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Experimental and Analytical Study of Tensile Properties For Hyper Composite Material

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Abstract:

In this work, an experimental and analytical solution for tensile properties of hyper composite material is presented. The composite material consist of composite matrix, bounded from resin material and short fiber, and long reinforcement fiber.

The result for the tensile properties of composite material combined from composite matrix and reinforcement fiber, E_1, E_2, G_{12}, and ν_{12}. In addition, the results showing the effect of volume fraction of short and long fiber, and the types of short and long fiber reinforcement, presented by analytical solution. And, the yield stress of hyper composite material is defined by experimental study with various of volume fraction of resin, short fiber, and long fiber.

الخلاصة

في هذا البحث، تمت دراسة خواص المواد المركبة المكونة من مزج ثلاثة مواد بالطريقة النظرية والعملية. المواد المركبة التي تمت دراستها هي المواد المكونة من تركيب الألياف المستمرة (الطولية) مع الأرضية المركبة المكونة من المادة الرابطة والألياف المتقطعة.

خواص المواد المركبة، المكونة من الألياف المستمرة والأرضية المركبة، التي تمت حسابها هي معامل المرونة بالاتجاه الطولي والعرضي للمواد المركبة ومعامل الجساءة ونسبة بوايسن. بالإضافة إلى حساب تأثير نسبة حجم كلا من الاليا ف المستمرة (الطولية) والمتقطعة ونسبة المادة الرابطة على خواص المواد المركبة، وتأثير نوع الألياف المستخدمة على خواص المواد المركبة. وتمت دراسة إجهاد الخضوع للمواد المركبة وتأثير نسبة حجم الألياف والمادة الرابطة على الاحهاد.

*** Analytical Study (Composite Lamina Combined of Composite Matrix and Reinforcement Continuous Fiber)**

I- Composite Matrix (Combined of resin and discontinuous fiber)

For unidirectional fiber matrix shown in Figure 1 the following Halpin-Tsai relation are used to determine the elastic properties, [1],

$$E_{1m} = \frac{1 + 2.a_f.\eta_l.\forall_{sfm}}{1 - \eta_l.\forall_{sfm}}.E_m \quad , \; E_{2m} = \frac{1 + 2.\eta_T.\forall_{sfm}}{1 - \eta_T.\forall_{sfm}}.E_m$$

$$G_{12m} = G_{21m} = \frac{1 + \eta_G.\forall_{sfm}}{1 - \eta_G.\forall_{sfm}}.G_m$$

$$\nu_{12m} = \nu_{sf}.\forall_{sfm} + \nu_m.\forall_{mm} \tag{1}$$

where,

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

let E_{1m} and E_{2m} be the longitudinal and transverse moduli defined by (1) 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 Figure 2. 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, [1],

$$E_{cm} = \frac{3}{8}.E_{1m} + \frac{5}{8}.E_{2m} \quad G_{cm} = \frac{1}{8}.E_{1m} + \frac{1}{4}.E_{2m} \tag{3}$$

and, [2],

$$G_{cm} = \frac{E_{cm}}{2.(1 + \nu_{cm})} \; \text{or} \; , \; \nu_{cm} = \left(\frac{E_{cm}}{2.G_{cm}} - 1 \right) \tag{4}$$

The fraction $\forall_{sfm}$ and $\forall_{mm}$ are respected to matrix, then,

$$\forall_{sfm} + \forall_{mm} = 1 \tag{5}$$

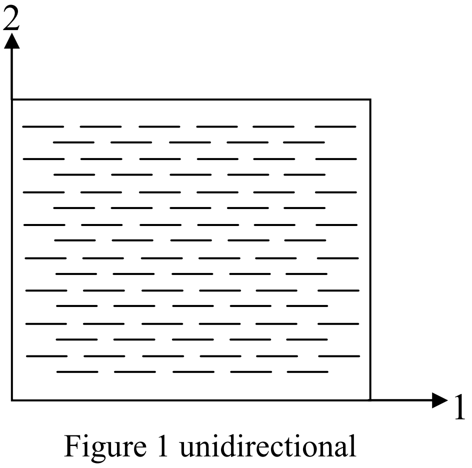


Figure 1 unidirectional discontinuous matrix.

