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EFFECT OF FIBER ORIENTATION ON FATIGUE OF GLASS-FIBER REINFORCEMENT EPOXY COMPOSITE MATERIAL

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ABSTRACT

In this research, the main objectives of this investigation as, first, study the effect of fibers orientation on fatigue strength for composite materials, second, study the effect of fiber orientation on shape and direction of fracture surface for composite materials. The experimental work using to study fatigue limit for composite material with different fiber orientation as (0^0, 30^o, 45^0, 60^o, 90^o) and study of the fatigue surface (shape and direction of fatigue surface of composite material) for each fiber orientation fiber.

The material using for composite material in this research are epoxy resin matrix and glass reinforcement fiber with volume fracture of fiber in composite material about (0.21). The results are endurance fatigue strength with number of cycle for fiber orientation (0^0, 30^o, 45^0, 60^o, 90^o) and the shape and direction of surface fatigue of composite material.

الخلاصة

في هذا البحث تمت دراسة تأثير، أولا: زاوية الألياف على مقاومة الكلل للمادة المركبة، ثانيا: دراسة تأثير زاوية الألياف على شكل الكسر الناتج وعلى اتجاه مساحة الكسر للمادة المركبة. تضمنت الدراسة العملية دراسة تأثير زاوية الألياف (0^o، 30^o، 45^o، 60^o، 90^o) على إجهاد الكلل وشكل واتجاه مساحة الكسر.

المادة المركبة التي تمت دراستها مكونة من مزيج مادة الايبوكسي (كمادة رابطة) والياف الزجاج (كمادة تقوية). النتائج التي تم الحصول عليها هي مقاومة الكلل للمادة المركبة وعدد الدورات التي تسبب الكسر وشكل الكسر وزاوية الكسر للمادة المركبة لعدة زوايا لالياف التقوية (0^o، 30^o، 45^o، 60^o، 90^o).

INTRODUCTION

Fatigue damage in composite materials is very complex, due to several damage mechanisms occurring at many locations throughout a laminate. Damage is observed in a series of mechanisms, such as matrix cracking, fiber fracture, longitudinal cracking, crack coupling, and delaminating growth. As a result of this damage, composite components generally do not fail due to a single, large macro-crack, **Daniel B. Miracle (2001).**

Fatigue failures can and often do occur under loading conditions where the fluctuating stress is below the tensile strength and, in some materials, even below the elastic limit. Because of its importance, the subject has been extensively researched over the last one hundred years but even today one still occasionally hears of a disaster in which fatigue is a prime contributing factor, **E. J. Hearn (1997)**.

The difference between the thermal expansions coefficient of the matrix and fiber materials must be minimized. This is not always possible. Flex able fiber coatings save used to reducing the differences in thermal expansion coefficient between the matrix and fibers. But this step adds considerably cost to the composite materials.

Fatigue mechanisms in composite materials specimens are considerably different when comparable with metallic materials specimens. The fatigue mechanisms in composite materials consist of the, ply-cracking, delaminating, and ultimately fiber fatigue.

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EXPERIMENTAL WORK

In this search we study fatigue behavior for composite material and effect of the direction for the fiber on the fatigue stress and the behavior of fracture of composite material. The process of manufacturing composite samples depends on the components of the composite material. These components are matrix and fibers,

1. ***The matrix***, The resin type used in this work is Epoxy resin (Quickmast 105) which is manufactured by (Ayla Construction Chemicals Under Licence From DCP ,England). The (Quickmast 105) is a low viscosity component epoxy resin system with formulated amine hardener .This type of epoxy has the following properties, **Valery V. Vasiliev (2007)**, tabulated in **Table 1**,

- (Mixing volume ratio (A/B) : 1.31/0.39, A= Epoxy resin , B = The hardener)

Table 1. Properties of matrix materials.

Compressive Strength	> 72 N/mm2 at 7days@ $20°$
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Flexural Strength	> 25 N/mm2
Pot life	85 minutes at $20° C$
Specific gravity	1.04
Viscosity	1.0 poise at $35° C$
Min. application Temperature	$5° C$

This type of resin has the ability to undergo a quick transformation from the liquid state to hard solid at room temperature and this process is much faster at a high temperature and is called (curing process).

2. ***The fiber glass***, The type of fibers used is (E-glass) with the commercial name of (Vela Glass 875U) .This type of fibers is dry, unidirectional glass fiber . For most applications Vela Glass 875U is a proven cost effective alternative to traditional strengthening techniques .The general properties of this glass fiber are, **Valery V. Vasiliev (2007)**, tabulated in **Table 2**,

Table 2. Properties of reinforcement Fiber materials.

Color	white
Primary Fiber Direction	0^{o} (unidirectional)
Density (Kg/m3)	2285
Tensile Strength (N/mm2)	1350
Modulus of Elasticity (GPa):	60

After measuring its Length (L) to get the fiber volume according to the relations:

$$V = \frac{m}{\rho} \tag{1}$$

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Preparation of Samples

For the work of test samples were manufactured five glass forms as shown in **Fig. 1**. The objective of this method is to get a careful organization of the fiber and the required angles, which is (0^o, 30^o, 45^o, 60^o, 90^o). The mixing of resin –fiber using are about 0.21 (volume fraction of fiber 0.21) for all sample of test using in the fatigue test shown below.

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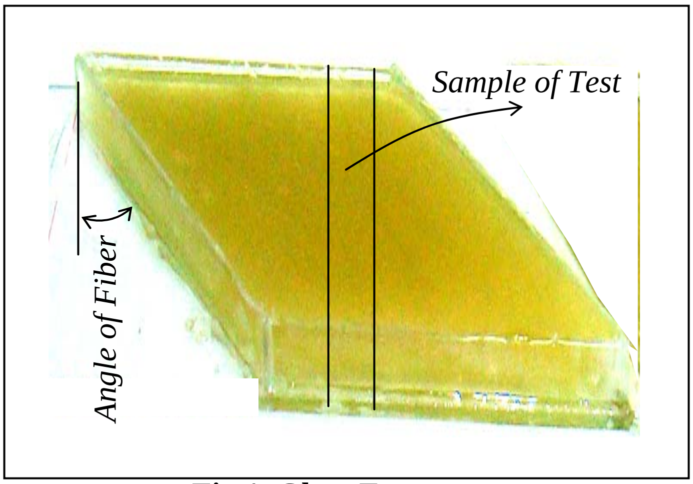


Fig.1. Glass Forms

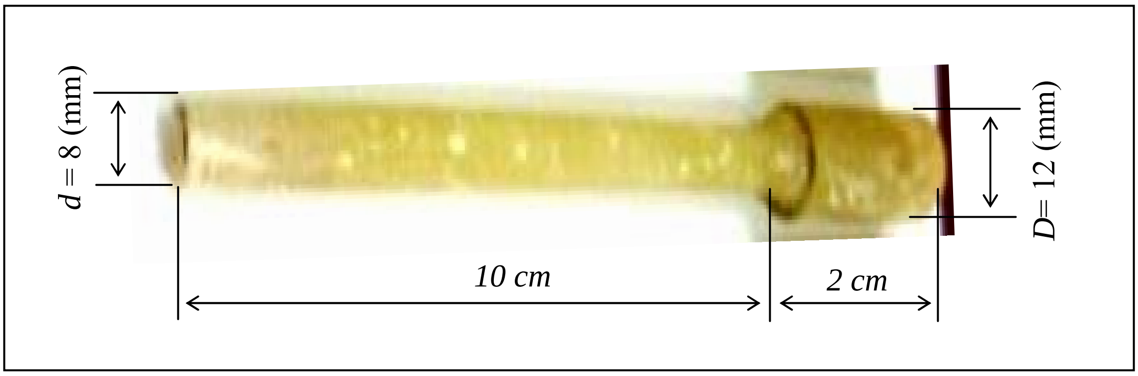


Fig.2. Dimension of Simple of Test.

