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Mechanical Behavior of Polyester and Fiber Glass as a Composite Material used in a Vehicle under Dynamic Loading

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ABSTRACT

The automobile industry has shown increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength compared to weight. The aim of this paper is to study two kinds of fiberglass, regular direction (0-90) and random direction immersed in polyester resin. They were tested under static load, as tensile test for their mechanical properties, and under dynamic load in fully reversible bending tests as fatigue test, to estimate S-N curves, and impact test for their mechanical properties. Results from the tensile tests showed that the tensile strength of the regular type is greater than random type. The fatigue test results showed that the number of cycles to failure in regular type of composite material is greater than that of the random type and the endurance limit is also greater than in random, the increase percentage in endurance limit is 7.5%. Results due to impact test showed that there were on increasing in fracture energy for the random type the increase ratio is 13.9%. The Important characteristics of composites that make them excellent for leaf spring instead of steel are higher strength-to-weight ratio, superior fatigue strength. Application of composite structures reduces the weight of leaf spring without any reduction on the load carrying capacity and stiffness in automobile suspension system.

Keywords: composite material, tensile test. E-Glass fiber, fatigue.

السلوك الميكانيكي للبولستر والالياف الزجاجية كمواد مركبة استعملت في العربات تحت الاحمال الديناميكية

الخلاصة

اظهرت صناعة السيارات اهتماما متزايدا بابدال النوابض الورقية الفولاذية بالنوابض الورقية المصنوعة من الالياف الزجاجية المركبة بسبب المتانة العالية مقارنة مع الوزن. يتناول هذا البحث دراسة نوعين من الياف الزجاج هما النوع الاول المنتظم (0-90) والنوع الثاني العشوائي مغمور بمادة البوليستر. تم اختبار كلا النوعين للحصول على المواصفات الميكانيكية تحت الحمل المستقر كأختبار الشد وأختبار تحت حمل ديناميكي كاختبار الصدمة. وللحصول على مخططات العمر تم اجراء التجارب تحت حمل ديناميكي متعاكس وهو أختبار الكلال. اظهرت نتائج اختبار الشد ان مقاومة الشد في النوع المنتظم اعلى من مقاومة الشد في النوع العشوائي ومن نتائج اختبار الكلال لوحظ بان عدد الدورات اللازمة للفشل اعلى في النوع المنتظم ,وان نسبة الزيادة في حد الكلال هي 7.5%. اظهر اختبار الصدمة زيادة في الطاقة المصروفة للكسر في النوع العشوائي بنسبة 13.9%. الخصائص المهمة للمواد المركّبه مثل المقاومة العالية نسبة للوزن والتي تعطي مميزات ممتازة للنوابض الورقية عند استخدامها بدلاً مِنْ النوابض الورقية المصنعة من الفولاذِ ، ان استخدام النوابض الورقية المصنعة من المواد المركبة يعطي خفة في الوزن دون أيّ تخفيض على الحملِ والمتانة في نظام التعليق في السيارة.

الكلمات الدالة: المواد المركبة ، فحص الشد ، فايبر كلاس نوع (E) ، الكلال.

INTRODUCTION

The improvement of performance and weight reduction has been the main focus of automobile manufactures; interest in reducing the weight of automobile parts has necessitated the use of better material, design and manufacturing processes. The suspension leaf spring is one of the potential elements for weight reduction in automobiles particularly in trucks. Leaf spring should be subjected to impacts due to road irregularities by means of variations in the spring deflection so that potential energy is stored in spring as strain energy and then released slowly. So, increasing energy storage capability of a leaf spring ensures a more compliant suspension system. A material with maximum strength and minimum modulus of elasticity in longitudinal direction is the most suitable material for a leaf spring.

In 2006 M Senthil Kumar and S. Vijayarangan,[1], were studied the Static analysis and fatigue life prediction of steel and composite leaf spring for light passenger vehicles. Primary objective is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. Composite leaf spring had 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. A weight reduction of 68.15 % was also achieved by using composite leaf spring.

Shiva Shankar studied the Mono Composite Leaf Spring for Light Weight Vehicle, design, end joint analysis and testing. The results showed that the composite spring has stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85 % lower when compared with steel.