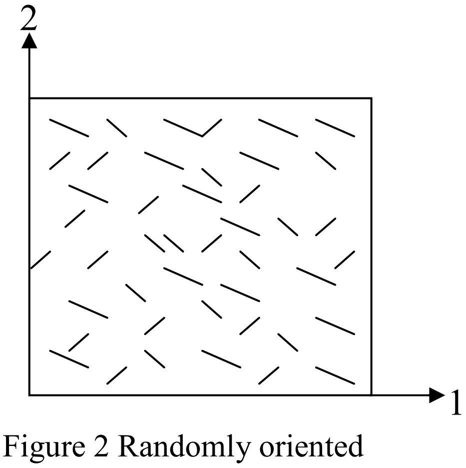


Figure 2 Randomly oriented discontinuous fiber matrix.

the composite matrix with continuous fiber, the total volume fraction divided to volume fraction of discontinuous fiber ($\forall_{sfp}$), resin material ($\forall_{mp}$), and continuous fiber ($\forall_f$), respected to composite lamina, Then,

$$\forall_{sfp} + \forall_{mp} + \forall_f = 1\ ,\ \forall_f + \forall_m = 1\ ,\ \text{for, } \forall_{sfp} + \forall_{mp} = \forall_m \tag{6}$$

then can be defined $\forall_{sfm}$ and $\forall_{mm}$ as,

$$\forall_{sfm} = \frac{\forall_{sfp}}{\forall_{sfp} + \forall_{mp}} = \frac{\forall_{sfp}}{\forall_m}\ ,\ \forall_{mm} = \frac{\forall_{mp}}{\forall_{sfp} + \forall_{mp}} = \frac{\forall_{mp}}{\forall_m} \tag{7}$$

Then, by using equation (7) in to equation (1). Then, by substitution the results in equations (3),and (4), get,

$$E_{cm} = \left[\left(\frac{3.\left(1-\forall_f\right) + 6.a_f.\eta_l.\forall_{sfp}}{\left(1-\forall_f\right) - \eta_l.\forall_{sfp}}\right) + \left(\frac{5.\left(1-\forall_f\right) + 10.\eta_T.\forall_{sfp}}{\left(1-\forall_f\right) - \eta_T.\forall_{sfp}}\right)\right].\frac{E_m}{8}$$

$$G_{cm} = \left[\left(\frac{\left(1-\forall_f\right) + 2.a_f.\eta_l.\forall_{sfp}}{\left(1-\forall_f\right) - \eta_l.\forall_{sfp}}\right) + \left(\frac{2.\left(1-\forall_f\right) + 4.\eta_T.\forall_{sfp}}{\left(1-\forall_f\right) - \eta_T.\forall_{sfp}}\right)\right].\frac{E_m}{8}$$

and,

$$\nu_{cm} = \left(\frac{E_{cm}}{2.G_{cm}} - 1\right) \tag{8}$$

where E_{cm} and G_{cm}as above.

There are in all quantities, E_{cm}, G_{cm}, and ν_{cm} to describe the elastic behavior of the composite matrix combined of discontinuous random oriented fibers and resin bonding material.

II- Composite Lamina (discontinuous random fibers, resin, continuous fiber):

Figure 3 shows a simple lamina with a unidirectional continuous fiber at 0^0 . The fibers are assumed to be uniformly distributed throughout the composite matrix, combined of discontinuous random fiber and resin material, and a perfect bonding is assumed to be free of any voids. The fibers as well as matris are further assumed to behave like elastic materials.

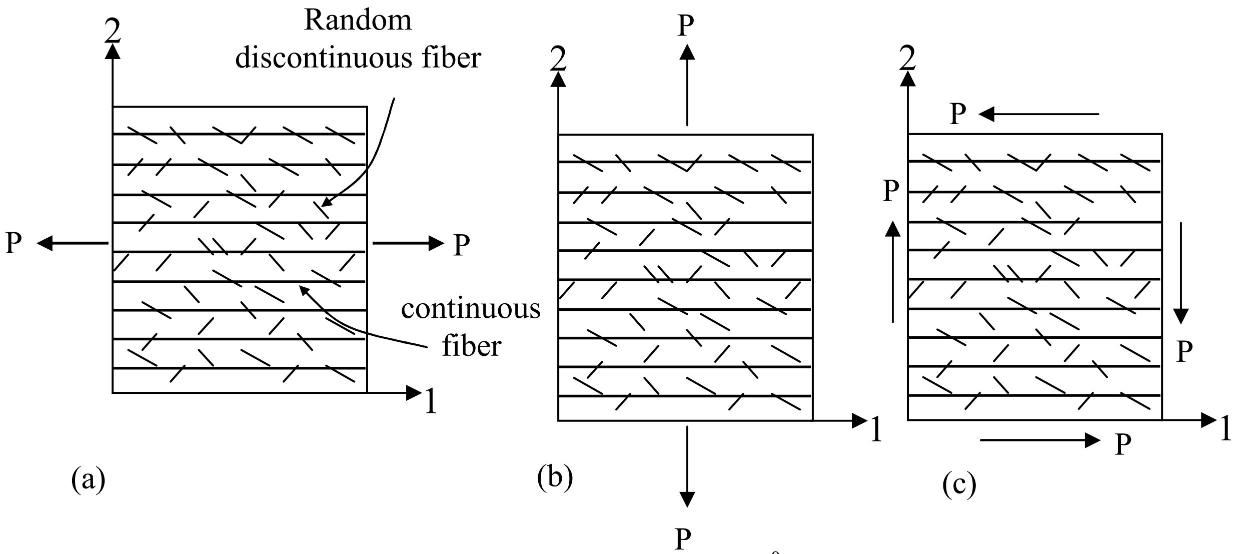


Figure 3 unidirectional continuous fiber 0^0 lamina.