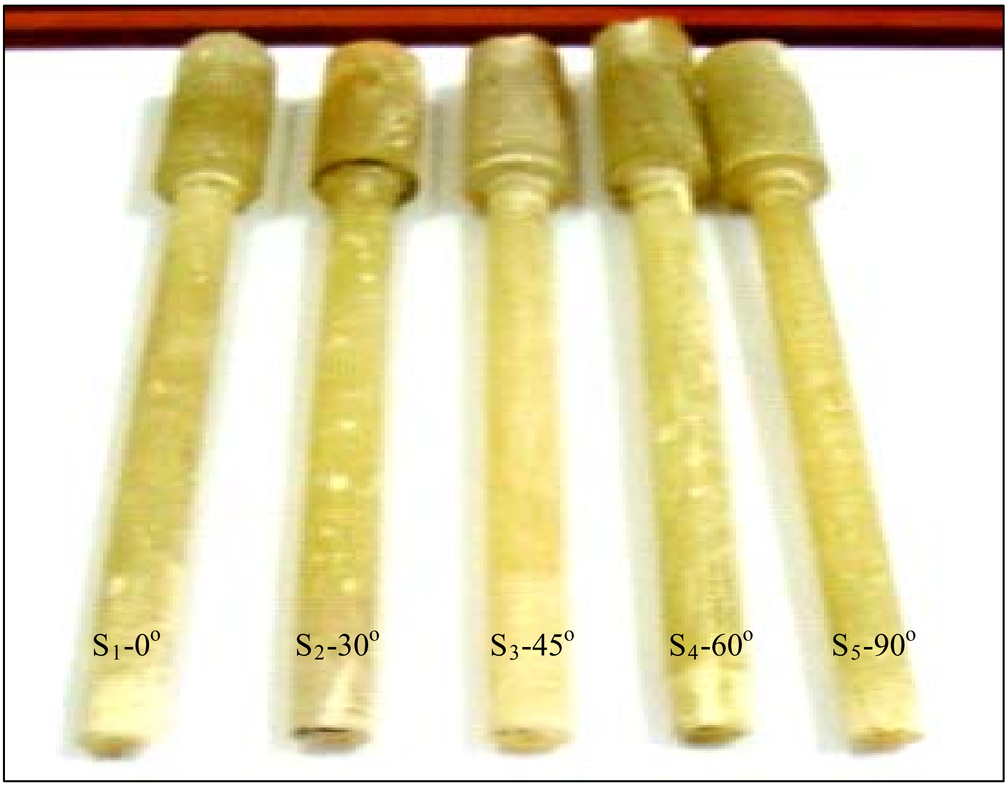
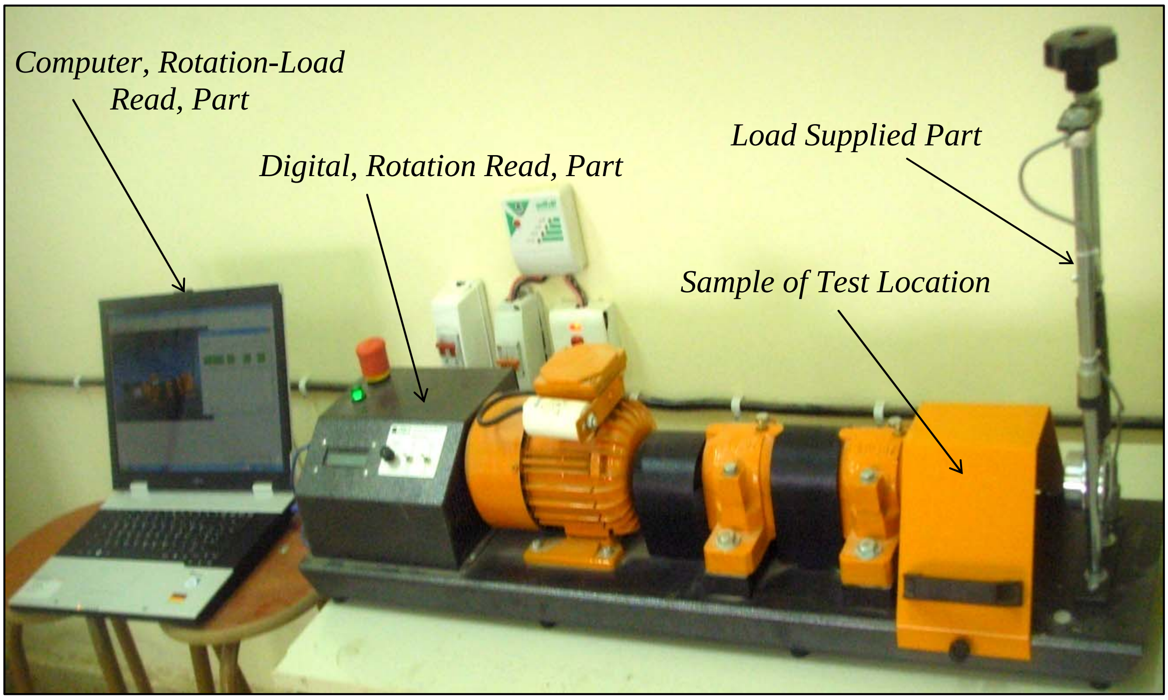


Fig.3. Test Samples.



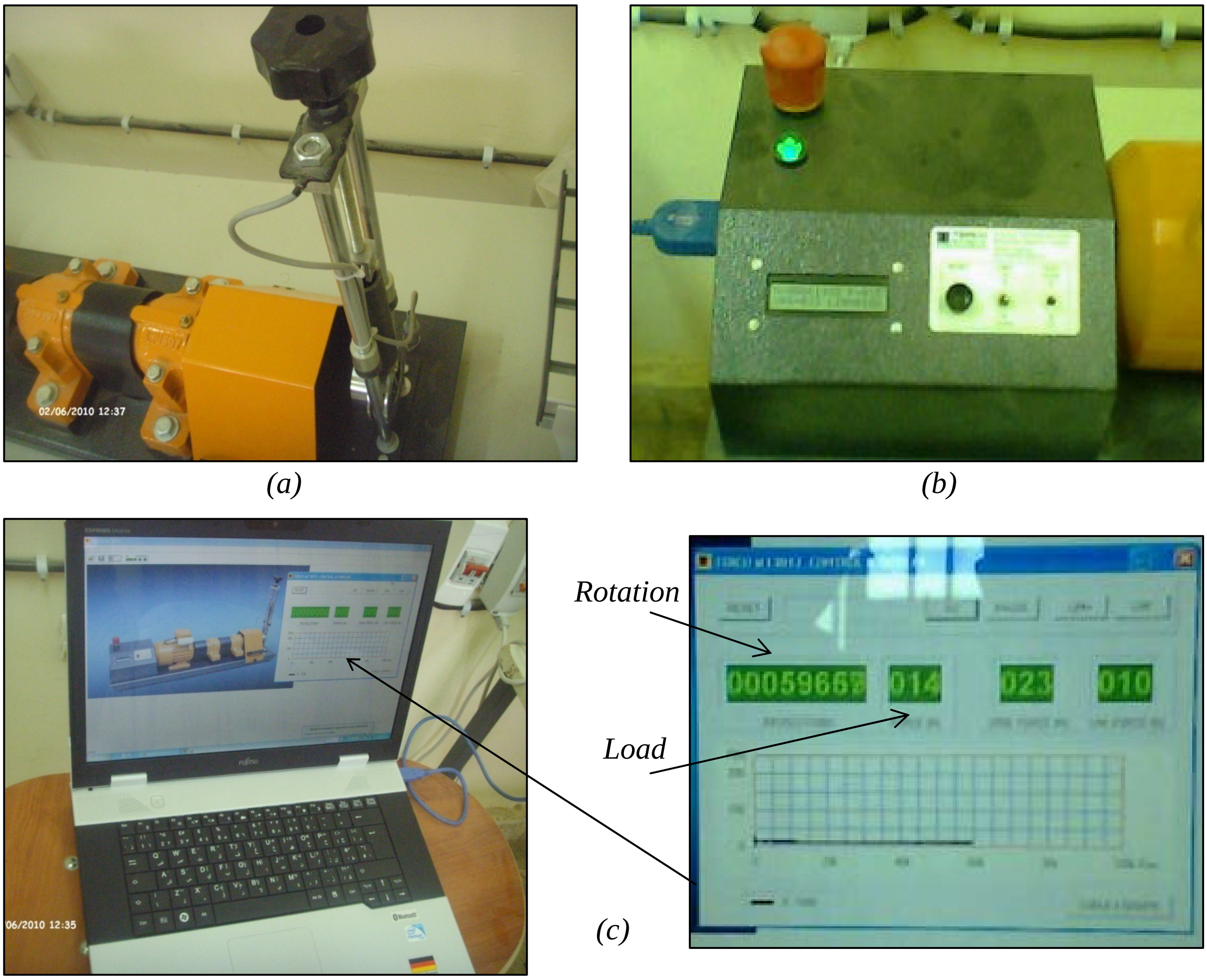


Fig.5. Parts of fatigue Test Machine, (a) load part machine, (b) digital part machine, (c) computer part machine.

Test of Samples

Has been shed loads specimens according to the following, **Tables 3 and 4**. and **Figs. 6 to 13.**, **Figs. 14 to 19**. shown the samples of fatigue after the test (fatigue shape).

Table 3. Fatigue Stress and Number of Cycle with various fiber orientation angle.

Fiber Orientation (deg)	*Endurance Fatigue Stress (Mpa)*	*Number of Cycle Fatigue Stress*
0^o	95.7405	35935
30^o	39.62763	27067
45^o	33.52418	20824
60^o	28.44629	15056
90^o	23.68721	10508

Table 4. Fatigue Stress (Mpa), for Different Fiber Orientation Angle (deg).