Dr. Muhannad Z. Khelifaand Hayder Moasa (2008) studied the fatigue behaviors experimentally and theoretically of a composite material manufactured by stacking four layers of E-glass fiber in different angle orientations (0o, ± 45o, 0o/90o) immersed in polyester resin. They were tested under two types of dynamic loads in fully reversible tension-compression load at (R=-1) and spectrum load as fatigue testing, to estimate life curves. Finite Element Analysis was used to evaluate the composite behavior under fatigue conditions. The results of the fatigue test show that the uniaxial composite has the highest strength and the fatigue degradation is also the highest. The high magnification optical microscopy method shows that the failure of laminas at $\pm 45^o$and $0^o/ 90^o$ is due to matrix failure in the direction of the fiber, whereas for the unidirectional lamina at 0^o, the failure is due to fiber breakages. The aim of this paper is to study two kinds of fiberglass, regular direction (0-90) and random direction immersed in polyester resin. They were tested under static load, as tensile test for their mechanical properties, and under dynamic load in fully reversible bending tests as fatigue test, to estimate S-N curves, and impact test for their mechanical properties.

THEORETICAL PART

Composite material

The term composite could mean almost anything if taken at face value, since all materials are composed of dissimilar subunits if examined at close enough detail. But in modern materials engineering, the term usually refers to a "matrix" material that is reinforced with fibers. For instance, the term 'FRP" (Fiber Reinforced Plastic) usually indicates a thermosetting polyester matrix containing glass fibers. Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra-demanding applications such as spacecraft. But heterogeneous materials combining the best aspects of dissimilar constituents have been used by nature for millions of years [1].

Stiffness

The fibers may be oriented randomly within the material, but it is also possible to arrange for them to be oriented preferentially in the direction expected to have the highest stresses. Such a material is said to be anisotropic (different properties in different directions), and control of the anisotropy is an important means of optimizing the material for specific applications. At a microscopic level, the properties of these composites are determined by the orientation and distribution of the fibers, as well as by the properties of the fiber and matrix materials. The topic known as composite micromechanics is concerned with developing estimates of the overall material properties from these parameters.

Table (1) Mechanical Properties of E-glass Fibers and polyester

material	Specific Density g/cm^3	Tensile strength Mp	Modulus of Elasticity Mpa	Yield Elongation %	Rockwell Hardness M
E-glass	2.5	3450	72	4.8	70
polyester	1.25	45 – 90	25		

Table (2) Mechanical properties for composite material

Type	Yield strength	Tensile strength (Mpa)	percentage Elongation %
Regular (0-90)	220	250	18.5
random	75	75	11

Consider a typical region of material of unit dimensions, containing a volume fraction V_f of fibers all oriented in a single direction. The matrix volume fraction is then[2].

$V_m = 1-V_f$ ……………………………………(1)

This region can be idealized as shown in figure (1) by gathering all the fibers together, leaving the matrix to occupy the remaining volume this is sometimes called the "slab model". If a stress σ_1 is applied along the fiber direction, the fiber and matrix phases act in parallel to support the load. In these parallel connections the strains in each phase must be the same, so the strain ε_1 in the fiber direction can be written as:

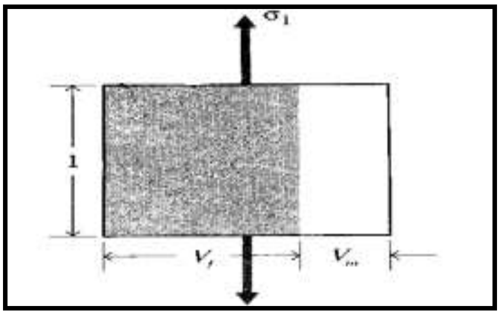

Fig. (1): Loading parallel to the fibers.

$\epsilon_f = \epsilon_m = \epsilon_1$……………………………………(2)

The forces in each phase must add to balance the total load on the material. Since the forces in each phase are the phase stresses times the area (here numerically equal to the volume fraction), we have [3].

