WOVEN FACTOR FOR THE MECHANCIAL PROPERTIES OF WOVEN COMPOSITE MATERIALS

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ABSTARCT

In the past years, the use of composite materials in the aircraft industry, among others, has grown immensely. Composite systems offer an advantage over traditional aircraft materials (metals) because they tend to exhibit higher strength/weight and stiffness/weight ratios than metals, thus making the aircraft lighter and improving performance. Woven composites are increasingly considered for such applications because they offer ease in manufacturing of complicated geometries, but the mechanical properties for different weave patrons of the material is even less well characterized than that of non-woven (angle-ply) laminates. For this reason and because the woven composite mechanical properties is impotent for the theoretical work of the presented work way. The woven factors were evaluated and measured for the composite with different weave patrons, fiber materials and matrix materials. The woven factors were calculated from the measuring mechanical properties from tensile tests of woven composite and for the cross-unidirectional composite made from the same materials. Three types of fiber were used which are E-Glass, Kevlar, and Carbon, while epoxy and polyester were used as a matrixes. The results showing that the woven factors for the Kevlar is higher than the E-Glass and the Carbon and the composites reinforce epoxy have higher woven factors than the composites reinforced polyester.

معاملات النسج في الخواص الميكانيكي للمواد المركبة النسيجية

الخلاصة

ازداد استعمال المواد المركبة في السنوات الاخير للما تتميز به من خواص نسبية للمقاومة الى الكثافة و الشدة الى الكثافة و التي جعلت الاجزاء الميكانيكية اقل وزنا . وتميزت منها المواد المركبة النسيجية لهولة تشكيلها بتظاريس معقدة الشكل. لهذا السبب اصبح استخراج الخواص الميكانيكية لها ذ اهمية يالغة في التحليلات النظرية. لكن وبسبب تغير طبيعة النسج وسمكة و ترتيبه فان الخواص الميكانيكية لها امتلكت التعقيد من ناحية التعامل و التخمين. في هذا البحث استحدثت معاملات خاصة بالنسج للمواد المركبة النسيجية تمثل نسبة الخواص الميكانيكية للمواد النسيجية الى الخواص الميكانيكية لمثيلاته للمواد المركبة احادية اتجاه الالياف. اشتقت في هذا البحث العلاقات بين الخواص الميكانيكية محتوية على هذه المعاملات ونفذت تجارب للمواد المركبة النسيجية و الاحادية لتخمين هذه المعاملات. المواد المركبة المستخدمة صنعت من الياف مختلفة هي الكفلر و الكاربون و الالياف الزجاجية بينما اختلفت المواد الطامرة من الايبوكي الى البولستر. اظهرت النتائج ان معامل النسج للمواد المركبة بالياف الاكفلر هي اعلى منه للكاربون و الالياف الزجاجية. وانها للمواد المركبة بمادة طمر ايبوكسي اعلى منه للبولستر.

KEYWORDS: woven composite materials, tensile, stress, Young modulus, Poisson’s ratio, satin.

INTRODUCTION

Woven fiber reinforced plastics are becoming increasingly important as they have the following advantages over laminates made from individual layers of unidirectional materials(Tsai et.al 1990)

- Improving formability and drape
- Bi-directional reinforcement in a single layer
- Improving impact resistance
- Balanced properties in the fabric plane

There is no mathematical modeling for the mechanical properties of woven fiber reinforced composite, then approximate one was derived here using the approximation that the woven fibers are constructed from two orthotropic unidirectional fiber plays with the effect of bent yearn through the weave.

Consider the 0,90 cross ply composite shown in **Fig. 1**.

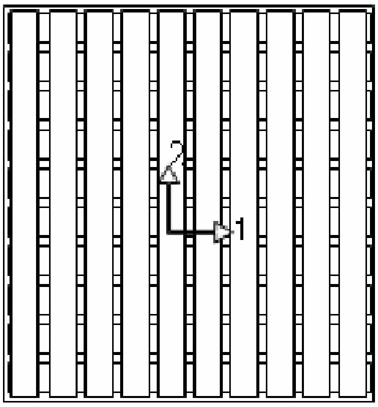


Fig. 1. The composite plate of two orthotropic unidirectional fibers is considered as an infinite-end satin woven fibers composite.

Using the lamina stress-strain relations then for this laminate for presented plate of two orthotropic layers (Rao 1999)

$$\mathrm{A}_{\mathrm{ij}} = \sum_{\mathrm{k=1}}^{\mathrm{N}} (\mathrm{Q}_{\mathrm{ij}})(\mathrm{z}_{\mathrm{k}} - \mathrm{z}_{\mathrm{k-1}})$$

Then

$$[A] = h\begin{bmatrix} \dfrac{Q_{11}+Q_{22}}{2} & Q_{12} & 0 \\ Q_{12} & \dfrac{Q_{11}+Q_{22}}{2} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \quad \text{and} \quad [\mathrm{a}] = [\mathrm{A}]^{-1} \tag{1}$$

then

$$a_{11} = a_{22} = \frac{2(Q_{11}+Q_{22})}{h\left\{(Q_{11}+Q_{22})^2 - 4Q_{12}^2\right\}} = \frac{2(\mathrm{E}_{11}+\mathrm{E}_{22})(1-\nu_{12}\nu_{21})}{\mathrm{h}\left\{(\mathrm{E}_{11}+\mathrm{E}_{22})^2 - 4\,\nu^2_{21}\,\mathrm{E}_{11}\right\}} = \frac{2(1-\nu_{12}\nu_{21})\left(1+\dfrac{\nu_{12}}{\nu_{21}}\right)}{hE_{11}\left\{\left(1+\dfrac{\nu_{12}}{\nu_{21}}\right)^2 - 4{\nu_{21}}^2\right\}}$$

$$a_{12} = a_{21} = \frac{-4Q_{12}}{h\left\{(Q_{11}+Q_{22})^2 - 4Q_{12}^2\right\}} = \frac{-4\nu_{21}E_{11}(1-\nu_{12}\nu_{21})}{h\left\{(E_{11}+E_{22})^2 - 4\nu^2_{21}E_{11}\right\}} = \frac{-4(1-\nu_{12}\nu_{21})\nu_{21}}{hE_{11}\left\{\left(1+\dfrac{\nu_{12}}{\nu_{21}}\right)^2 - 4{\nu_{21}}^2\right\}} \quad a_{66} = \frac{(Q_{11}+Q_{22})^2 - 4Q_{12}^2}{hQ_{66}\left\{(Q_{11}+Q_{22})^2 - 4Q_{12}^2\right\}} = \frac{1}{hG_{12}} \tag{2}$$

Then the an infinite-end satin woven fibers composite properties are

$$
\begin{aligned}
&(E_1)_\infty = (E_2)_\infty = \frac{1}{ha_{11}} = \frac{\left\{\left(1+\dfrac{\nu_{21}}{\nu_{12}}\right)^2 - 4\nu_{21}{}^2\right\}}{2(1-\nu_{12}\nu_{12})\left(1+\dfrac{\nu_{21}}{\nu_{12}}\right)} E_{11} \\
&(G_{12})_\infty = \frac{1}{ha_{66}} = G_{12} \\
&(\nu_{12})_\infty = -\frac{a_{12}}{a_{11}} = \frac{2\nu_{21}}{\left(1+\dfrac{\nu_{21}}{\nu_{12}}\right)} = \frac{2\nu_{12}\nu_{21}}{(\nu_{12}+\nu_{21})}
\end{aligned}
\qquad (3)
$$