Fiber Orientation (deg)				
0^o	**30^o**	**45^o**	**60^o**	**90^o**

Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)
40000	95.7291	35107	38.48812	30081	32.78317	30407	28.30827	30246	23.12245
35935	95.7405	33025	38.98041	25045	32.63669	25288	28.35936	25208	23.21693
33008	96.36609	30563	39.61357	20824	33.52418	20742	28.34446	20903	23.32372
30000	98.22766	27067	39.62763	17491	34.94178	15056	28.44629	15058	23.47127
25040	101.8474	25040	40.2914	15056	36.20798	12052	28.55785	10508	23.68721
20198	106.3256	22010	41.41578	12264	38.01507	10264	28.75434	7012	24.39942
17538	109.375	20084	42.23309	10259	39.66109	8071	29.14297	5002	25.01052
15012	112.8347	17023	43.75	8906	41.01563	6086	29.62091	3113	25.89442
12591	116.879	15049	44.916	5069	46.88867	4088	30.01246	1328	27.5625
10357	121.5408	10016	48.99292	3197	52.31193	1054	31.23377	1086	28.13994
7615	129.2614	6074	54.51153	1775	60.15625	/	/	/	/
5001	140.6156	4665	57.67045	1169	68.93698	/	/	/	/
2570	160.6674	2055	68.69555	/	/	/	/	/	/

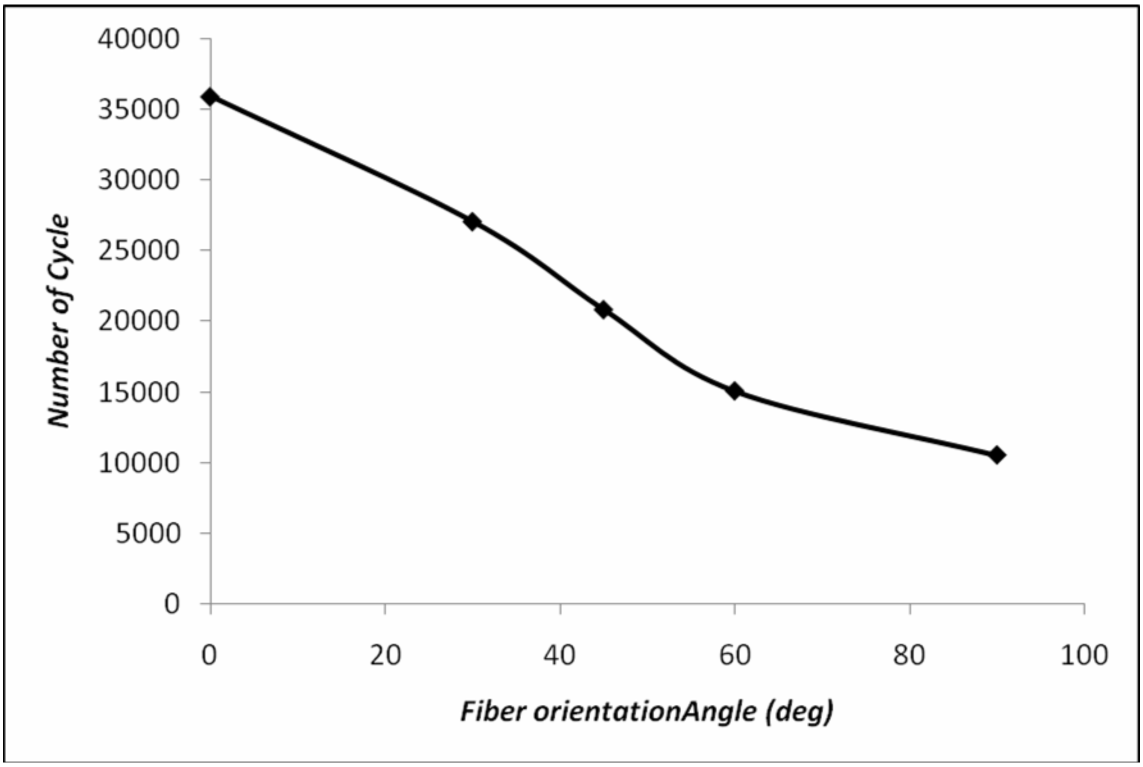


Fig.6. Number of Fatigue Cycle with Various Fiber Orientation Angle.

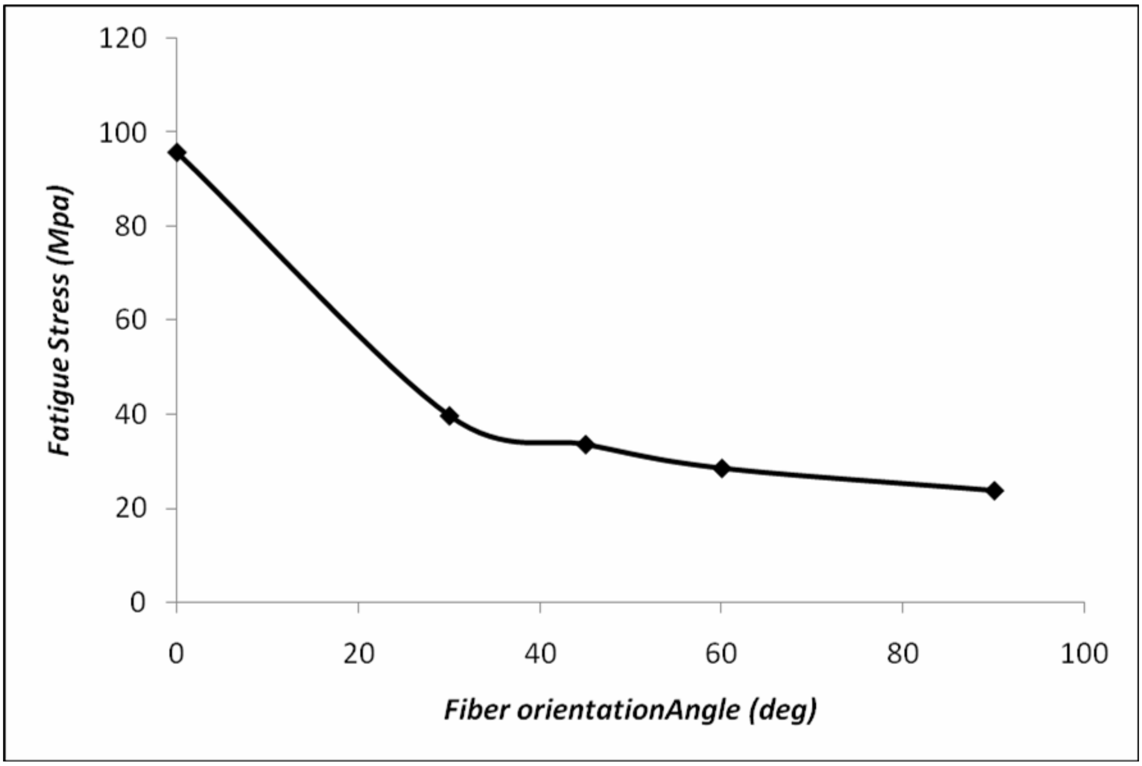


Fig.7. Endurance Fatigue Stress with Various Fiber Orientation Angle.

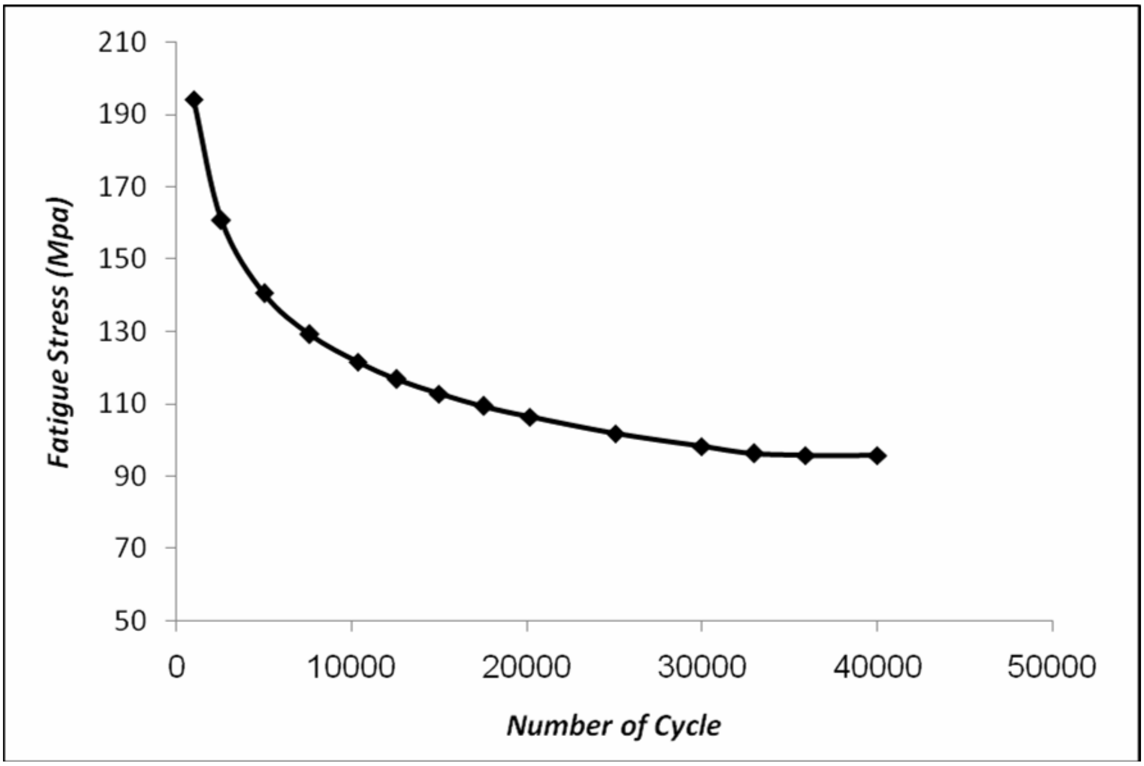


Fig.8. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (0^o).

