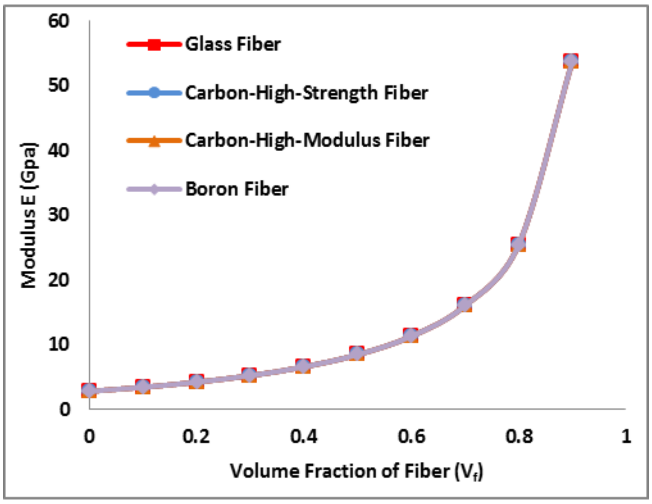


Fig. 36. Modulus of elasticity for spherical fillers composite material-nylon matrix with different reinforcement fibers.

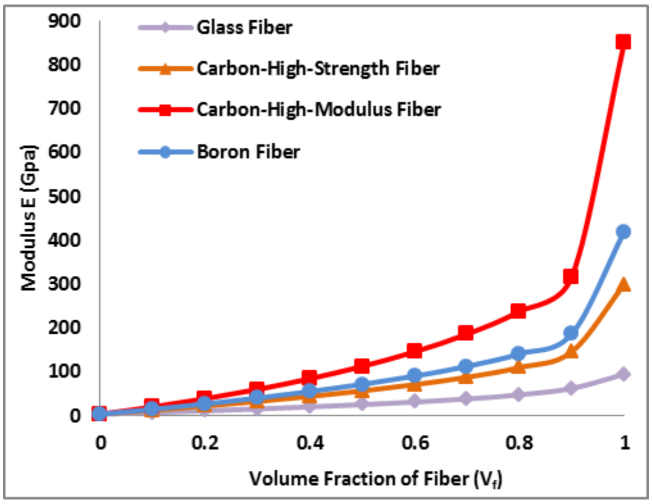


Fig. 39. Modulus of elasticity for discontinuous (short) composite material-polyester matrix with different reinforcement fibers.

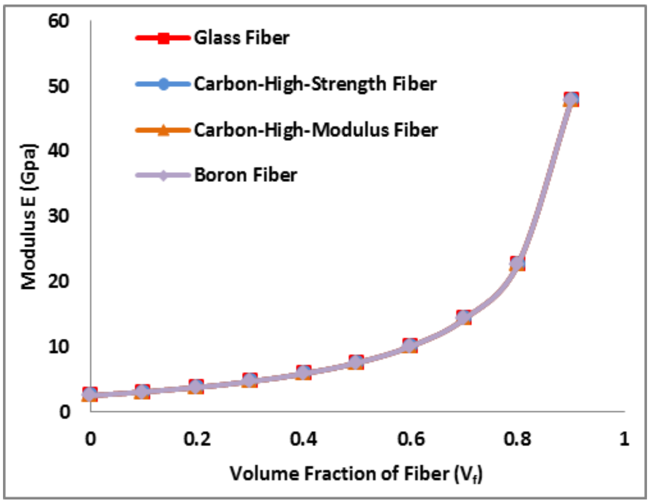


Fig. 37. Modulus of elasticity for spherical fillers composite material-polyester (PC) matrix with different reinforcement fibers.

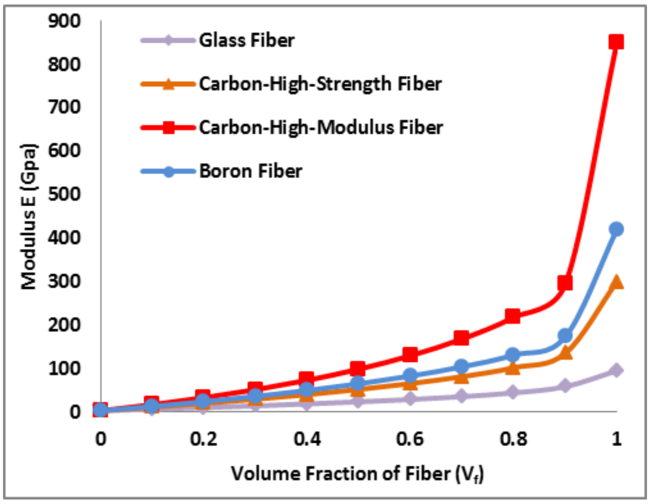


Fig. 40. Modulus of elasticity for discontinuous (short) composite material-nylon matrix with different reinforcement fibers.