1-2 axes system denotes the direction of the fiber. For an applied load (P) parallel to the direction of fibers.

The longitudinal modulus of the lamina is given by,[2],

$$E_1 = \frac{\sigma_c}{\varepsilon_c} = E_f.\forall_f + E_{cm}.(1-\forall_f) \quad (9)$$

By using equations (8), in to equation (9), get,

$$E_1 = E_f.\forall_f + \left(1-\forall_f\right)E_m.\left[\left(\frac{3\left(1-\forall_f\right)+6.a_f.\eta_l.\forall_{sfp}}{8\left(1-\forall_f\right)-8.\eta_l.\forall_{sfp}}\right)+\left(\frac{5.\left(1-\forall_f\right)+10.\eta_T.\forall_{sfp}}{8\left(1-\forall_f\right)-8.\eta_T.\forall_{sfp}}\right)\right]$$

(10)

The corresponding Major Poisson's ratio is,

$$\nu_{12} = \nu_f.\forall_f + \nu_{cm}.\left(1-\forall_f\right) \quad (11)$$

By using equations (8), and (3) in to (11), get,

$$\nu_{12} = \nu_f.\forall_f + \left(\frac{E_{cm}}{2.G_{cm}}-1\right)\left(1-\forall_f\right) = \nu_f.\forall_f + \left(\frac{3.E_{1m}+5.E_{2m}}{2.E_{1m}+4.E_{2m}}-1\right)\left(1-\forall_f\right)$$
$$= \nu_f.\forall_f + \frac{1}{2}\left(1-\forall_f\right)\left(\frac{E_{1m}+E_{2m}}{E_{1m}+2.E_{2m}}\right) \quad (12)$$

The transverse modulus and minor Poisson's ratio for the loading transverse to the continuous fiber direction as shown in Figure (3-b) are,

$$E_2 = \frac{E_f.E_{cm}}{E_f\left(1-\forall_f\right)+E_{cm}.\forall_f}$$

or,

$$E_2 = \frac{E_f.E_m.\left[\left(\frac{3.\left(1-\forall_f\right)+6.a_f.\eta_l.\forall_{sfp}}{8.\left(1-\forall_f\right)-8.\eta_l.\forall_{sfp}}\right)+\left(\frac{5.\left(1-\forall_f\right)+10.\eta_T.\forall_{sfp}}{8\left(1-\forall_f\right)-8.\eta_T.\forall_{sfp}}\right)\right]}{E_f.\left(1-\forall_f\right)+E_m.\forall_f\left[\left(\frac{3.\left(1-\forall_f\right)+6.a_f.\eta_l.\forall_{sfp}}{8.\left(1-\forall_f\right)-8.\eta_l.\forall_{sfp}}\right)+\left(\frac{5.\left(1-\forall_f\right)+10.\eta_T.\forall_{sfp}}{8\left(1-\forall_f\right)-8.\eta_T.\forall_{sfp}}\right)\right]}$$

(13)

and,

$$\nu_{21} = \frac{E_2}{E_1}\nu_{12} \quad (14)$$

where, E_1, E_2, and ν_{12} as in equations (10), (12), and (13).

For a shear force loading as shown in Figure (3-c),get,

$$G_{12} = \frac{G_f.G_{cm}}{G_f.\forall_m + G_{cm}.\forall_f} = \frac{G_f.G_{cm}}{G_f\left(1-\forall_f\right)+G_{cm}.\forall_f} \quad (15)$$

by substitution equations (8) into (15), get,

$$G_{12} = \frac{G_f.E_m.\left[\left(\frac{\left(1-\forall_f\right)+2.a_f.\eta_l.\forall_{sfp}}{\left(1-\forall_f\right)-\eta_l.\forall_{sfp}}\right)+\left(\frac{2.\left(1-\forall_f\right)+4.\eta_T.\forall_{sfp}}{\left(1-\forall_f\right)-\eta_T.\forall_{sfp}}\right)\right]}{8.G_f.\left(1-\forall_f\right)+E_m.\forall_f\left[\left(\frac{\left(1-\forall_f\right)+2.a_f.\eta_l.\forall_{sfp}}{\left(1-\forall_f\right)-\eta_l.\forall_{sfp}}\right)+\left(\frac{2.\left(1-\forall_f\right)+4.\eta_T.\forall_{sfp}}{\left(1-\forall_f\right)-\eta_T.\forall_{sfp}}\right)\right]} \quad (16)$$

There are in all quantities, E_1, E_2, G_{12}, and ν_{12} to describe the elastic behavior of the lamina combined of composite matrix and continuous reinforcement fibers.