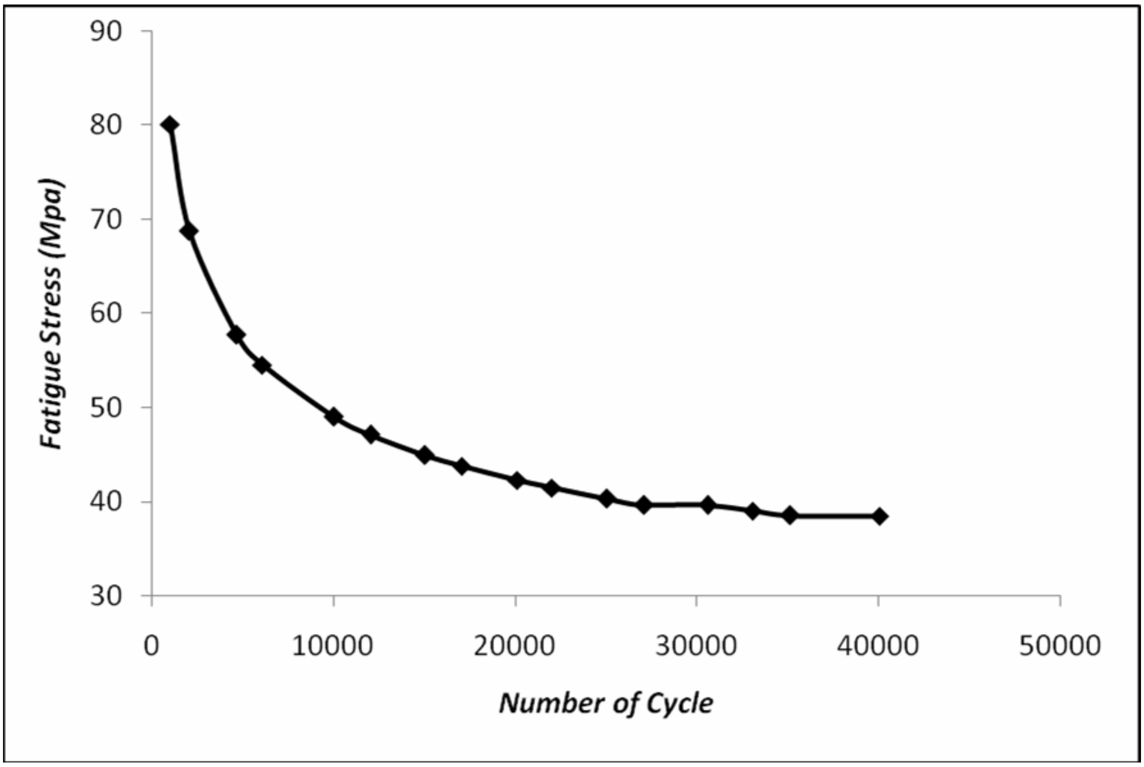


Fig.9. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (30^o).

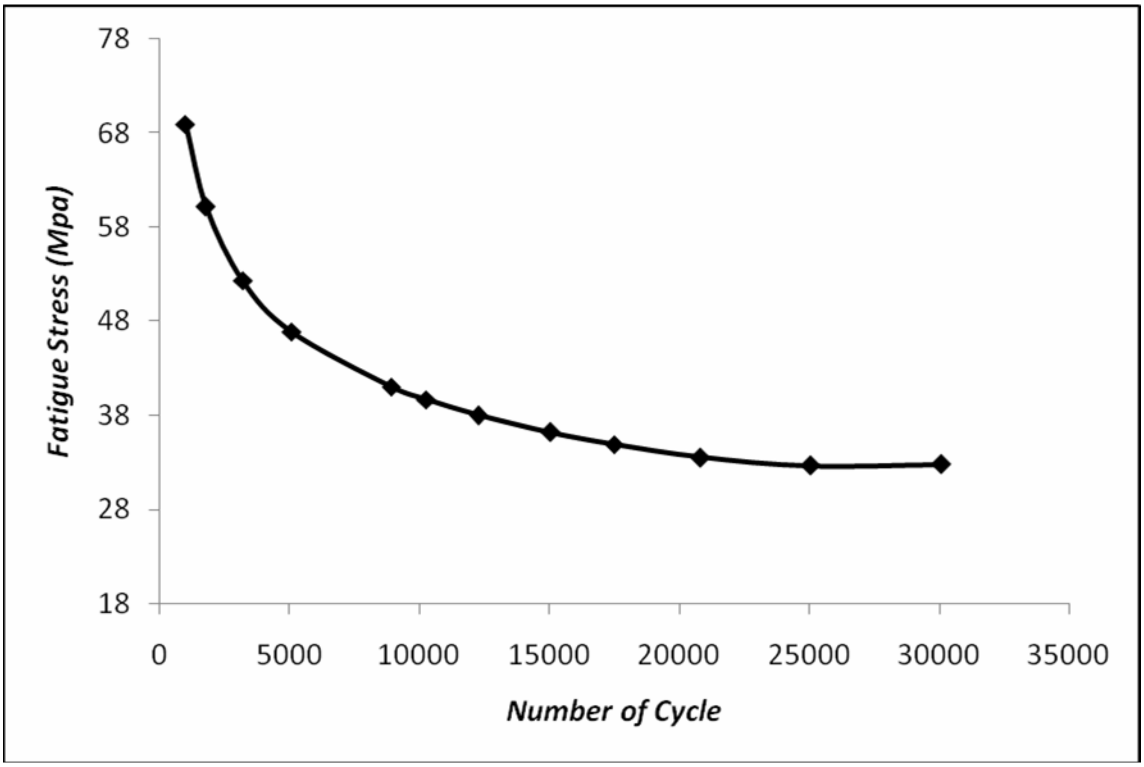


Fig.10. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (45^o).

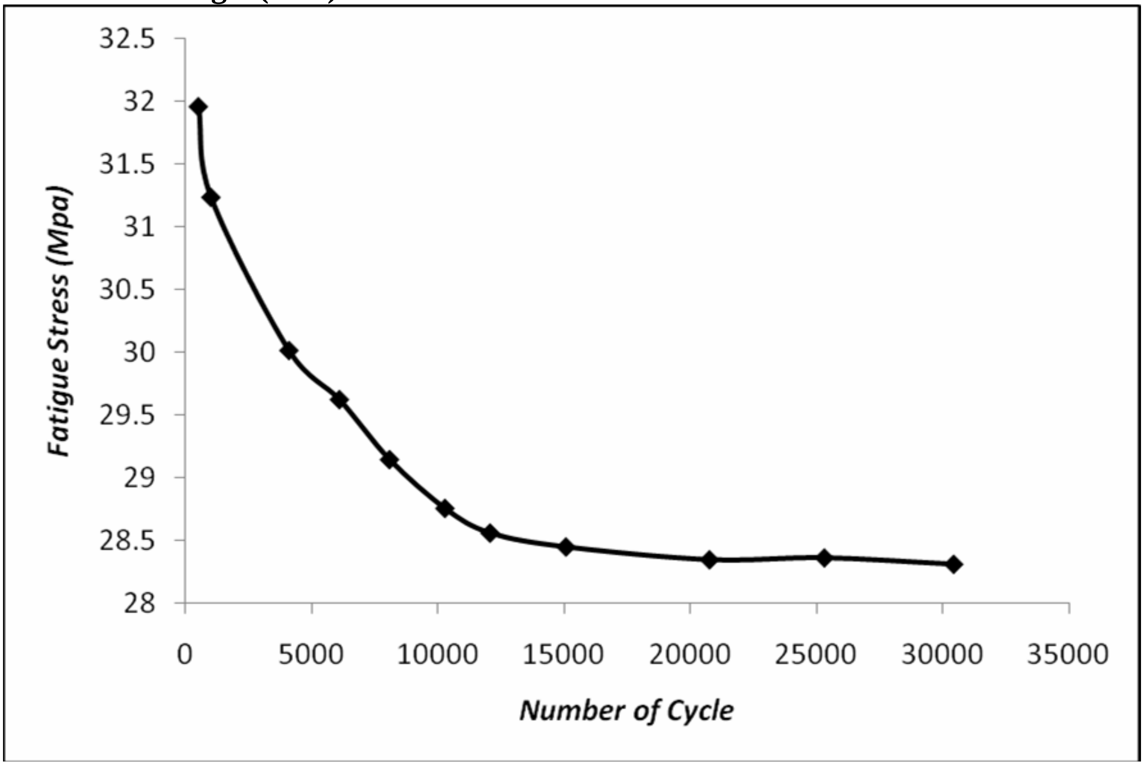


Fig.11. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (60^o).