$\sigma_1 = \sigma_f V_f + \sigma_m V_m$ ………………………….(3)

then:

$\sigma_1 = E_f \epsilon_1 V_f + E_m \epsilon_1 V_m$ ………………(4)

The stiffness in the fiber direction is found by dividing by the strain:

$E_1 = \frac{\sigma 1}{\epsilon 1} = V_f E_f + V_m E_m$ ………………….(5)

This relation is known as a rule of mixtures prediction of the overall modulus in terms of the moduli of the constituent phases and their volume fractions.

If the stress is applied in the direction transverse to the fibers as depicted in fig. (2), the slab model can be applied with the fiber and matrix materials acting in series. In this case the stress in the fiber and matrix are equal (an idealization), but the deflections add to give the overall transverse deflection [4].

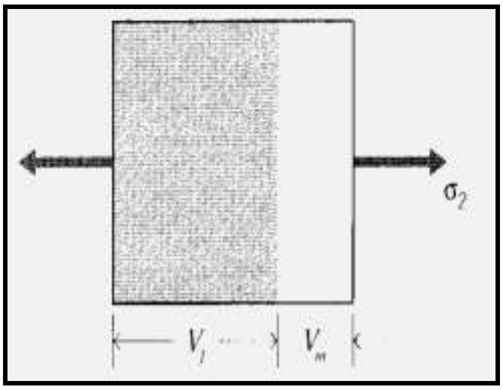

Fig. (2) Loading perpendicular to the fibers

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \quad \text{.........................(6)}$$

The prediction of transverse modulus given by the series slab model (Eq. 6) is considered unreliable, in spite of its occasional agreement with experiment. Among other deficiencies the assumption of uniform matrix strain being untenable; both analytical and experimental studies have shown substantial non uniformity in the matrix strain [10].

In more complicated composites, for instance those with fibers in more than one direction or those having particulate or other non-fibrous reinforcements, (Eq. 5) provides an upper bound to the composite modulus, while (Eq. 6) is a lower bound. Most practical cases will be somewhere between these two values, and the search for reasonable models for these intermediate cases has occupied considerable attention in the composites research community [5].

Strength

Rule of mixtures estimates for strength proceed along lines similar to those for stiffness. For instance, consider a unidirectional reinforced composite that is strained up to the value at which the fibers begin to break. Denoting this value ϵ_{fb}, the stress transmitted by the composite is given by multiplying the stiffness (Eq. 5):

$$\sigma_b = \epsilon_{fb} E_1$$

$$= V_f \, \sigma_{fb} + (1-V_f)\, \sigma \quad \text{..............................(7)}$$

The stress σ is the stress in the matrix, which is given by $\epsilon_{fb}E_m$. This relation is linear in V_f, rising from σ to the fiber breaking strength $\sigma_{fb} = E_f\, \epsilon_{fb}$. However, this relation is not realistic at low fiber concentration, since the breaking strain of the matrix ϵ_{mb} is usually substantially greater than ϵ_{fb}. If the matrix had no fibers in it, it would fail at a stress:

$$\sigma_{mb} = E_m \epsilon_{mb}.$$

If the fibers were considered to carry no load at all, having broken at $\epsilon=\epsilon_{fb}$ and leaving the matrix to carry the remaining load, the strength of the composite would fall off with fiber fraction according to $\sigma_b = (1-V_f)\sigma_{mb}$ Since the breaking strength actually observed in the composite is the greater of these two expressions, there will be a range of fiber fraction in which the composite is weakened by the addition of fibers.

EXPERIMENTAL WORK

The polyester resin type (palatal A420) with density (1.25 g/cm^3) and its hardener type (HY 956) with density (1.25) g/cm^3).

The hardener was added to the resin in ratio 1:6 and left at room temperature to solidify after 24 hour.

The fiber glass type E-glass with surface density (2.5 g/cm^3) was used for reinforcing the polyester resin. The volume fraction was 20%

Hand lay–up molding technique used to prepare two types of sheet of polyester composite reinforced with randomly and regular (0-90) direction glass fibers figure (3).