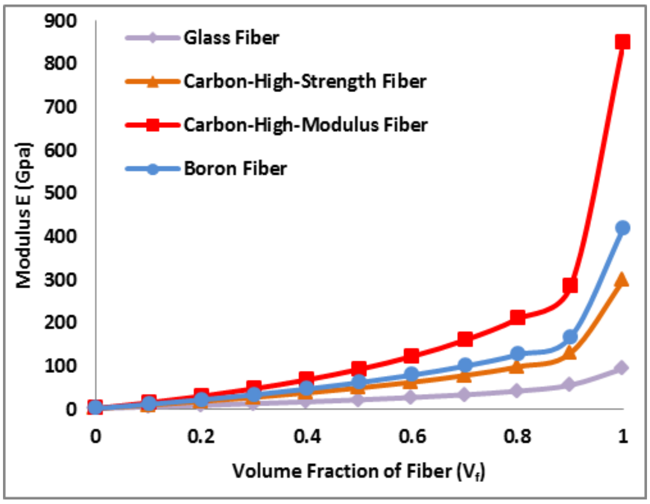


Fig. 41. Modulus of elasticity for discontinuous (short) composite material-polyester (PC) matrix with different reinforcement fibers.

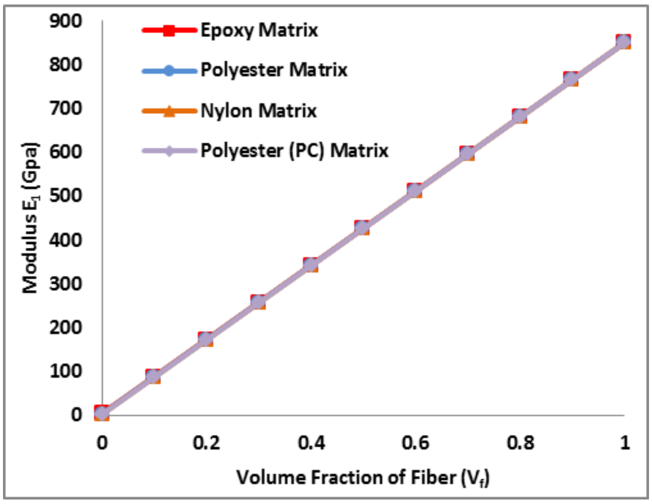


Fig. 42. Modulus of elasticity for unidirectional composite material-carbon-high-modulus fiber with different matrix.

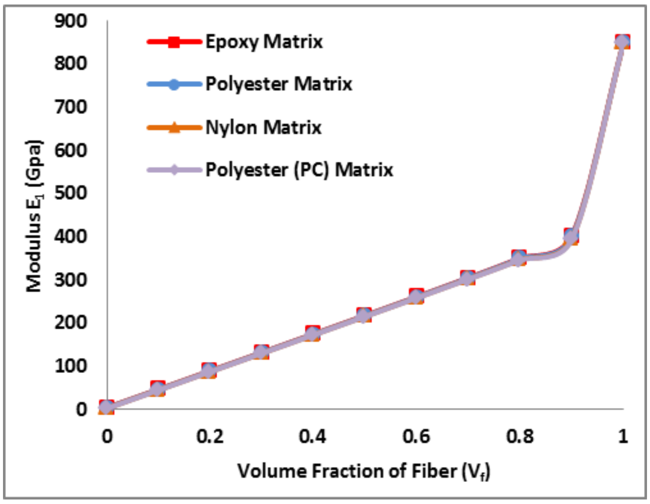


Fig. 43. Modulus of elasticity for woven composite material-carbon-high-modulus fiber with different matrix.

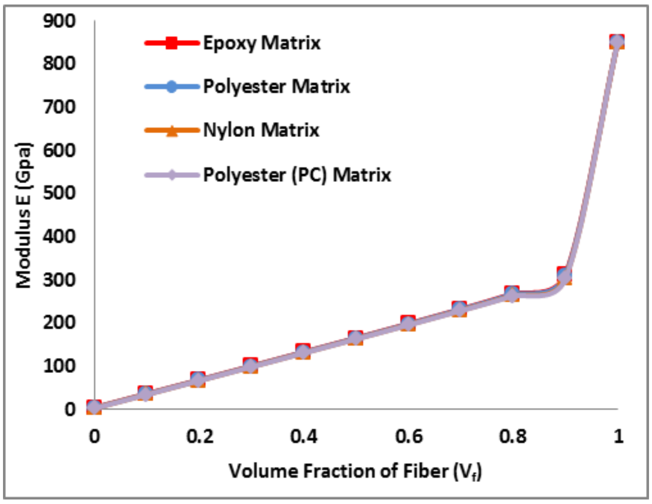


Fig. 44. Modulus of elasticity for mats composite material-carbon-high-modulus fiber with different matrix.