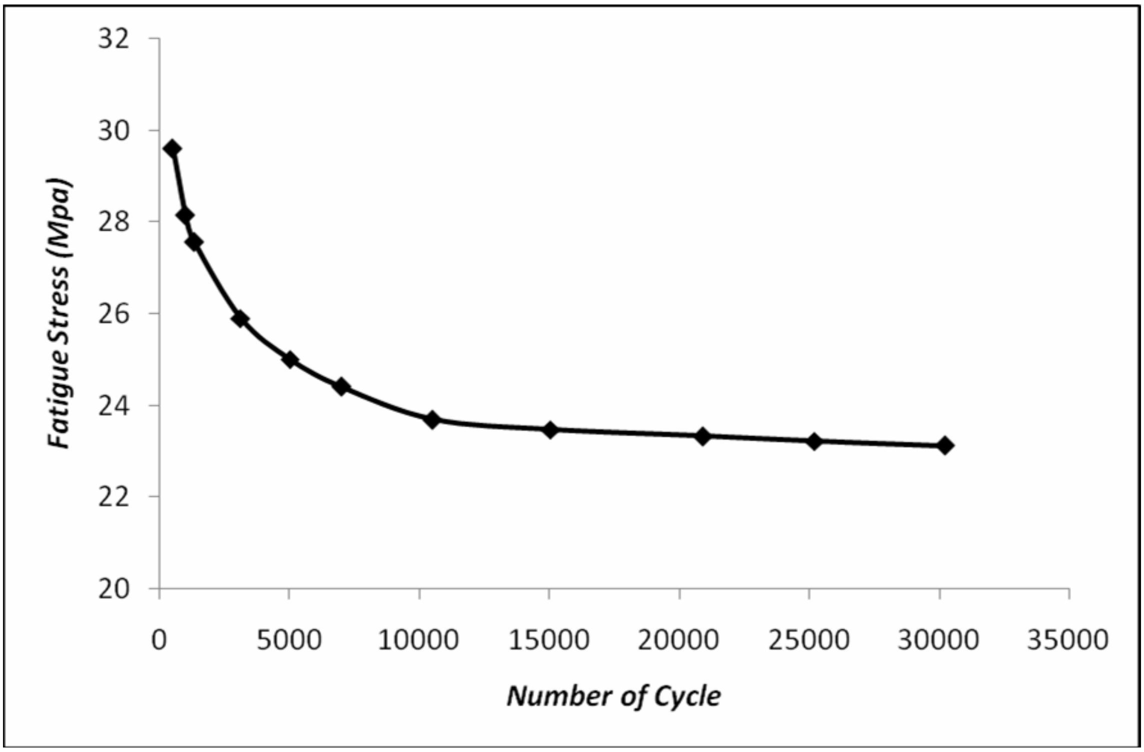


Fig.12. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (90^o).

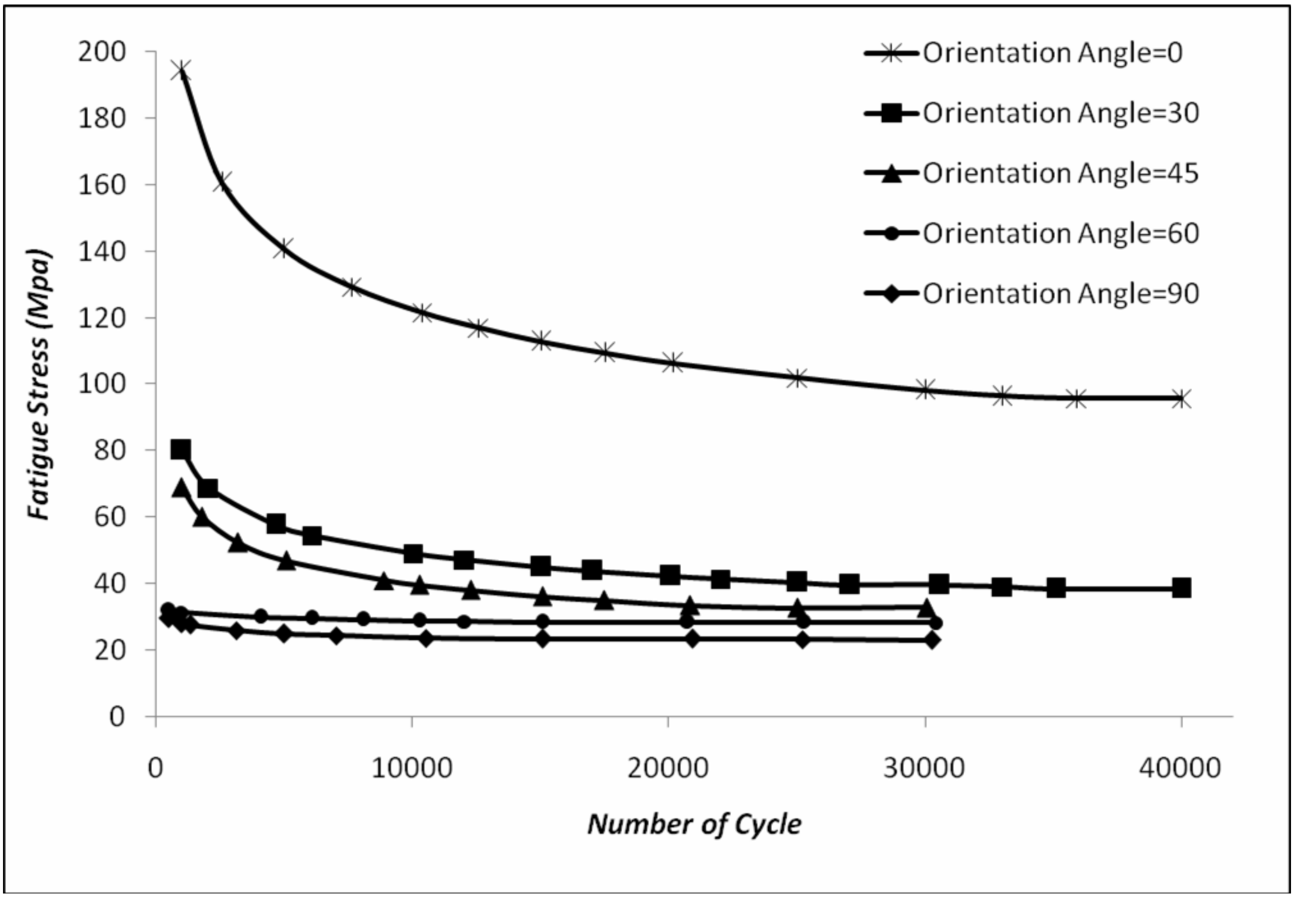
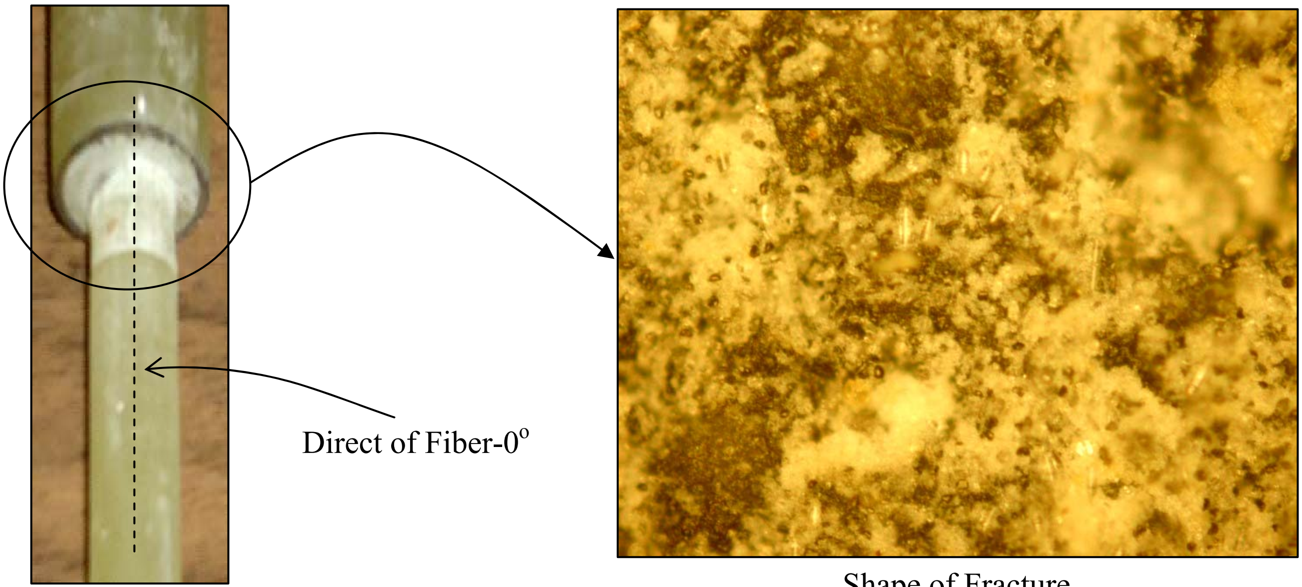