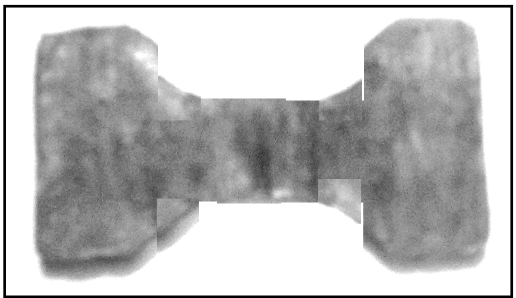
*** Experimental Work**

The experimental study of hyper composite material are consist of determining the yield stress of composite material. The stress of hyper composite material defined for different parameters, as,

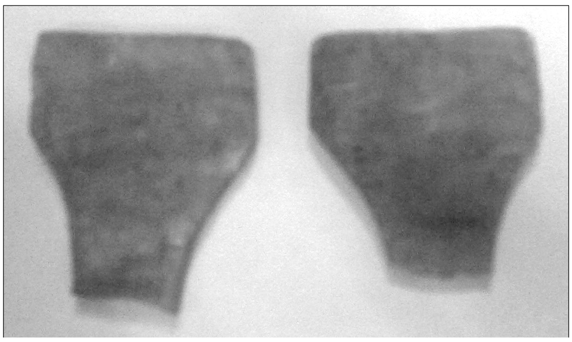
1. for various fiber orientation of long fiber, as in Table 1 and Figure 5.
2. for various volume fraction of short fiber and resin material, constant matrix volume fraction, with same volume fraction of long fiber, as in Table 2 and Figure 6.
3. for various volume fraction of short fiber and long fiber, with same volume fraction of resin material, as in Table 3 and Figure 7.
4. for various volume fraction of long fiber and resin material, with same volume fraction of short fiber, as in Table 4 and Figure 8.

Sample Shape:-

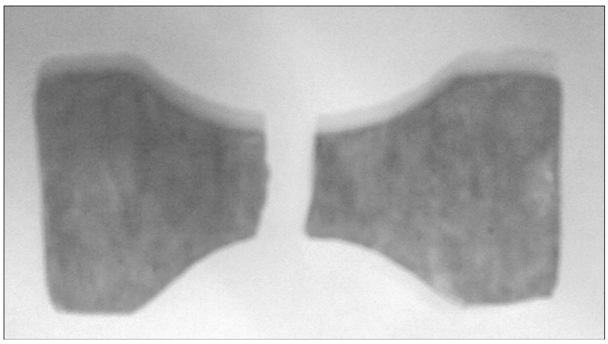
The samples in experimental analysis and the shape of failure of samples are shown in Figure 4,



a- shape of test samples



b- Shape of failure of sample (S1) (0^0) direction



c- Shape of failure of sample (S2) (90^0) direction

Figure 4 shape using of experimental results

The dimension for sample testing are,
Width= 15 (mm), Thickness = 4 (mm) , and, Length = (26 (mm)
The material using in samples of experimental results are, Epoxy resin and Glass short and long fiber.

Experimental Results of hyper Composite material:-

The experimental results of hyper Composite material shown as in Tables 1, 2, 3, and 4 and as in Figures 5, 6, 7, and 8, as,

Table 1 yield stress of (0^0) and (90^0) direction sample.

Sample	$\forall_{sfm}$	$\forall_{mp}$	$\forall_m$	$\forall_f$	σ_{yeild} (Mpa)	E (Mpa)
S_1 (0^0)	0.1715	0.417	0.5885	0.4115	39.000	23.914
S_2 (90^0)	0.1715	0.417	0.5885	0.4115	12.833	15.84