Fig. 3

Specimens Preparation

Composite sheets were prepared through a hand lay-up process. The sheets thickness and lamina orientations were controlled by performing the lay-up process in a specially made mold frame.

The frame was manufactured from Perspex plate in the workshop with dimension (200*200) mm figure (4) the plate thickness is 6mm, all the inside wall of the frame was painted with paraffin wax to prevent adhesion the material. The cover was applied to prevent any buckling occurring during the curing process. The curing process was completed in 24 hours at room temperature.

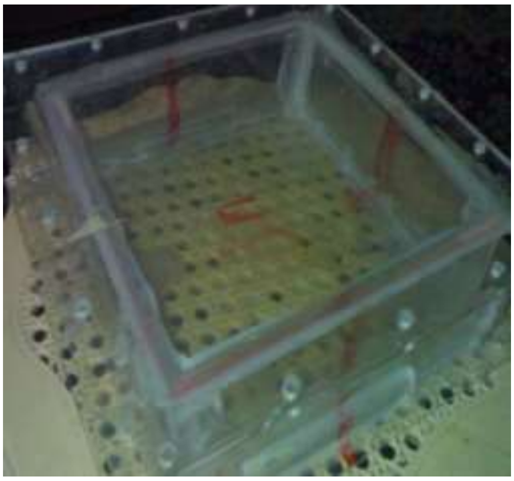

Fig. 4

The specimens of fatigue test were cut in dimension as shown in figure (5). And it's prepared in two types random and regular about twelve specimens for each type.

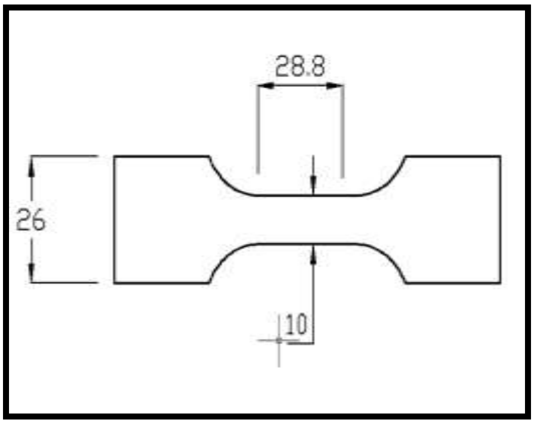

Fig. 5a Tensile test specimen

(all dimension in mm)

Fig. 5b Tensile test specimens

The tensile specimens were cut according to ASTM (3039), three specimens for each type figure (6).

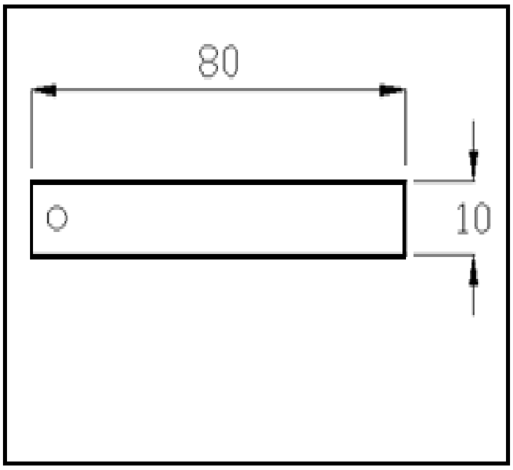

Fig. 6a Fatigue test specimen

Fig. 6b Fatigue test specimens

The impact specimens were cut according to ISO-179 three specimens for each type figure (7).

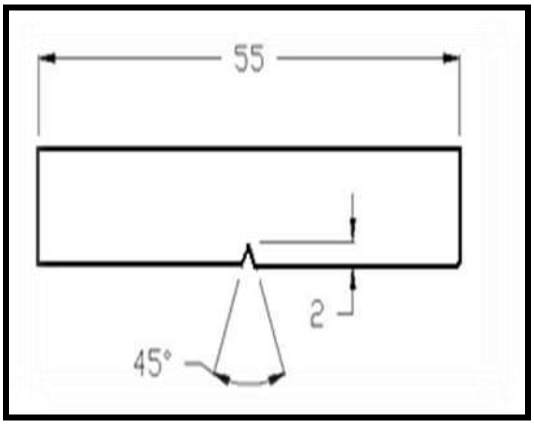

Fig. 7 impact test specimen

Fatigue Test

A fatigue testing machine type Hi-tech alternative bending figure (8) was used to execute the fatigue test. The purpose of used this device is to apply the alternative bending to one side of the specimen figure (9) that it's fixed from the other side to perform the fatigue life of the material, so it can determine the stress and the modulus for the specimens from the equations.