For a woven fibers of finite-end satin, the properties will be decreased due to fibers bent assume that there a multiplication factors which when multiplied by the infinite-end satin woven fibers composite properties give the properties of the woven fibers of finite-satin then:-

$$
\begin{aligned}
&(\mathrm{E}_{11})_w = (\mathrm{E}_{22})_w = \mathrm{W}_\mathrm{E}(E_{11})_\infty = \mathrm{W}_\mathrm{E}\,\frac{\left\{\left(1+\dfrac{\nu_{21}}{\nu_{12}}\right)^2 - 4\nu_{21}{}^2\right\}}{2(1-\nu_{12}\nu_{12})\left(1+\dfrac{\nu_{21}}{\nu_{12}}\right)} E_{11} \\
&(\mathrm{G}_{12})_w = \mathrm{W}_\mathrm{G}\ \mathrm{G}_{11} = \mathrm{W}_\mathrm{G}(G_{12})_\infty \\
&(\nu_{12})_w = (\nu_{21}) = \mathrm{W}_\nu\ (\nu_{12})_\infty = \mathrm{W}_\nu\,\frac{2\nu_{12}\nu_{21}}{(\nu_{12}+\nu_{21})}
\end{aligned}
\qquad (4)
$$

Where W_E, W_G and W_ν are new factors call the woven multiplication factors for E_{11}, G_{12}, and ν_{12} respectively. These factors can be evaluated from the evaluation of these properties experimentally which are done in the tensile tests of the 0, 90 composite plates and the woven fibers composites formed.

Now because of the homogenous orthotropic behavior of the woven fiber lamina the mechanical properties of angle ply woven lamina were stay covered by expressions

For angle ply woven lamina (Sharma 2000).

$$
\begin{aligned}
&\mathrm{E}_{xx} = \mathrm{E}_{yy} = \left[\frac{\mathrm{m}^4+\mathrm{n}^4}{\mathrm{E}_{11}} + \left(\frac{1}{\mathrm{G}_{12}} - \frac{2\nu_{12}}{\mathrm{E}_{11}}\right)\mathrm{m}^2\mathrm{n}^2\right]^{-1} \\
&\mathrm{G}_{xy} = \left[\frac{1}{\mathrm{G}_{12}} + 4\left(\frac{2(1+\nu_{12})}{\mathrm{E}_{11}} - \frac{1}{\mathrm{G}_{12}}\right)\mathrm{m}^2\mathrm{n}^2\right]^{-1} \\
&\nu_{xy} = \mathrm{E}_{xx}\left[\frac{\nu_{12}}{\mathrm{E}_{11}} - \left(\frac{2(1+\nu_{12})}{\mathrm{E}_{11}} - \frac{1}{\mathrm{G}_{12}}\right)\mathrm{m}^2\mathrm{n}^2\right] \\
&\nu_{yx} = \frac{\mathrm{E}_{yy}}{\mathrm{E}_{xx}}\nu_{xy}
\end{aligned}
\qquad (5)
$$

FABRICATION OF LAMINATED PLATES TEST SPECIMENS

Fiber Reinforcements and Matrix Resins

As mentioned earlier, the fibrous composite laminates fabricated mainly from two main constituents, which are the fibers reinforcements, and the unsaturated matrix resin. It is important to remember that the inter ply layer, or the adhesive layer between any two successive layer is the resin itself with some adding thickness for distinguishing this interply layer. The followings demonstrate the physical and chemical specification of these two constituents.

(A) The Fiber Reinforcements

The fiber materials used as reinforcements in the presented work are E-Glass, Carbon, and Kevlar aramid fibers. Now the compositions, forming, and properties were listed.

I) E-Glass

The type used in the presented work is E-glass, which is the material most widely used as a reinforced medium for plastic as well as for textile fiberglass product applications. The representative chemical compositions of these four glasses are given in **Table 1** and the inherent properties are given in **Table 2**.

Table 1 Glass composition

	Material, percentage weight (%)							
Glass type	Silica	Alumina	Calcium oxide	Magnesia	Boron oxide	Soda	Calcium fluoride	Minor oxides
E-glass	54	14	20.5	0.5	8	1	1	1
Commercial fiberglass used in the present work								
A-glass	72	1	8	4	-	14	-	1
ECR-glass	61	11	22	3	-	0.6	-	2.4
S-Glass	64	25	-	10	-	0.3	-	0.7

Table 2 Inherent properties of glass fibers

Glass type	Specific gravity	σ_{ult} (MPa)	E_t (GPa)	α (10^{-6}/K)	Dielectric constant(a)	Liquidus temperature ^oC
E-glass	2.58	3450	72.5	5.0	6.3	1065
Commercial fiberglass used in the present work						
A-glass	2.50	6043	69.0	8.6	6.9	996
ECR-glass	2.62	3625	72.5	5.0	6.5	1204
S-Glass	2.48	4590	86.0	5.0	5.1	1454

II) Carbon Fibers

Fiber produced by the pyrolysis of organic precursor fibers, such as rayon, polyacrylonitrile (PAN), and pitch, in an inert environment. Carbon fibers typically carbonized in the region of 1315 oC and assay at 93 to 95% carbon. There are some types of carbon fibers (which their properties are available in (Reinhart et.al 1987)), the commercial type was used in presented work is P-55 carbon-high modulus fiber which its properties are shown in **Table 3.**

Table 3.Mechanical properties of P-55 carbon-high modulus fiber.

Product name	Manufacturing	Precursor type	Density Kg/m^{3})	σ_{ult} (GPa)	E_t (GPa)
P-55	Union Carbide	Pitch	2000	1.73	379

III) Kevlar

The predominate organic reinforcing fiber used in advanced composites since the early 1970s has been aramid or aromatic polyamide, known as Kevlar. Kevlar 49 fabric with the mechanical properties shown in **Table 4** was used in the tests.

Table 4.Mechanical properties of Kevlar 49 used in the presented work

Material	Density Kg/m^3	Filament diameter μm)	E_t (GPa)	σ_{ult} (GPa)	ε_{break} (%)	Available yarn count, No. Filaments
Kevlar 49	1440	12	131	3.6	2.8	≈150

(B)The Unsaturated Matrix Resin:

Two types of matrixes were considered in the tests, which are polyester resin and epoxy resin.

I) Polyester resin

It is used a chemical compound of reactive polymers (glycol's or "phthalic" anhydride with the acid "malice" anhydride). The compound is sTable liquid for months or even years, as long as the carbon double – bonds in the poly –molecular structure, is kept conservative. In his patents, sixty years ago, Ellis (Reinhart et.al 1997) discovered that the adding of a reactive monomer (usually referred to "peroxide" catalyst or "styrene") then an exothermic reaction (rejecting heat) or "curing" will be set up involving the conversion of double – bond into single – bond through cross – linkage polymerization process. The added catalyst initiates and shares the polymer network within certain duration time, called the "gel time" of the process. A typical catalyst, frequently used in practice, is the (MEKP, refereed to methyl ethyl ketone proxide). In order to decrease the unprofiTable much gel time, during the lay – up procedure, an "accelerator" agent may be employed for this purpose, like the "cobalt – naphthenate" as being used for a general – purpose polyester resin.