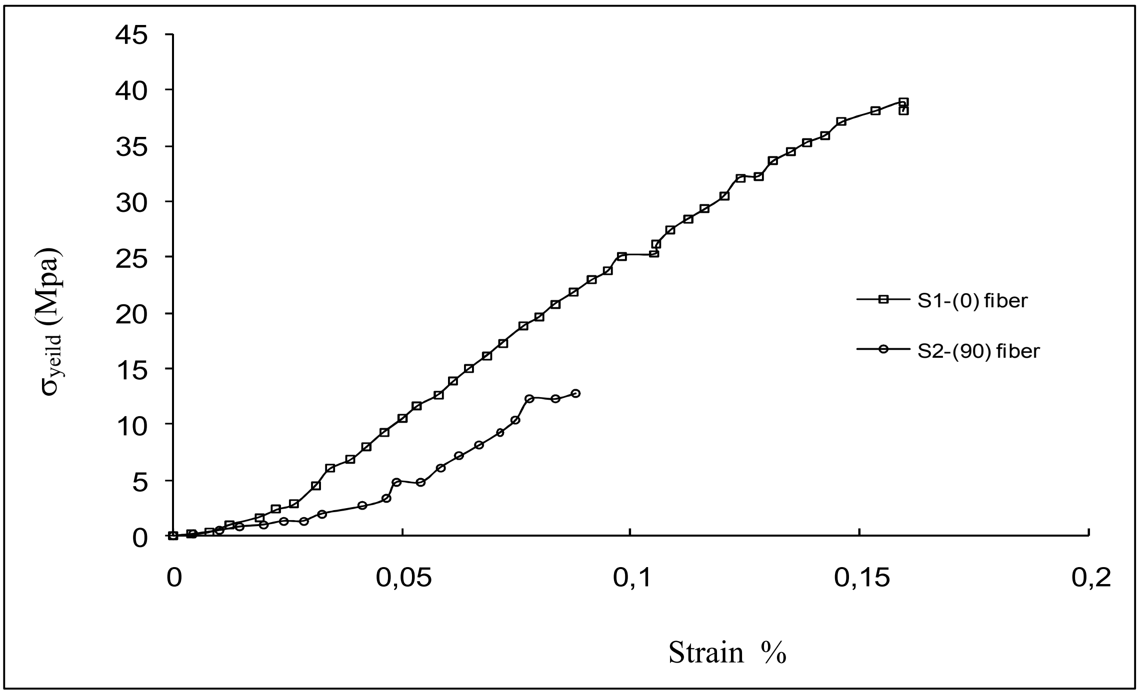


Figure 5 yield stress of (0^0) and (90^0) direction sample

Table 2 stress-strain relation for various volume fraction of short fiber and resin

Sample test	$\forall_{sfm}$	$\forall_{mp}$	$\forall_m$	$\forall_f$	σ_{yeild} (Mpa)	E (Mpa)
S_3	0.1896	0.4654	0.655	0.345	27	24.734
S_4	0.3964	0.2586	0.655	0.345	35	32.98
S_5	0.50	0.155	0.655	0.345	50	42.25

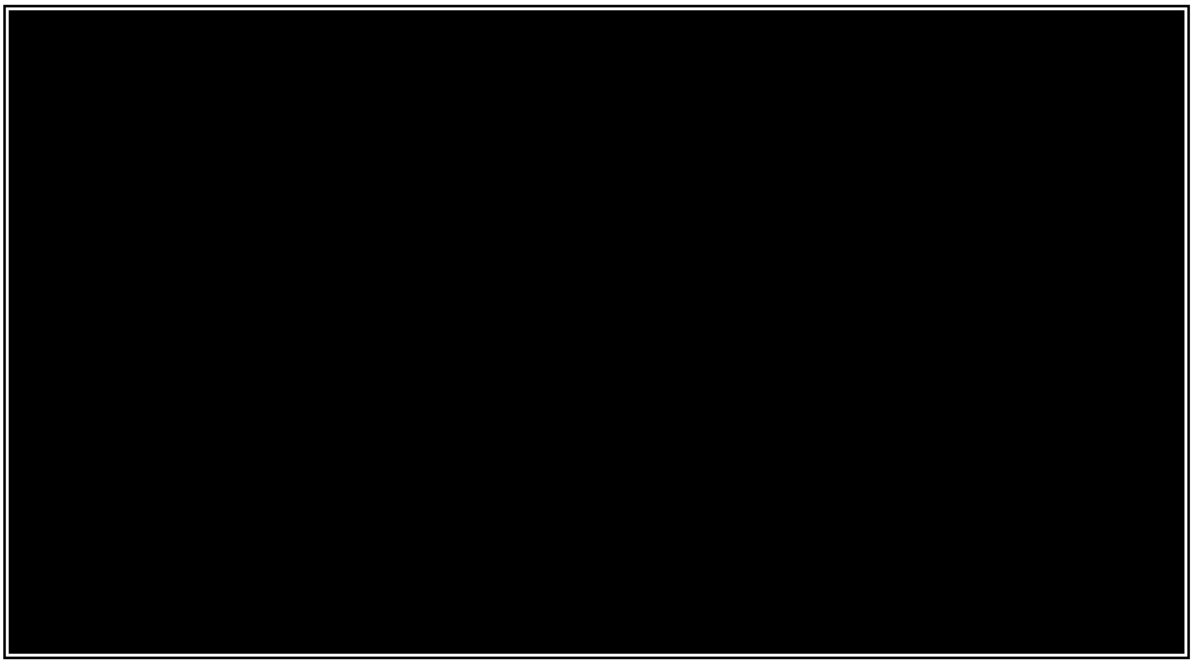


Figure 6 stress-strain relation for various volume fraction of short fiber and resin