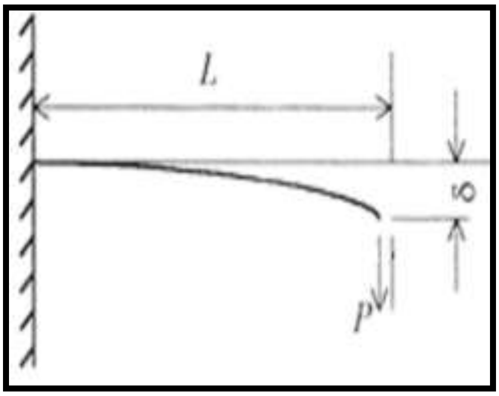

Fig. 8 Displacement Fatigue Specimens

Max. Bending moment = Pl

Max. Bending stress

$$\sigma = \frac{Pl}{Z} = \frac{6Pl}{bt^2} \quad \text{.......................... (8)}$$

Where the strip cantilever is b wide and t thick. Free end deflection

$$\delta = \frac{Pl^3}{3EI} = \frac{4Pl^3}{Ebt^3} \quad \text{......................(9)}$$

$$E = \frac{\sigma}{1.5t\delta}\ell^2 \quad \text{........................(10)}$$

Where:

δ: deflection (mm)

p: load effect (N)

b: specimen width (mm)

ℓ: specimen length

t: specimen thickness

Tensile Test

A tensile test machine type (WDW-50) was used to execute the tensile test the average value of these test of specimens was recorded and used to draw the stress-strain curve and to determine the properties of the material like tensile strength, young's modulus.

The tensile strength can be calculated using the following equation [6]:

σ =P/bd .... (10)

Where

σ: ultimate tensile strength, Mpa

P: maximum load, N

b: width, mm

d: thickness, mm

And the elastic modulus can be calculated using the following equation:

$$E = \left(\frac{P}{\Delta L}\right)\left(\frac{L}{bd}\right) \quad \text{........................ (11)}$$

Where E= modulus of elasticity, Mpa

$P/\Delta L$ = slope of plot of load as a function of deformation with linear portion of the curve.

L= gauge length of measuring specimen, mm.

Impact Test

Charpy impact test was used for three specimens. The result of the impact tests the energy needed to fracture a material and can be used to measure the toughness of the material and the yield strength from these equations.

Ef = mg (H-h) ....(12)

$$To = \frac{E_f}{A} \quad \text{..............................(13)}$$

Where

To : toughness of the material

Ef : impact energy

A: cross sectional area

m= mass (kg)

g= acceleration

H= height from the specimen before impact

h= height after impact

RESULTS AND DISCUSSION

Tensile Test Results

Tensile tests were carried out under the test standard method ASTM 3039 [2], to estimate material modulus (E), material strength in fiber direction (σ)

Two types of specimens are used in the tensile tests; first tests were done for specimens with fiber direction (0-90). The load was applied and then increased gradually till the failure of the specimens. The relationships between the stress and strain for the specimens are illustrated in figure (9).

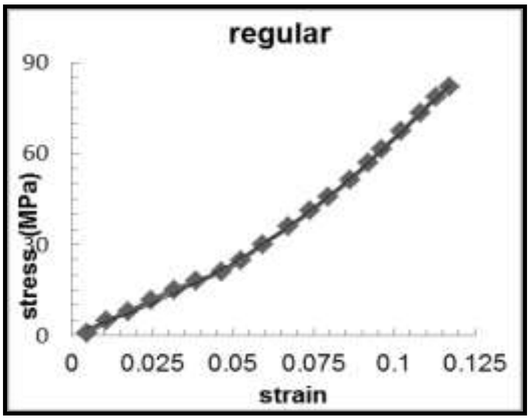

Fig. 9 stress-strain curve for regular direction

The second tests are done on specimens with fiber direction random. The relations between the stress and strain for the specimens are shown in Figure (10). The magnitude of the tensile strength (σ) and elastic modulus (E) for both tests are calculated using equation (10) and (11).