The new product is, hence, the "saturated" polyester resin. Depending on the mole ratio of the phthalic / maleic, and the mass percentage of the catalyst / accelerator agents, the mechanical properties of the resin will be cited. Other glycol compounds and additive agents produce wide variety of resin type for broad range of applications. Recently, the polyester resin, as refereed to "Palatal P50T" (Whitny et.al 1970), is found commercially used and officially approved in German standards under DIN 16946.

(C) Fabric Forms and Materials Used:

The geometrical aspect of the fibers used in the presented work have the detail shown in **Table 5**, the selection of different fiber materials is to study the effect of it on the properties and impact, also the using different fabric forms and weights are to study the fabric effect and to determine the woven facture defined in the theoretical part of work. The matrix types and their density are tabulated also.

Table 5.materials used in the presented tests

(A) Fibers

Fiber material	Weave	Construction tows/cm	Mass/area kg/m^2
E-glass	Plain	2.5*2.5	0.500
	Plain	12.5*12.5	0.260
	5-end satin	5*5	0.280
	Random	-	0.450
Carbon	Plain	7*7	0.170
	3-end satin	5*5	0.210
Kevlar	3-end satin	7*7	0.230

(B) Matrixes

Polyester	ρ= 1268 kg/m^3	Epoxy	ρ= 1430 kg/m^3

Mould Preparation

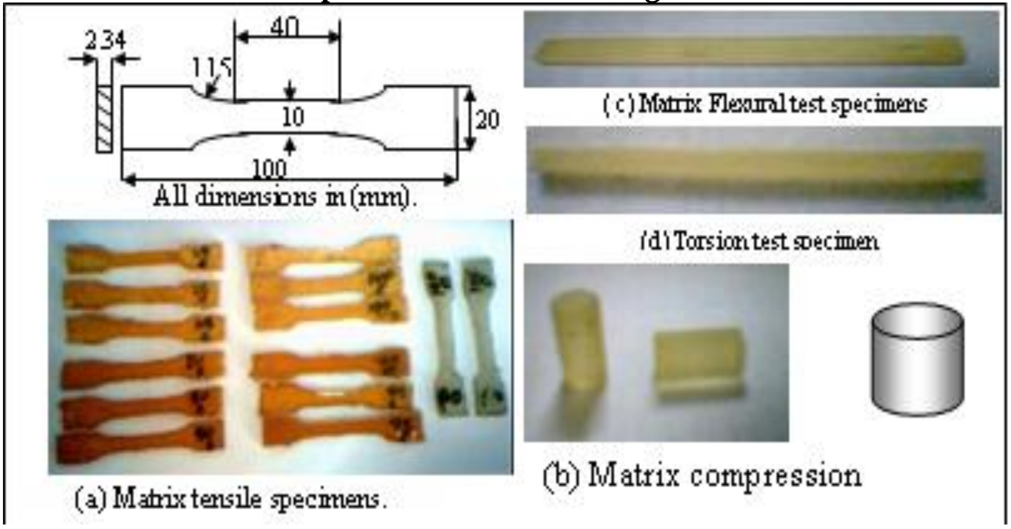
There are two groups of samples molded, matrix samples, and layered fiber composite plates samples. The matrix samples was made to verifying the mechanical properties of matrix specially because the environment conditions and process of molding are vary important parameters effecting on the properties, because of that there is no offered properties can be use it directly, then the Tensile, Bending, and torsion tests were done. Composite plates samples was made for using different fibers and matrix material to verifying mechanical properties and to use them as target in the high velocity impact test.

I) Matrix Samples:

For product the samples of tests (Tensile, Bending), made one sample for each test from pure epoxy with standard dimensions and then used these samples to make the moulds.

Moulds that used, produced from paste of panes rolled out at pane and then formed the shape of each sample on it as shown in **Fig. 2**.

Fig. 2 matrix sample produced from paste of panes rolled out at pane and then formed the shape of tensile and bending tests.



(c) Matrix Flexural test specimens

(d) Torsion test specimen

(a) Matrix tensile specimens.

(b) Matrix compression

Fig. 3 matrix specimens fabricated and used for tests

The tensile test specimens have been produced according to (D638) as shown in **Fig. 3.a**. The tensile test specimens produced for pure epoxy. The tensile test specimens produced using a mould shown in **Fig. 2**, And after solidification made grinding processes for each specimen to get the standard dimensions.

II) Composite Plate Samples

The plate strip specimens used in the investigation were fabricated from the fiber matrix plies, and symmetrical lay – up were prepared by using a 30*30cm ceramic open mold with x-ray photo sheet painted with wax film to avoid abrasive and inshore flattening as shown in the schematic arrangement shown in **Fig. 4**, the molder applies a pigments “release” material to the mold, as the First step in making any open mold product. Without such material, the part will permanently bond to the mold surface.

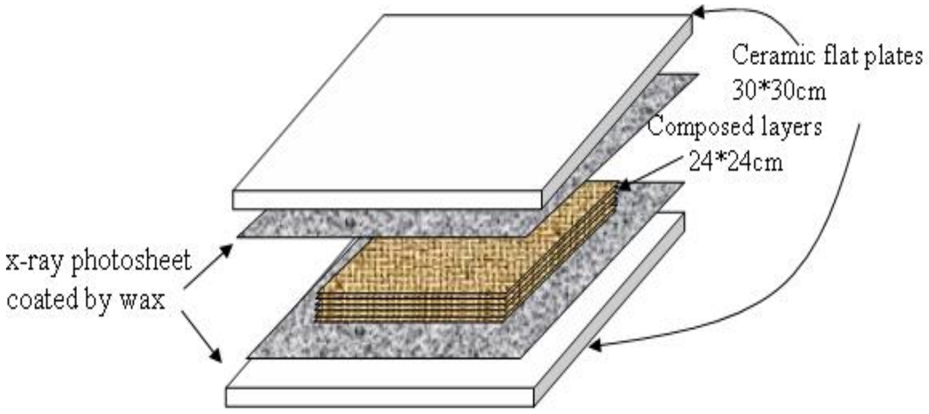


Figure (4) Schematic of mold of test specimen

Fig. 4 Schematic of mold of test specimen

Secondly, a pre – measured unsaturated polyester and catalyst (or matrix) are then thoroughly mixed together, and for ensuring complete air removal and wet out, it should cover the base surface completely especially at the end edges.

The Thirdly step is the application of fiber in the resin layer, these woven or chopped fiber layer are put in the resin layer and with using brushes and rollers the fiber layer would saturated by resin, then another fiber sheet would be putted and return the process until end layer, x-ray photo sheet coated with wax will cover the composite and with rolling over all layers to ensuring complete air removal. When using polyester resin, the curing step of the specimens, which are a change of properties of thermosetting resin by chemical reactions, this process forming a strong three-dimensional network thus, the cross- link structure is known as curing.. The curing step related to a curing temperature, and curing time Thus, the specimens were cured according to the manufacture’s recommendations, in a dryer oven for the recommend time and temperature are 8hr and 70 0C respectively (Thompson 2004).