Table 3 stress-strain for various volume fraction of short fiber and long fiber

Sample test	$\forall_{sfm}$	$\forall_{mp}$	$\forall_{m}$	$\forall_{f}$	**σ_{yeild} (Mpa)**	**E (Mpa)**
S_6	0.1896	0.4654	0.655	0.345	29	25.93
S_7	0.142	0.4654	0.6074	0.3926	39.1	33.83
S_8	0.10	0.4654	0.5654	0.4346	63.7	55.14

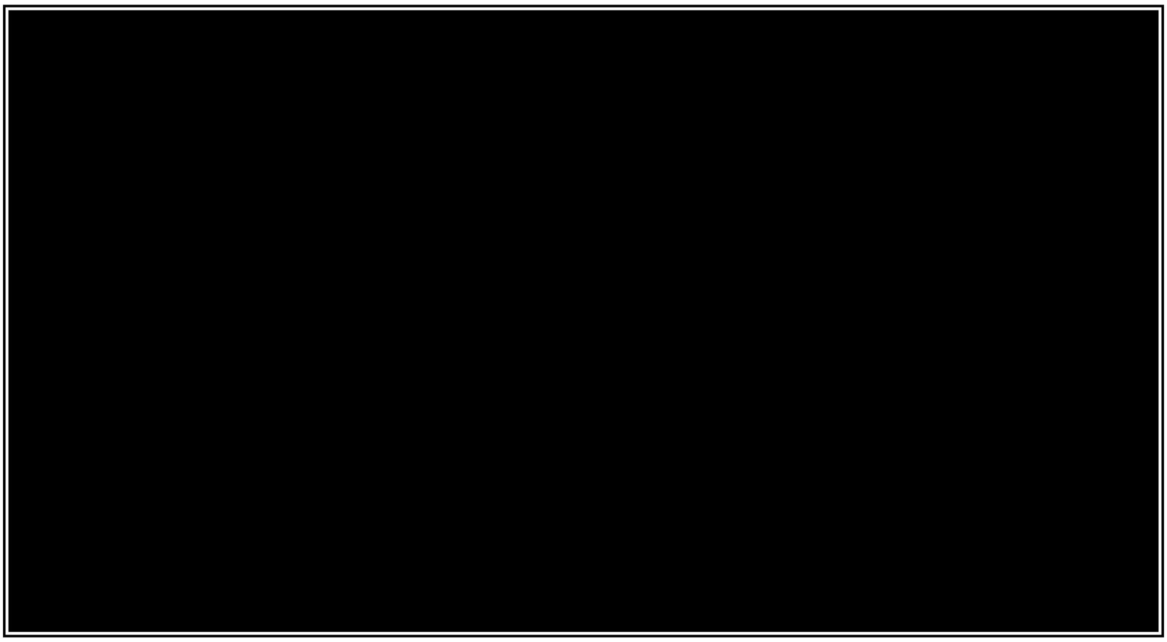


Figure 7 stress-strain for various volume fraction of short fiber and long fiber

Table 4 stress-strain for various volume fraction of long fiber and resin material

Sample test	$\forall_{sfm}$	$\forall_{mp}$	$\forall_{m}$	$\forall_{f}$	σ_{yeild} (Mpa)	E (Mpa)
S_9	0.1896	0.4654	0.655	0.345	29	25.93
S_{10}	0.1896	0.2586	0.4482	0.5518	44.89	36.9
S_{11}	0.1896	0.155	0.3446	0.6554	72.4	59.53