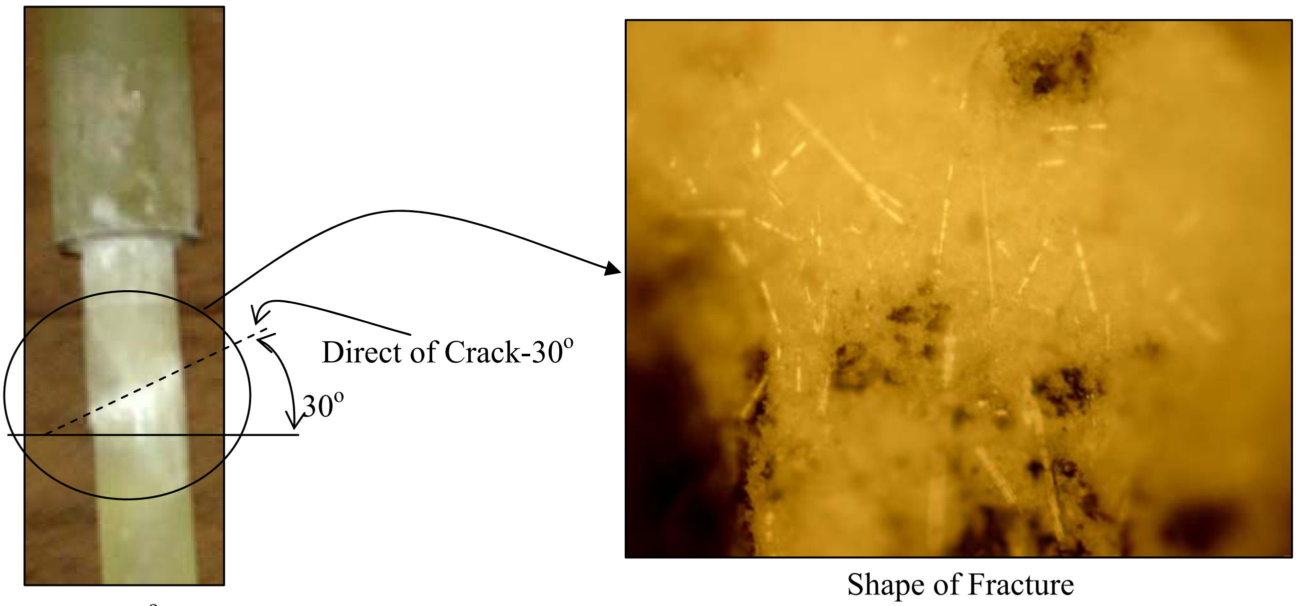
Fig.13. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Various Fiber Orientation Angle.

Fig. 14 . fatigue shape of samples with Various Fiber Orientation Angle (Sample After Testing).



$\theta = 0^o$ Shape of Fracture

Fig.15. Optical Micrograph of Sample at angle (0^o).



Shape of Fracture

$\theta = 30^o$

Fig.16. Optical Micrograph of Sample at angle (30^o).

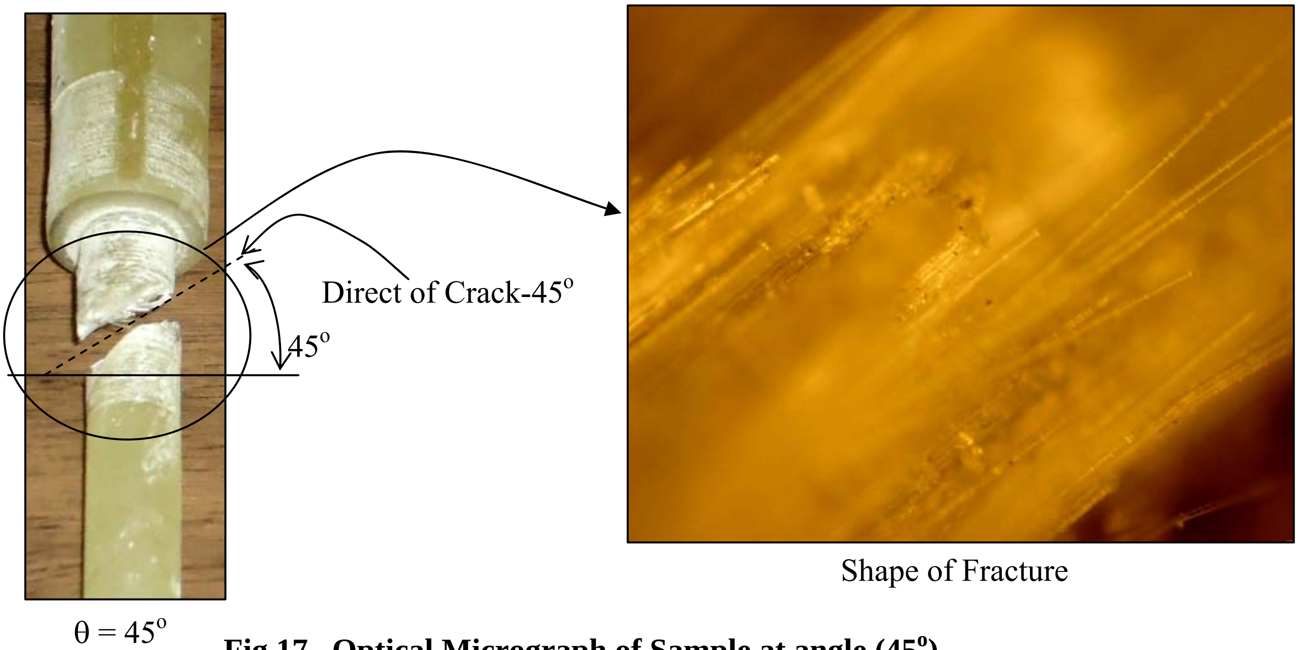


Fig.17. Optical Micrograph of Sample at angle (45°)

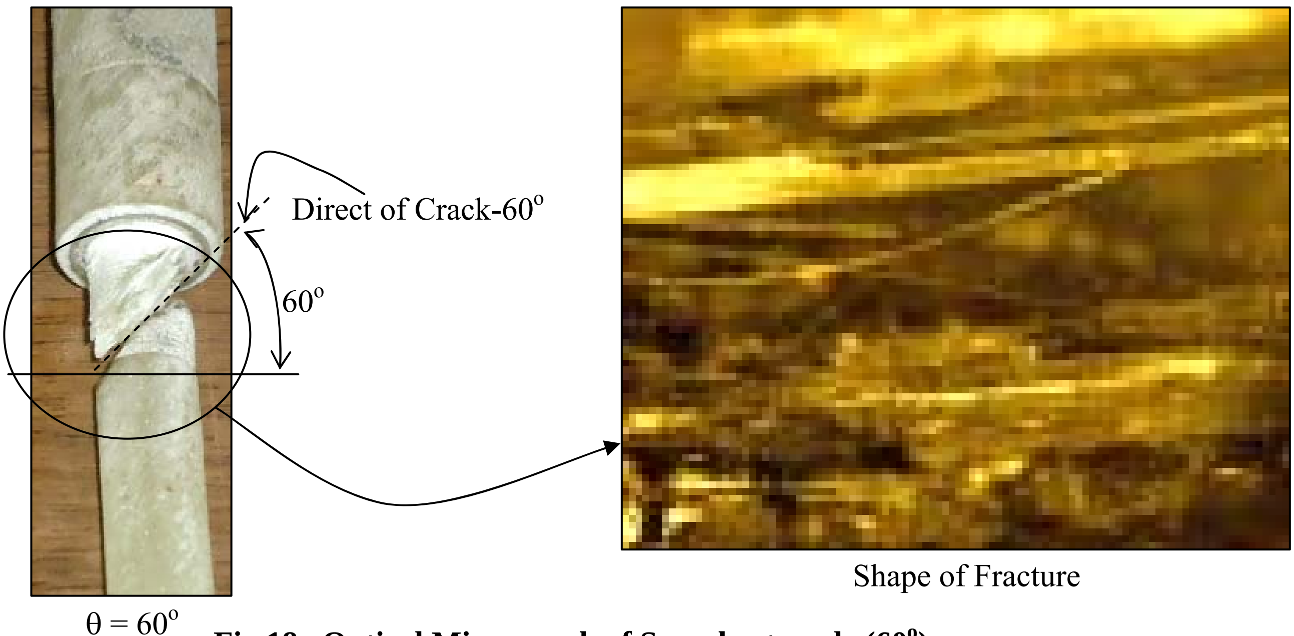


Fig.18. Optical Micrograph of Sample at angle (60°).