The pressure applied through the forming of the specimens was optimized from trail and error to give approximate 60% fiber volume fraction, which was calculated from the mass fraction, the composite volume is equal to the summation of fiber and matrix volumes

$V_c = V_F + V_M$ or $1 = v_F + v_M$

Where V and v represent the volume and volume fraction respectively, and subscripts C, F and M represent the composite, fibers and matrix respectively.

Form $V = m/\rho$ then

$m_c / \rho_c = m_F / \rho_F + m_M / \rho_M$

Where m and ρ are the mass and density respectively. The density of composite plate can be calculated from $\rho_c = m_c / V_c$, the mass of plate was measured using three digital electronic balance, the volume of the plate was measure by hand Verna.

The mass of fiber can be measured by multiplying the area of all layers times the mass per unit area {see **Table5**} and the density of the fiber is from **Tables 2** to **4**, then the volume fraction of fiber will be calculated using

$$v_F = V_F / V_c = (m_F / \rho_F) / (V_c) \qquad (6)$$

Manual scissors, rotating grinding, and manual grinding used to cut the plies for the lay-up. For the tensile specimens the patterns are necessary.

II) Test samples:

Three types of composite sample are used which are the tensile test specimens, friction disk specimens, and impact test specimens

Tensile tests were conducted in according to the (ASTM D412) standard(Noble 1996). The test specimens, shown in **Fig. 5** with strain gauge at center and locate normal to the length to measure the lateral stain, any composite where tests for two direction principle, and 30o to evaluate the required material properties.

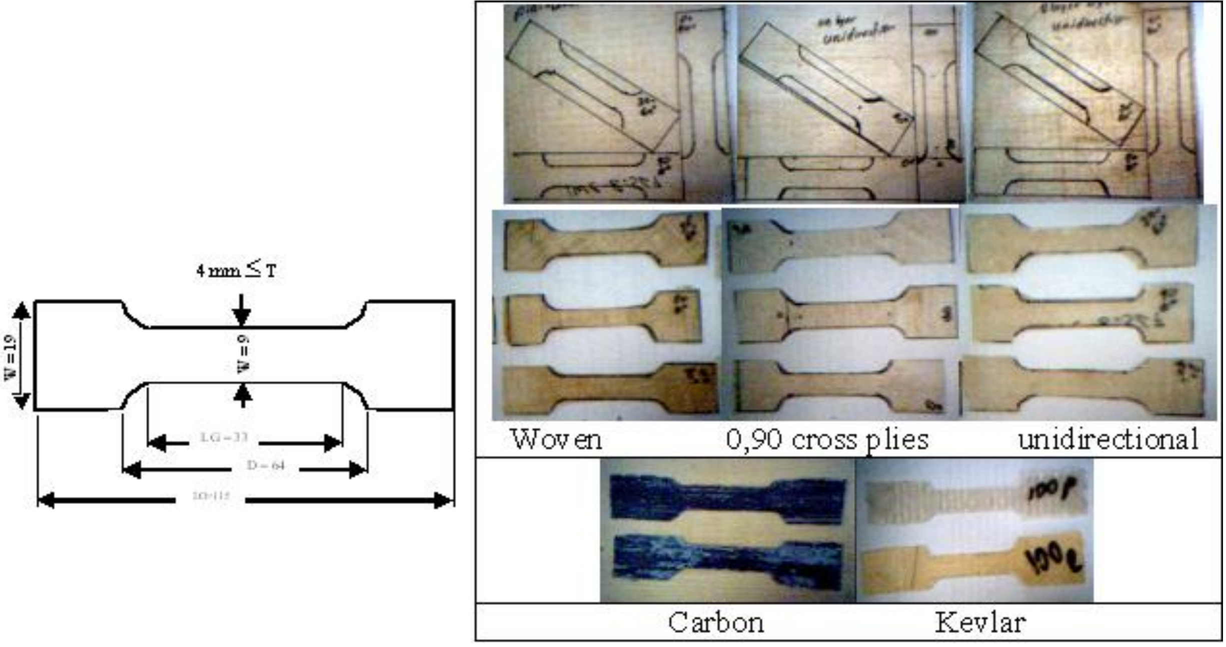


Fig. 5 some specimens use for testing the properties

Tests for Mechanical Properties

The mechanical properties for matrixes were measured using four tests (tensile, compression, bending, and torsion), while the mechanical properties of composites were measured using (tensile and friction).

Tensile and Compression Tests:

Tensile and compression testing device, which used type PHYWE, model D-3300 and has a maximum supported load 30KN that displayed by a digital display of a strain gage and measuring displacement using a dial gage as shown in **Fig. 6.a**. In tensile and compression tests used a digital camera to record the force and displacement values in each moment to get more accuracy.

Fig. 6 (a)Tensile tester (b) Microstrain meter

The tensile test was used for matrix and composite, The stress and strain in normal to the load axis is $\sigma_L = F / A$, and $\varepsilon_L = \delta / LG$, while the lateral srtain is from strain gauge directly, where the strain gauge used is Omega using quarter Bridge (**Fig. 6.b**) and 120Ω strain gauge prop was used. Then the passion's ratio can be determined using $\nu_{12} = -\varepsilon_T / \varepsilon_L$, the modulus of elasticity ($E_{11}=E_{22}$) and the ultimate tensile stress (σ_{ult}) are evaluated from the stress strain curves.

For composite specimens the modulus of rigidity can be measured after knowing E_{11}, E_{22}, and ν_{12} and from E_{xx} evaluated from the tensile test of 30^0 specimens with m= cosθ, and n=sinθ and from elasticity relation for orthotropic lamina

$$E_{xx} = E_{yy} = \left[\frac{m^4 + n^4}{E_{11}} + \left(\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_{11}} \right) m^2 n^2 \right]^{-1} \tag{7}$$

The unique unknown is G_{12}, which can be calculated.

For using results for woven composite and the 0,90 composite the new woven multiplication factures W_E, W_G, and W_ν can be calculated from eq. (4).

RESULTS

Matrixes

The mechanical properties the matrixes (epoxy and polyester) were found using the tensile, compression and torsion tests. The results of these tests are shown in **Fig.s** (**7** to **9**), while there evaluated properties from these tests are listed in **Table 6**.

It was shown that the epoxy resin used is equivalent to the epoxy casting resin, no filler at 25oC(Rao 1999). The polyester resin used is equivalent the cast polyester neat resin (Rao 1999). It was shown that the epoxy resin have amore strength and modulus than the polyester resin, this behavior is known because of the chemical composition bond in the epoxy which were give a longer chains and network for its chemical structure. And that is give the same resin for appearing the instability point in the epoxy resin and not occurs in the polyester resin.

The compression stress strain curves shown in **Fig. 8** show that the epoxy resin has greater compression modulus and smaller ultimate compression strength than the polyester resin and these results were conventional with the earliest tests (Rao 1999).

Because of the assumption that the resins were isotropic then the measuring of the modulus of rigidity is benefit to evaluate the poisons ratio for the resins and the ultimate shear strength, which is importants with the ultimate tensile strength in the delamination failure criteria used in the theoretical parts of the thesis.