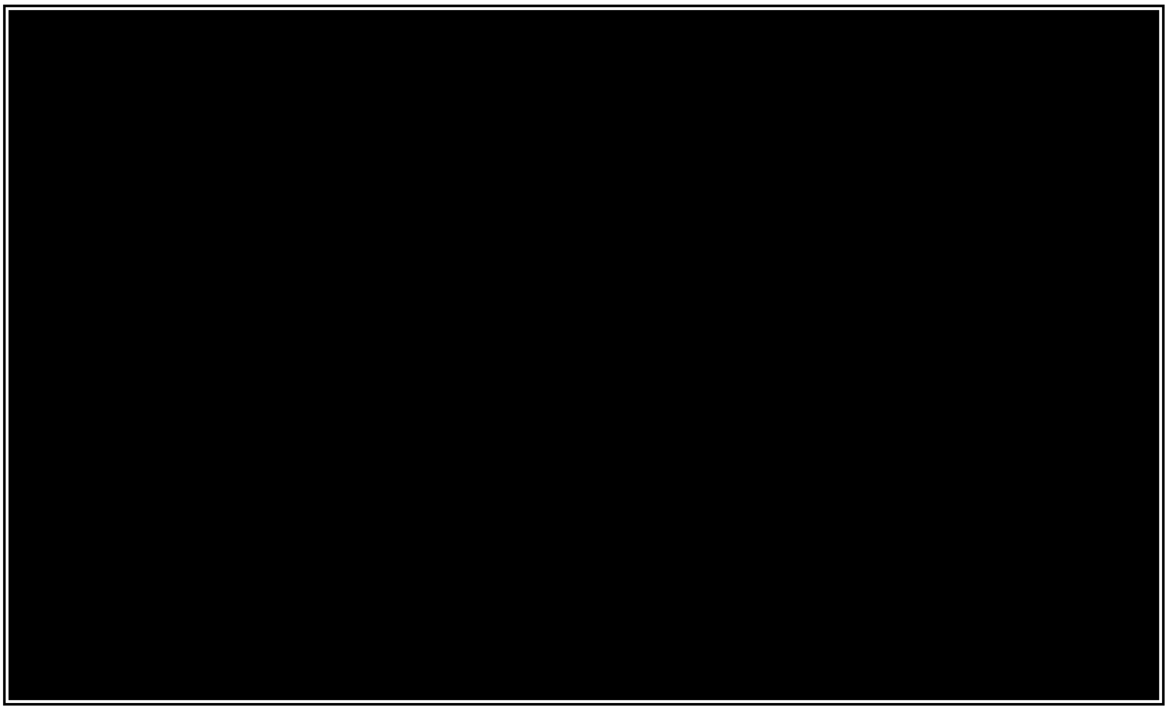


Figure 8 stress-strain relation for various volume fraction of long fiber and resin material.

From Tables 1, 2, 3, and 4 and Figures 5, 6, 7, and 8, shows that the yield stress of hyper composite material increasing with increases the short fiber or long fiber and decreases the resin material, and shows that the stresses increasing with increases the long fiber more that with increases the short fiber, with same weight increasing. And shows that when increasing long fiber and decreases short fiber, with constant resin material, increases the stress of composite material. And shows that the stress of (0^0) orientation long fiber greater than for (90^0) orientation long fiber .

Analytical Results of Hyper Composite Material:

The analysis results are E_1, E_2, G_{12}, and ν_{12} of hyper composite material. The properties defined for two types of hyper composite material, as,

1. hyper composite material combined of epoxy resin, glass short fiber, and glass long fiber.
2. hyper composite material combined of epoxy resin, boron short fiber, and glass long fiber.

The results shows that the effect of the volume fraction of resin, short fiber, and long fiber on the properties of hyper composite material, E_1, E_2, G_{12}, ν_{12}, and the effect of the type of the short fiber using in the hyper composite material.

The properties of epoxy resin, glass fiber, and boron fiber shown in the Table 5,

Table 5 properties of material using in hyper composite material.

Material	Modulus of elasticity E (GPa)	Rigid modulus of elasticity G (GPa)	Poisson's ratio ν
Resin epoxy	3.4	1.4	0.4
Glass fiber	72.4	30	0.3
Boron fiber	379	155	0.35

Table 6 properties of hyper composite material (epoxy resin, glass short fiber, and glass long fiber)

$\forall_{mp}$	$\forall_f$	$\forall_{sfp}$	E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	ν_{12}
0.2	0.8	0	58.6	14.31	5.45	0.3066
	0.6	0.2	50.91	33.67	12.54	0.3379
	0.4	0.4	45.17	36.07	13.34	0.352
	0.2	0.6	40.61	36.69	13.46	0.364
	0	0.8	36.87	36.87	13.41	0.375
0.4	0.6	0.0	44.8	7.94	2.99	0.313
	0.4	0.2	36.45	18.67	6.78	0.356
	0.2	0.4	29.42	21.94	7.92	0.362
	0.0	0.6	23.33	23.33	8.38	0.391
0.6	0.4	0	31	5.4946	1.26	0.32
	0.2	0.2	22.39	11.95	4.32	0.371
	0	0.4	14.78	14.78	5.297	0.395
0.8	0.2	0	17.2	4.2	1.57	.326
	0.0	0.2	8.45	8.45	3.04	0.385
1	0.0	0.0	3.4	3.4	1.4	0.4

Table 6 shows the composite material combined of Epoxy resin, Glass short fiber, and Glass long fiber. From Table 6 shown when increasing the resin in composite material decreases the modulus of elasticity E_1 due to decreases the fiber in composite, since the strength of fiber more than for resin, then, with increasing the fiber increasing the strength of composite material. And, shown when increasing the short fiber decreases modulus of elasticity E_1 due to decreases the long fiber and increasing modulus of elasticity E_2 due to increasing strength of composite matrix since E_2 depended on matrix material.