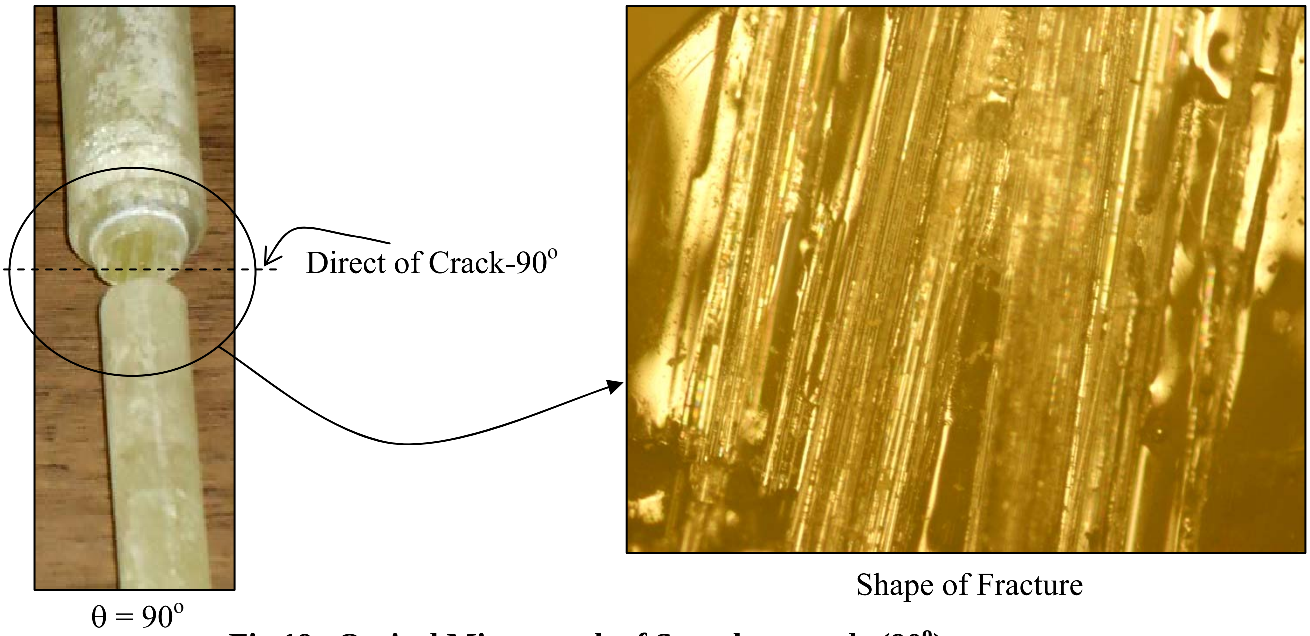


Fig.19. Optical Micrograph of Sample at angle (90^o).

RESULTS AND DISCUSSION

The composite for the experiment were subjected to forces to the point of fracture and examined the strength fatigue as shown in **Figs. 6 to 13**. And **Tables 3 and 4**. and microscopically as shown in **Figs. 14 to 19**.

Tables 3 and 4, and **Figs. 7 to 13**. Shows the relation between the strength fatigue and number of cycles for various fiber orientation angle (0^0, 30^o, 45^o, 60^o, 90^o) of composite materials. From tables and figures shows that the fatigue strength of composite material decreasing with increasing the fiber orientation angle due to decreasing module of elasticity (strength) of composite materials.

Table 3 and **Fig. 6** . shown cycle number of fatigue with various fiber orientation angle (0^0, 30^o, 45^o, 60^o, 90^o) of composite materials. From table and figure shows that the number of fatigue cycle decreasing with increasing the fiber orientation angle, maximum at fiber angle (0^o) and minimum at fiber angle (90^o).

The micro-structural changes that result from fatigue damage can be shown in the **Figs. 14 to 19**. for various fiber orientation angle (0^0, 30^o, 45^o, 60^o, 90^o) of composite materials. Figures shows that the fracture surface of composite materials oblique (fatigue surface parallel to fiber direction) with the fiber orientation angle for fiber orientation angle (30^o, 45^o, 60^o,90^o) as in **Figs. 16 to 19**, for non-unidirectional fiber or load applied oblique on the fiber direction, becomes, the poor plane is parallel on fiber direction since the strength of composite material in fiber direction (perpendicular plane of fiber direction) greater than strength in perpendicular on fiber direction (parallel plane of fiber direction).

Fig. 15 . shown the fracture and micro-structural of unidirectional fiber, load supplied parallel to fiber direction. From figure shown that the fatigue surface perpendicular on the fiber direction, fatigue surface perpendicular to fiber direction, due to no load on the parallel plane to fiber direction.

CONCLUSIONS

1. The magnitude of fatigue strength and number of cycle of fatigue for composite material using in this research are found to lie between (95.7405 and 23.68721 *MPa*) and (35935 and 10508 *cycle*), respectively, for different orientation states of fibers.
2. The magnitude of fatigue strength and number of cycle of fatigue for composite material are decreasing with increasing fiber orientation angle, increasing with increasing the strength of composite material and decreasing with decreasing the strength of composite materials.
3. For oblique load on fiber direction, the surface fatigue of composite materials parallel of fiber direction and for unidirectional fiber, surface fatigue perpendicular on fiber direction.

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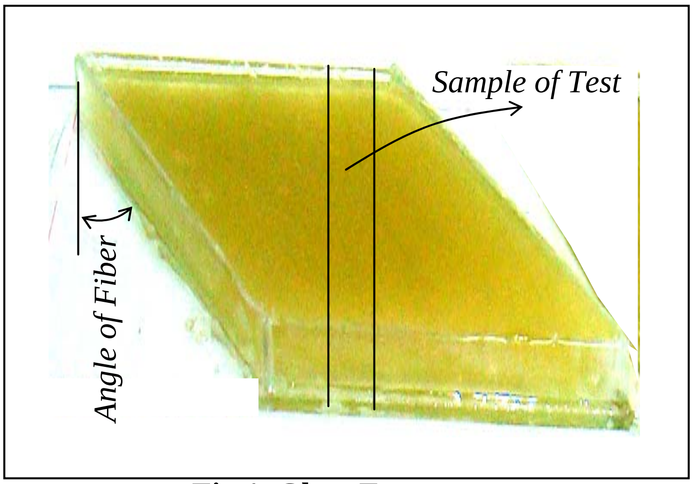

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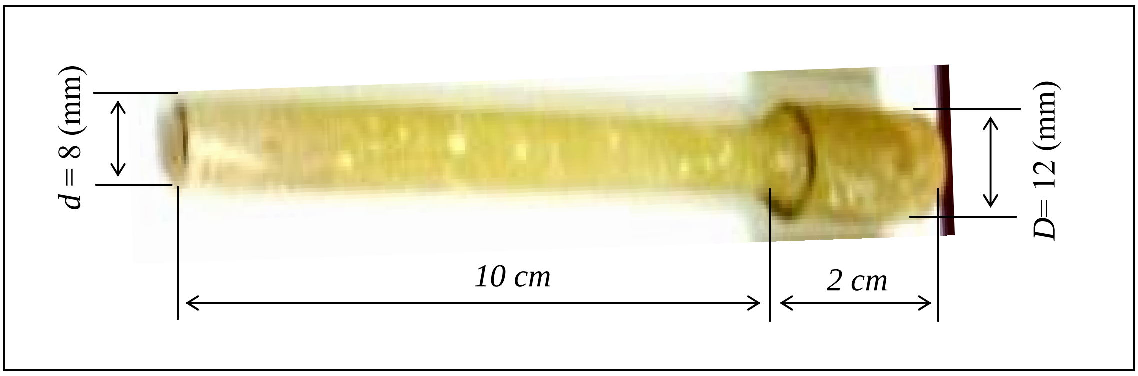


Fig.2. Dimension of Simple of Test.