Fig. 9 shows the shear stress shear strain relations for the resins used. In general the ability of resin in the shearing load relative to tensile load is grater than the metallic materials. That is Appear clearly for the epoxy resin and less in the polyester resins.

The summary of the mechanical properties for the epoxy and the polyester are shown in **Table 6**.

Table 6. The measured mechanical properties for matrixes.

Test →	Tensile				Compression		bending	Torsion			
Matrix↓	E_t (MPa)	σ_{Yt} (MPa)	σ_{ult} (MPa)	ε_F (%)	E_c (MPa)	σ_{Yc} (MPa)	E_b (MPa)	G (MPa)	τ_{ult}(MPa)	γ_F (%)	ν
Polyester (p)	933	33.8	58.5	9.4	1276	79.2	1352	324	37.2	13.4	0.44
Epoxy (e)	1714	47.7	57.6	5.2	1875	76	2563	620	80.6	17.9	0.382

Composites

Two types tests were used for measuring the mechanical properties of the composites, which are the tensile tests and the friction tests. the stress-strain curve for the tensile are shown in **Fig.s(10-19)** . The **Fig.s (a)** the tensile test in the direction of the fiber, which have a strain gauge to measure the lateral stain and the Poisson's ratio. While the **Fig.s (b)** represent the tensile tests in the (30^o) inclination angle with the fiber direction to evaluate the modulus of rigidity of the composites.

It is clear that the effect of the mechanical properties of the matrix type on the overall properties for the composite ply. This effect is decreased as increasing the properties of the fiber as in the stress strain curve for Kevlar reinforcement shown in **Fig. 12**.

The summary of the mechanical properties measured and evaluated from **Fig.s (10 to 12**) are listed in **Table 7**

Table 7 the mechanical properties of manufactured 0-90 fiber reinforced composite

0-90 specimens		Mechanical properties					
Fiber	Matrix	σ_{ult}(MPa)	$E_1=E_2$(MPa)	ν_{12}	E_{30}(MPa)	σ_{ult30}(MPa)	G_{12}(MPa)
Carbon	Epoxy	130	8292	0.048	4714	69	1349
Carbon	Polyester	105	5098	0.044	3105	64	925
E.Glass	Epoxy	87	4183	0.103	2138	59	573
E.Glass	Polyester	79	3957	0.095	2077	46.5	564
Kevlar	Epoxy	210	14241	0.075	5756	97	1422
Kevlar	Polyester	194	11492	0.038	5610	89	1498

The evaluations of the weave factors derived in the theory were needed to measure the mechanical properties of the woven composite. The stress strain relations for the tensile tests of the different weave structure of the fibers were shown in **Fig.s (13 to 19)**. The same effects of the matrix types were found as in **Fig. 13**, for this reason and because of the lower cost of the polyester resin the polyester resin were used for the other types of woven fiber composites.

It was shown that the epoxy matrix not only gives larger properties than polyester but also give large woven factors. This is because of its higher properties.

The composite properties were affected directly with the fiber properties. This cause the largest properties for the Kevlar fiber composite shown in **Fig. 19** and less for the carbon fiber composites {**Fig.s (17 and 18)**} and the lowest in the glass fiber composites {**Fig.s (14 and 17)**}.

The study woven style was affecting on the fiber composite properties as shown in **Fig.s (12 to 16)**, the meshing size affect was shown for **Fig. 13** and **Fig. 14**. It was shown that the greatest mesh size {**Fig. 13**} give large Young modulus and tensile strength than the low mesh {**Fig. 14**}. This is due to the largest consolidation through the weave for the largest mesh size. In the addition that the largest mesh size give lower number of the fiber bents.

The different weave styles for the same mesh size was not available through the period of the work, but the results for the available weave give that the increasing the number of end satin cause increasing the ultimate stress and Young modulus and the woven factors because the increasing the number of satin give to reaching to the infinite satin for E-glass and Carbon fibers. This conclusion can be generalized to all types of woven fiber.

The chopped random E-glass has the stress strain relation shown in **Fig. 16**, the random fiber was not need to find its modulus of rigidity using inclination tensile test because of it isotropic behavior

The results were summarized in **Table 8**

From **Table 8** it was shown that the Kevlar composite material has higher woven factors than the carbon and E-Glass composites, that is because the higher modulus for the Kevlar with it flexible yarn give more closely to the unidirectional fibers than that for the other types of fibers. The composite with epoxy matrix has higher woven factors than that for polyester matrix composite, this is because of higher modulus for epoxy. The satin weave composites have higher woven factors because of there geometries that were approaching to the cross unidirectional composite as the satin increase and be the same for an infinite satin woven composite as discussed previously.

Table 8. The measured mechanical properties for the composites manufactured.

Composition		Woven composite ply							0-90 composite ply				Woven factors		
Fiber	Matrix	Style	No. of Layers	h (mm)	σ_{ult} (MPa)	$E_1=E_2$ (MPa)	ν	G_{12} (MPa)	σ_{ult} (MPa)	$E_1=E_2$ (MPa)	ν	G_{12} (MPa)	W_E	W_{ult}	W_G
E-Glass	Epoxy	Plain (2.5*2.5)	3	1.8	53.94	2611	0.096	473	87	4183	0.103	573	0.79	0.62	0.83
E-Glass	Polyester	Plain (2.5*2.5)	3	1.82	46.61	2226	0.112	474	79	3957	0.095	564	0.75	0.59	0.84
E-Glass	Polyester	Plain (12.5*12.5)	6	1.9	43.45	2051	0.093	448	79	3957	0.095	564	0.72	0.55	0.79
E-Glass	Polyester	5-end satin (5*5)	5	1.75	41.08	2138	0.045	455	79	3957	0.095	564	0.74	0.52	0.81
E-Glass	Polyester	Random	4	1.8	32.39	3184	0.231	1293	79	3957	0.095	564	-	-	-
Carbon	Polyester	Plain (7*7)	6	1.72	54.6	3023	0.061	583	105	5098	0.044	925	0.77	0.52	0.63
Carbon	Polyester	5-end satin (5*5)	5	1.7	59.85	3512	0.085	550	105	5098	0.044	925	0.83	0.57	0.59
Kevlar	Polyester	3-end satin (7*7)	6	1.85	166.8	9517	0.043	852	194	11492	0.038	1498	0.91	0.86	0.57

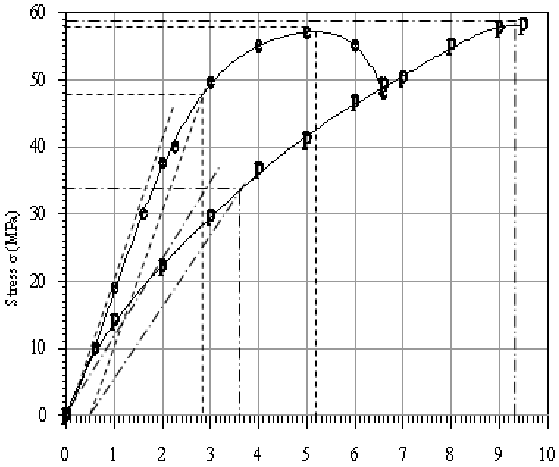


Fig. 7 Experimental tensile Stress-Strain curves for polyester (p) and epoxy (e) tensile test (Tensile speed = 3mm/min).