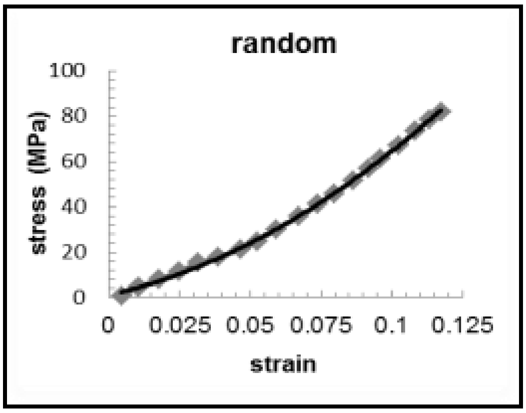

Fig. 10 stress-strain curve for random direction

Results showed that the tensile strength of the regular type is greater than random type, see figure (11).

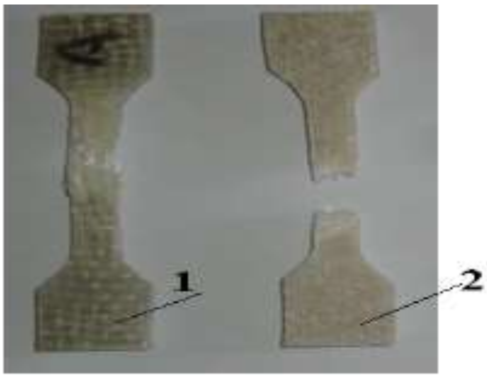

Fig. 11 1: regular type 2: random type

Fatigue Test Results

The results of S-N curves for all types are in tables (3) and (4) and plotted in figures (12) and (13). The constant amplitude fatigue data are summarized in S-N diagrams based upon power laws. The formats of regression trends are typical for fatigue data presentation, [7].

Table 3. expiremental data for regular type (0-90)

P (N)	δ mm	Stress(MPa)	N (Cycle)	E GPa
1	9	75	6876098	44.4
2	12	150	3327367	66.6
2.5	12.5	187.5	2501167	80
3.5	12.75	262.5	2112389	109.8
4	13	300	1893156	123
4.5	13.5	356.5	1523622	140.8
5.5	13.75	412.5	1121325	160.1
6	14	450	990875	177.6

Table 4. Experimental data for random type

P (N)	δ mm	Stress (MPa)	N (Cycle)	E GPa
3	4	276.5	1000	78.5
3.5	4.5	215	3320	81.5
4	5	165.4	13920	83.9
5	5.5	152.2	20987	94.4
6	6	123	33980	94.12
7	9	112	40224	81.5
9	11	108	50521	85.8