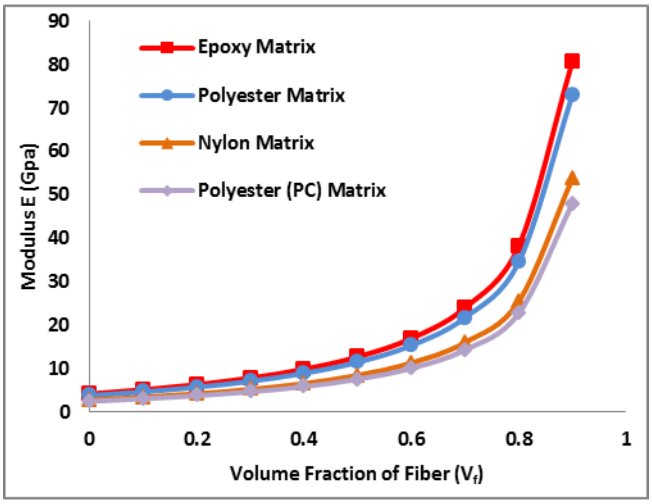


Fig. 45. Modulus of elasticity for spherical fillers composite material-carbon-high-modulus fiber with different matrix.

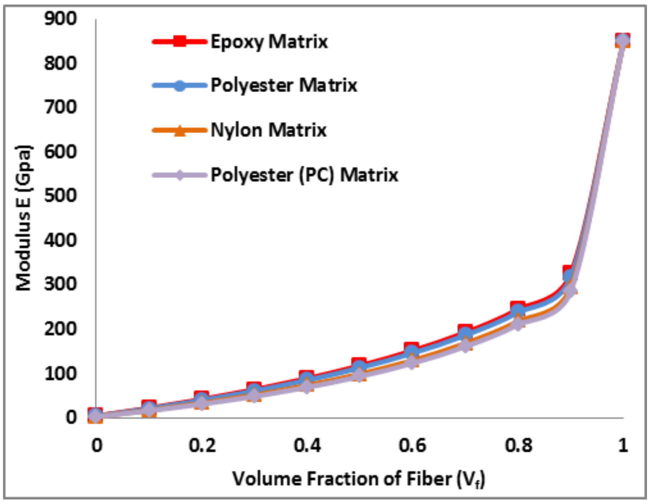


Fig. 46. Modulus of elasticity for discontinuous (short) composite material-carbon-high-modulus fiber with different matrix.

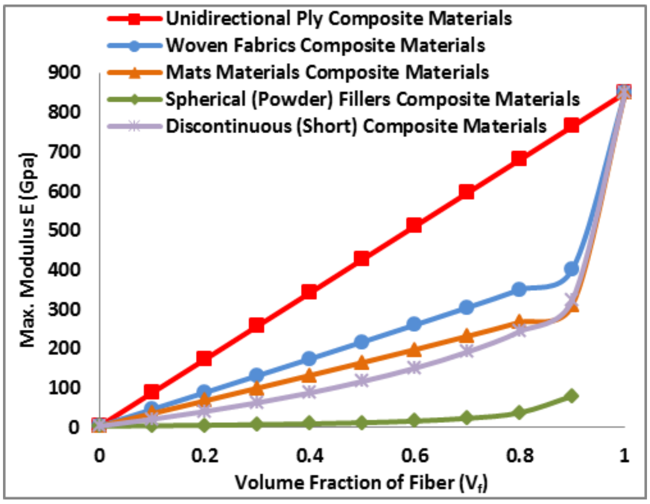


Fig. 47. Modulus of elasticity for different types of composite materials of epoxy matrix-carbon high modulus fiber.

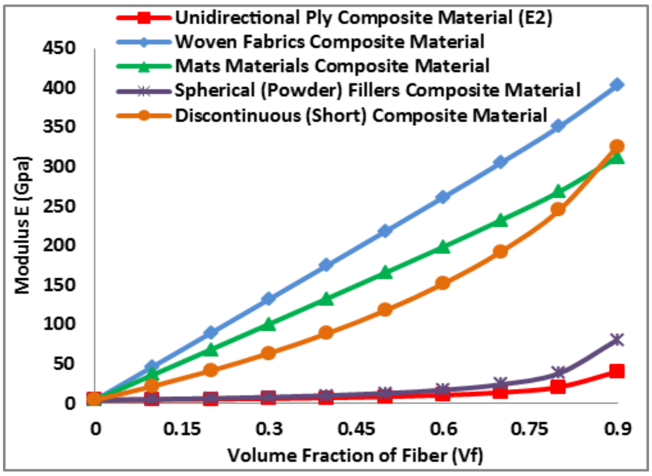


Fig. 48. Modulus of elasticity for different types of composite materials compare with E_2 for unidirectional ply composite.

V. CONCLUSIONS

The main conclusions of this work are,

1. The best modulus of elasticity for composite materials are unidirectional composite materials in longitudinal direction and woven composite materials in any direction.
2. The powder, particle, mats, and short fiber composite materials may be give isotropic properties of composite materials. With depend on resin materials properties.
3. The variable of matrix materials affect the properties in powder, short, and mats composite materials more than in properties of woven and unidirectional composite materials.
4. Unidirectional composite materials gives minimum modulus of elasticity in transverse direction compare with other composite materials types.
5. The increasing of mechanical properties of reinforcement fiber increasing of mechanical properties of composite materials.
6. For future work, study of hybrid composite materials properties.

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