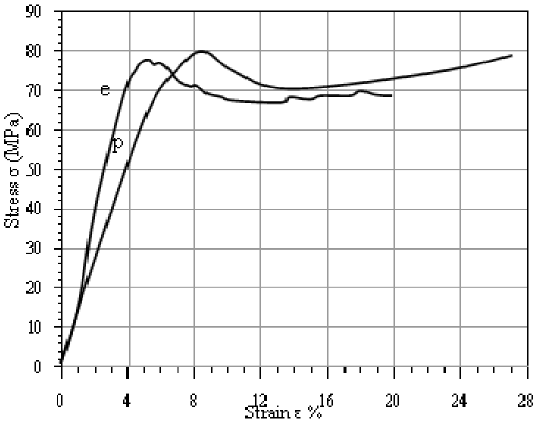


Fig. 8. Experimental compression Stress-Strain curves for polyester (p) and epoxy (e), Compression test (Compression speed = 3mm/min).

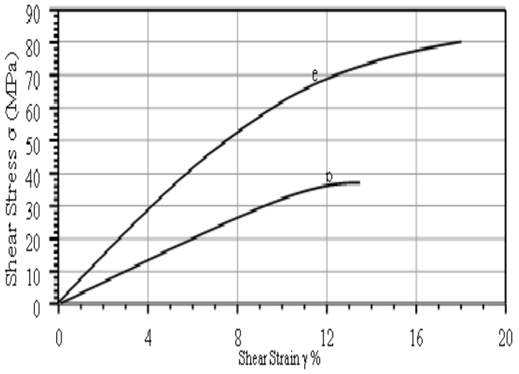


Fig. 9. Experimental Shear Stress- Shear Strain curves for polyester (p) and epoxy (e), Torsion test

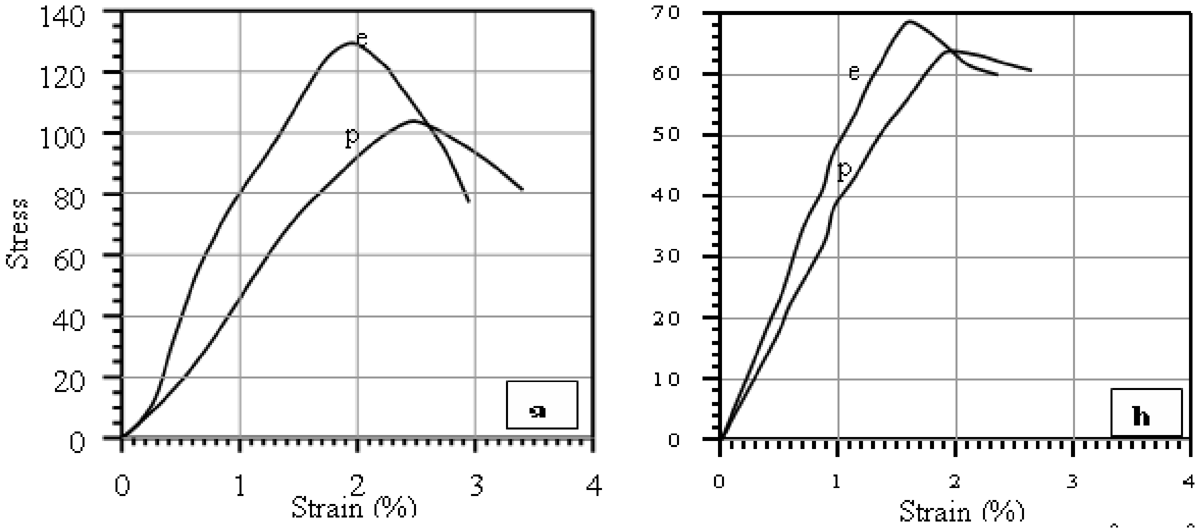


Fig. 10. Tensile stress-strain curves for 0-90 carbon reinforced {polyester (p) and epoxy (e). a) 0^{o}, b) 30^{o}

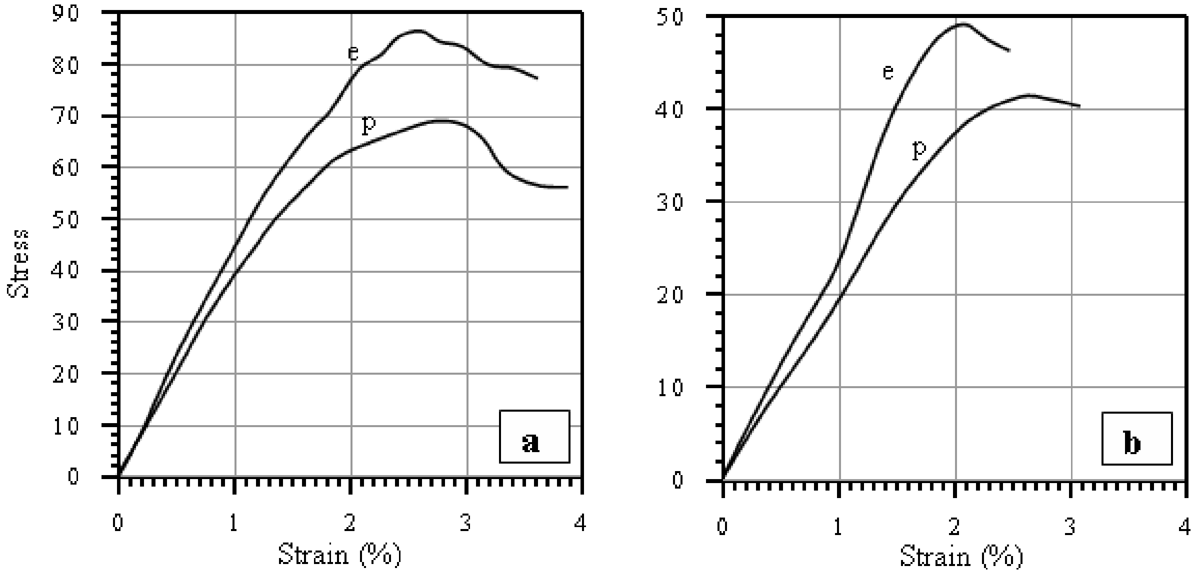


Fig. 11. Tensile stress-strain curves for 0-90 E-glass reinforced {polyester (p) and epoxy (e). a) 0^{o}, b) 30^{o}