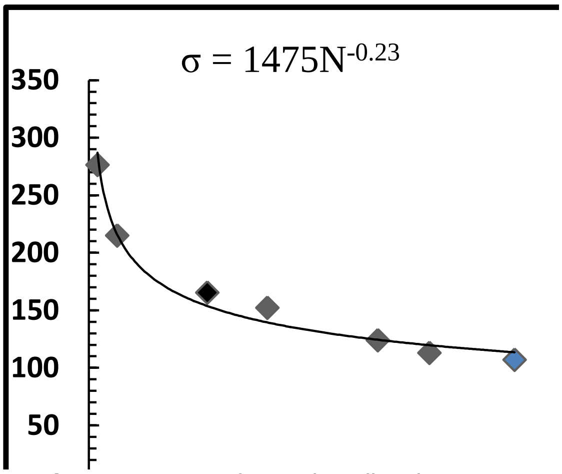

Fig. 12 S-N curve for random direction

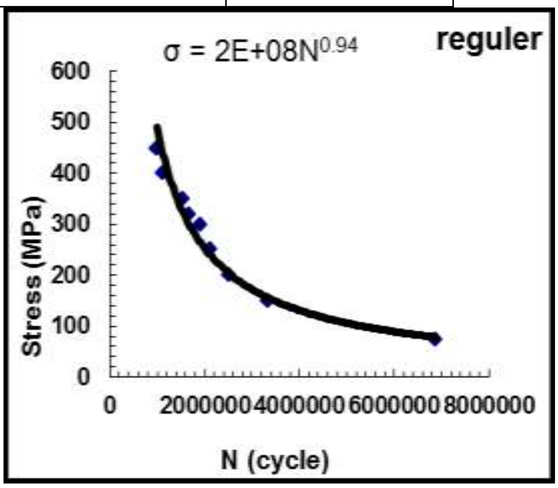

Fig. 13 S-N curve for regular direction

The power law regression equation is:
σ = a N b ……………..……………..(14)
Where:
σ: stress MPa
N: is the number of cycles at failure (cycle)
a: is related to the static bending strength.

The constants (b) and is related to the fatigue degradation.

Fatigue-life diagram is often used to interpret the fatigue failures in tensile fatigue of composites [8].

The results in tables (2) and (3) showed that the number of cycle to failure in regular type of composite material is greater than the value of the random type and the endurance limit is also greater in regular type that is because the direction of the fiber glass is effect to give the material more elasticity The increase percentage in endurance limit is 7.5% .

Impact Test Results

Experimental results from the impact test device, (see figure 14), showed that there is on increasing in fracture energy for the random type of composite material that is because the fiber glass which make as an impediments to fracture, and because of the toughness of the random type which increases compared with the regular type and when the toughness increase that meaning increase in energy spent to fracture, Table (5) showed the result of impact test which shows that the increase ratio is 13.9% in the random type.

Fig. 14 impact test device

Table 5. impact test data

Type	Impact Energy J
0-90	3.5
Random	13

CONCLUSIONS

1- For the purpose of using the composite material used in this paper for statically load; it is suitable to use the regular direction type (0-90), because over a higher resistance to use tension compared with random type.
2- If it is required to use this composite material for dynamic loading, also the regular construction according to experimental test was better than the random, due to larger endurance limit and more life compared with random.
3- Due to impact test, results showed that for the purpose of using this composite material to resist the impact load it is suitable to use the random construction
4- Due to the above conclusions, it is desired to use the regular construction of composite material in this paper as leaf springs in light truck vehicles because the long life of this type and it is better ability of dynamic loading.

REFERENCES

1- Springer G S & Kollár L P, "Mechanics of Composite Structures", (Cambridge university press, New York) 2003.
2- Hull, D. and Clyue, T.W. “An Introduction to Composite Materials” 2nd edition Cambridge solid-state science ,series, 1996.
3- Jones, R.M., “Mechanics of Composite Materials”, McGraw-Hill, New York, 1999.
4- Valery V. Vasiliev & Evgeny V. Morozov., " Mechanics and Analysis of Composite Materials",First edition 2001.
5- Roylance, D., “Mechanics of Materials”, Wiley & Sons, New York, 1996.
6- ASTM D3039 _ Standard Method for Tensile Properties of Fiber-Resin Composites _. 2004
7- Groover, M. P., “Fundamentals of Modern Manufacturing”, 2nd Edition. John Wiley & Sons Inc, 2002.

8- Rita R., and BOSE N. R., " Behavior of E-glass fiber reinforced vinylester resin composites under fatigue Condition", Bull. Mater. Sci., Vol. 24, 2001.

9- M.S. Kumar, and S. Vijayarangan, "Static analysis and fatigue life prediction of steel and composite leaf spring for light passenger vehicles" Journal of Scientific & Industrial Research Vol. 66, February 2007.

10- S.Vijayarangan and I. Rajendran “Optimal Design of a Composite Leaf Spring Using Genetic Algorithm” Computers and structures, 79(2001).

11- S.K. Mazumdar, Composites Manufacturing: Materials, Product, and Process Engineering, CRC Press, 2002.