Table 7 properties of hyper composite material (epoxy resin, boron short fiber, and glass long fiber)

$\forall_{mp}$	$\forall_f$	$\forall_{sfp}$	E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	ν_{12}
0.2	0.8	0	58.6	14.31	5.45	0.3066
	0.6	0.2	59.2	54.22	20.37	0.356
	0.4	0.4	67.7	67.47	24.96	0.382
	0.2	0.6	81.4	81.12	29.33	0.406
	0.0	0.8	98.91	98.91	34.61	0.429
0.4	0.6	0.0	44.8	7.94	2.99	0.313
	0.4	0.2	42.9	31.91	11.43	0.381
	0.2	0.4	46.1	43.37	15.35	0.412
	0.0	0.6	52.9	52.9	18.39	0.439
0.6	0.4	0	31	5.49	2.099	0.3198
	0.2	0.2	28.2	20.18	7.114	0.404
	0.0	0.4	28.97	28.97	10.06	0.438
0.8	0.2	0	17.2	4.20	1.57	0.326
	0.0	0.2	13.83	13.83	4.86	0.424
1	0.0	0.0	3.4	3.4	1.4	0.4

Table 7 shows the result of composite material combined of Epoxy resin, Boron short fiber, and Glass long fiber. From Table 7 shows that the modulus of elasticity of composite material decreases with increasing the epoxy resin due to decreases the fiber, and the modulus of elasticity E_1 increases with increasing the short boron fiber and decreases glass long fiber, since the strength of boron fiber greater than for glass fiber, then, with increasing the high strength reinforcement fiber increasing the strength of composite material.

Comparison of Between Analytical and Experimental Work:

Table 8 shows comparison between analytical and experimental results of properties for hyper composite material and shows the error between the analytical and experimental results.

Table 8 Comparison of Between Analytical and Experimental Results

Sample	$\forall_{sfm}$	$\forall_{mp}$	$\forall_{f}$	E_1 (Mpa) (Theoretical)	E_1 (Mpa) (Experimental)	Error %
S_3	0.1896	0.4654	0.345	25.2	24.734	1.849206
S_4	0.3964	0.2586	0.345	33.4	32.98	1.257485
S_5	0.50	0.155	0.345	43.6	42.25	3.09633
S_6	0.1896	0.4654	0.345	26.7	25.93	2.883895
S_7	0.142	0.4654	0.3926	35.26	33.83	4.055587
S_8	0.10	0.4654	0.4346	56.71	55.14	2.768471
S_9	0.1896	0.4654	0.345	26.7	25.93	2.883895
S_{10}	0.1896	0.2586	0.5518	38.55	36.9	4.280156
S_{11}	0.1896	0.155	0.6554	61.45	59.53	3.124491

Table 8 shows the results for modulus of elasticity for hyper composite material (epoxy resin, glass short and long fiber), that the experimental results less than analytical results with error between (1.25%) and (4.5%).

Conclusions

1- the yield stress of hyper composite material increasing with increases the short fiber or long fiber and decreases the resin material
2- the stresses increasing with increases the long fiber more that with increases the short fiber, with same weight increasing, also, when increasing long fiber and decreases short fiber, with constant resin material, increases the stress of composite material, and, when increasing the resin in composite material decreases the modulus of elasticity E1 .
3- the modulus of elasticity E1 increases with increasing the short boron fiber and decreases glass long fiber, and, when using boron short fiber, with same volume fraction of resin; short fiber; and long fiber in composite material, the properties of composite material are greater than the properties of composite material with using glass short fiber.
4- when the volume fraction of matrix equal to (1), zero long fiber, the properties of composite material, resin and short fiber only, are isotropic material with various volume fraction of short fiber, and, when increasing the volume fraction of short fiber, boron short fiber, the properties in 1-direction near the properties in 2-direction, then, the properties of composite material are near to isotropic properties
5- when increasing the short fiber, with decreases long fiber, decreases modulus of elasticity E1 due to decreases the long fiber and increasing modulus of elasticity E2 due to increasing strength of composite matrix

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