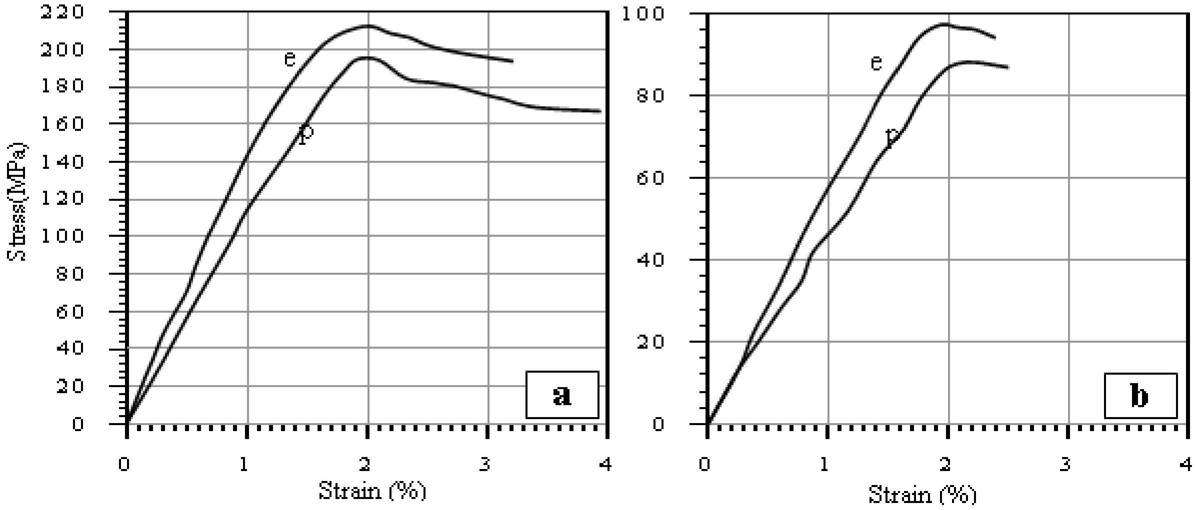


Fig. 12. Tensile stress-strain curves for 0-90 Kevlar reinforced {polyester (p) and epoxy (e). a) 0^{o}, b) 30^{o}

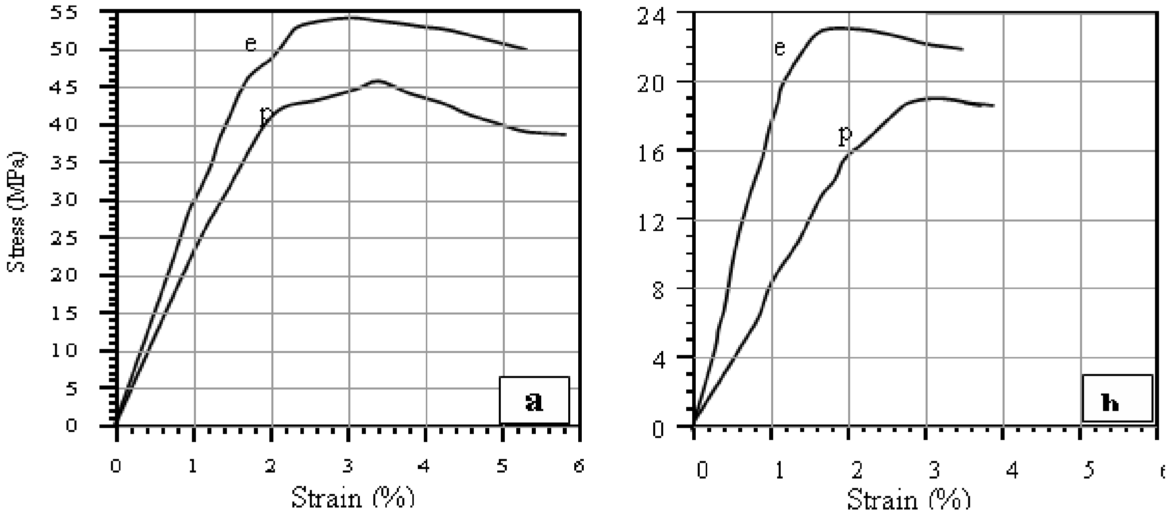


Fig. 13. Tensile stress-strain curves for plain-woven E-glass fiber (2.5*2.5) reinforced {polyester (p) and epoxy (e)}. a) 0^o, b) 30^o

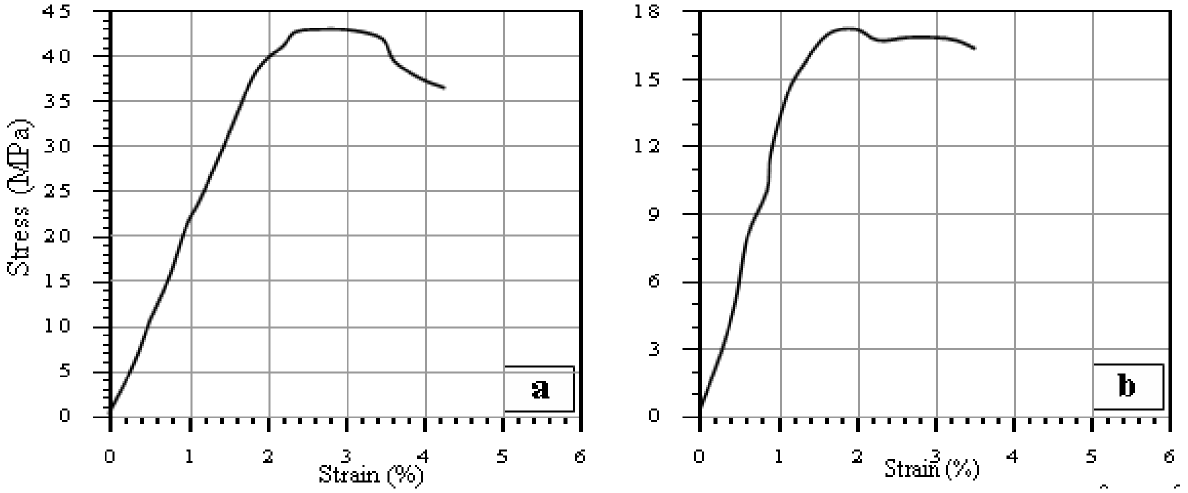


Fig. 14. Tensile stress-strain curves for plain-woven E-glass fiber (12.5*12.5) reinforced polyester. a) 0^o, b) 30

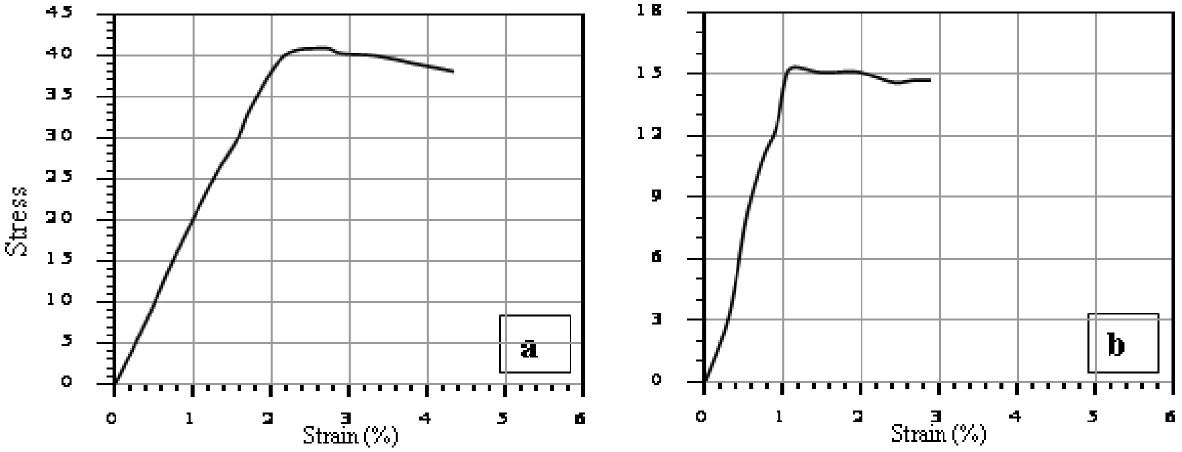


Fig. 15. Tensile stress-strain curves for 5-end satin woven E-glass fiber (5*5)) reinforced polyester. a) 0^o, b)30^o

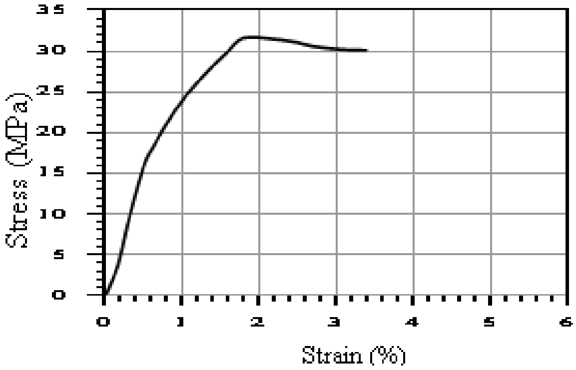


Fig. 16. Tensile stress-strain curves for random chopped E-glass fiber reinforced polyester

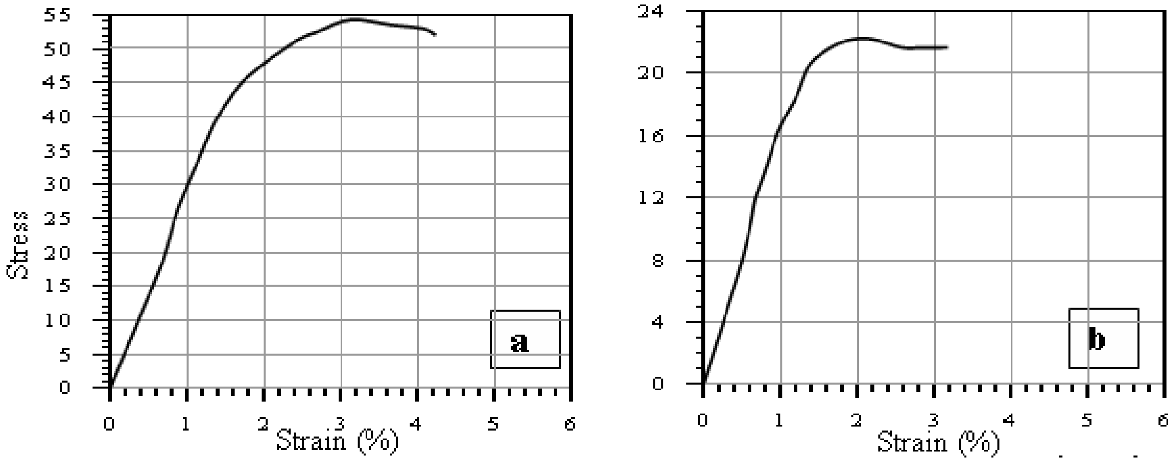


Fig. 17. Tensile stress-strain curves for plain-woven carbon fiber reinforced polyester. a) 0°
b) 30°

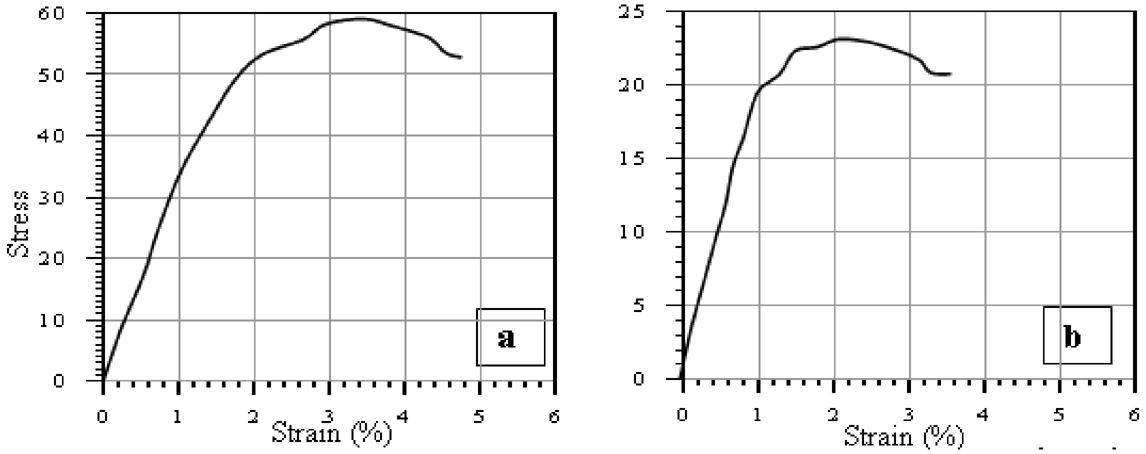


Fig. 18. Tensile stress-strain curves for 5-end satin woven carbon fiber reinforced polyester. a) 0°,
b) 30

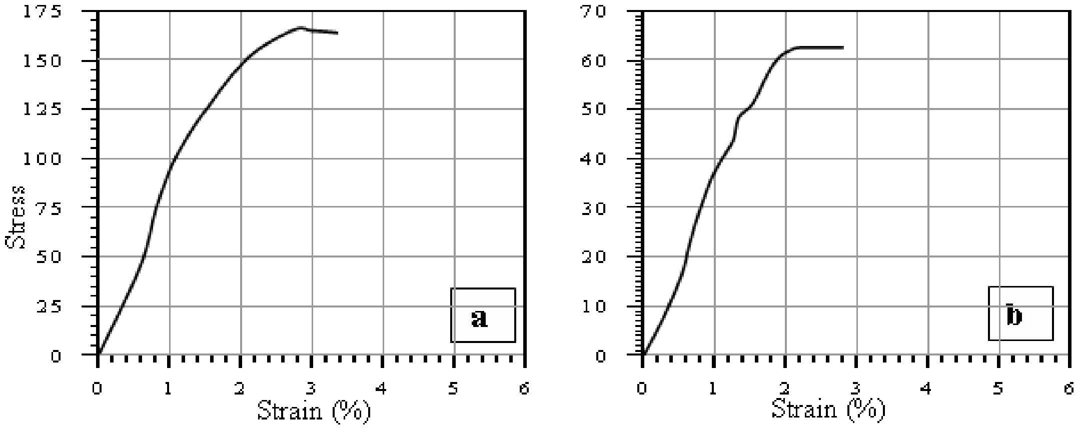


Fig. 19. Tensile stress-strain curves for 3-end satin Kevlar fiber reinforced polyester. a) 0^o, b) 30^o

* CONCLUSIONS

The tensile test for cross play and woven composite were done to evaluate the ratio of mechanical properties for the woven composites to that for cross composite, which were call the woven factors for woven composite materials. It was shown that the woven composites have lower mechanical properties than the cross ply composites. The Kevlar composite material has higher woven factors than the carbon and E-Glass composites. The composite with epoxy matrix has higher woven factors than that for polyester matrix composite. The satin weave composites have higher woven factors for different types of fiber composites.

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