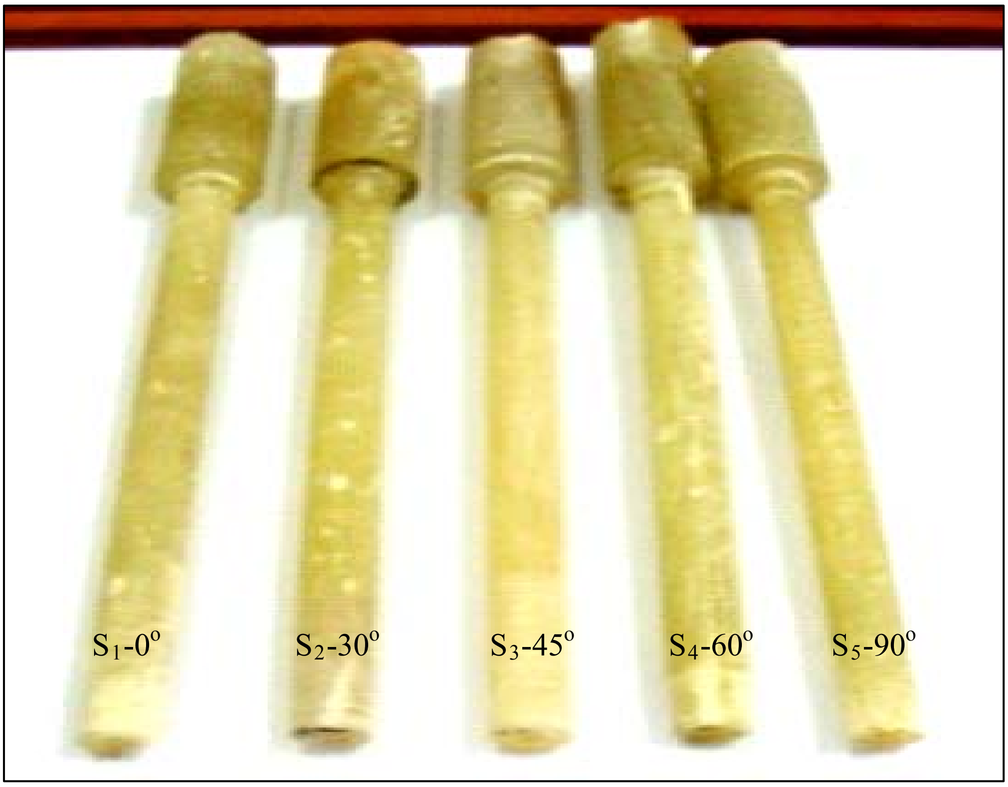
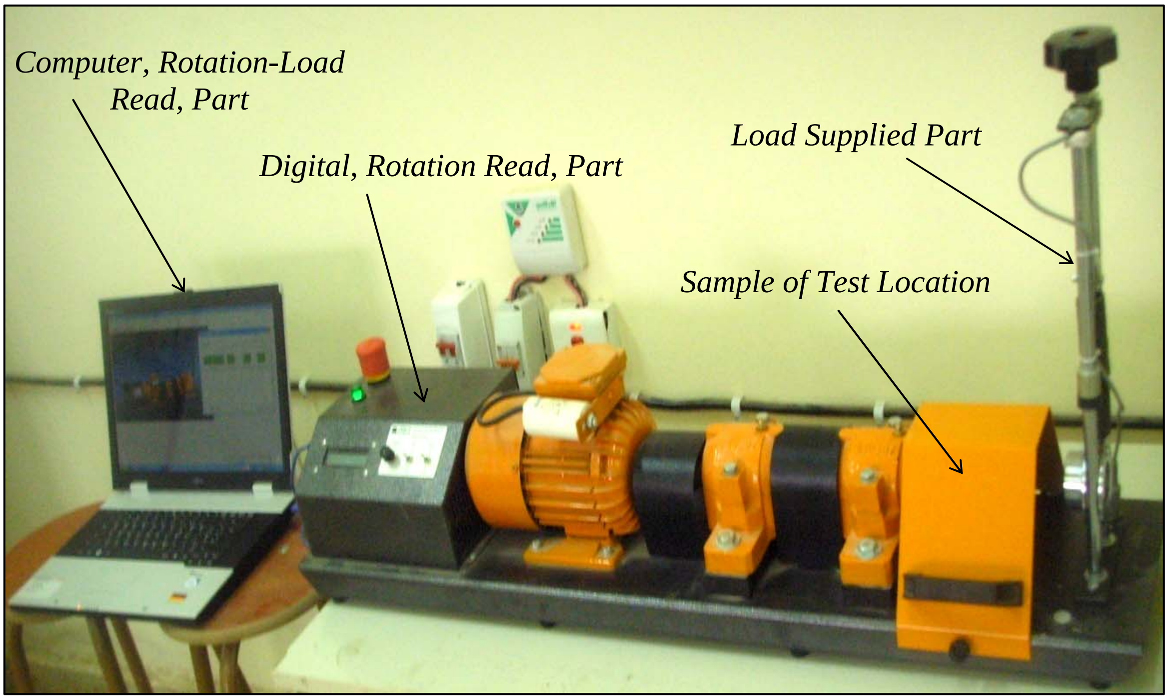


Fig.3. Test Samples.



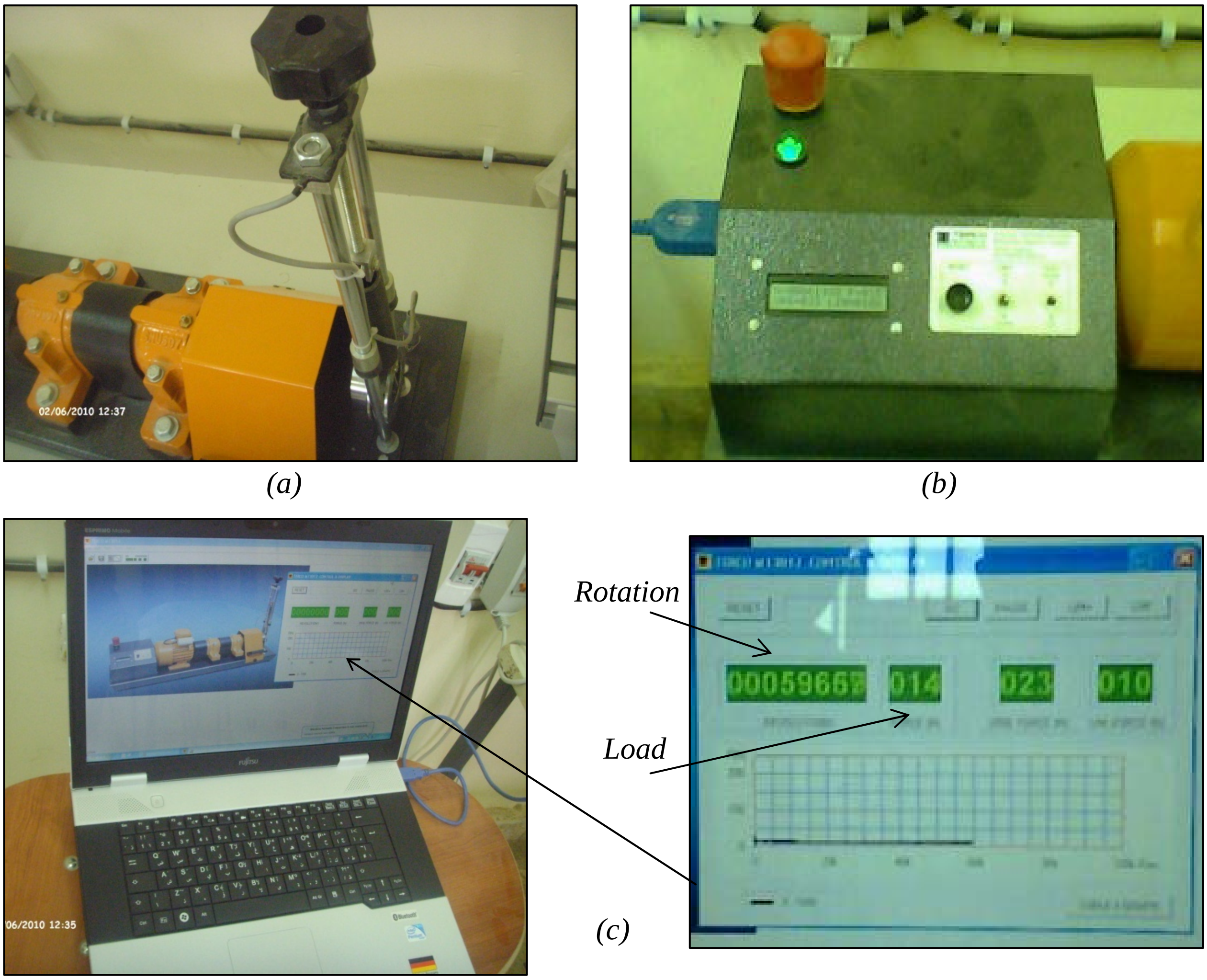


Fig.5. Parts of fatigue Test Machine, (a) load part machine, (b) digital part machine, (c) computer part machine.

Test of Samples

Has been shed loads specimens according to the following, **Tables 3 and 4**. and **Figs. 6 to 13.**, **Figs. 14 to 19**. shown the samples of fatigue after the test (fatigue shape).

Table 3. Fatigue Stress and Number of Cycle with various fiber orientation angle.

Fiber Orientation (deg)	*Endurance Fatigue Stress (Mpa)*	*Number of Cycle Fatigue Stress*
0^o	95.7405	35935
30^o	39.62763	27067
45^o	33.52418	20824
60^o	28.44629	15056
90^o	23.68721	10508

Table 4. Fatigue Stress (Mpa), for Different Fiber Orientation Angle (deg).

Fiber Orientation (deg)				
0^o	**30^o**	**45^o**	**60^o**	**90^o**

Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)	Number of Cycle	Fatigue Stress (Mpa)
40000	95.7291	35107	38.48812	30081	32.78317	30407	28.30827	30246	23.12245
35935	95.7405	33025	38.98041	25045	32.63669	25288	28.35936	25208	23.21693
33008	96.36609	30563	39.61357	20824	33.52418	20742	28.34446	20903	23.32372
30000	98.22766	27067	39.62763	17491	34.94178	15056	28.44629	15058	23.47127
25040	101.8474	25040	40.2914	15056	36.20798	12052	28.55785	10508	23.68721
20198	106.3256	22010	41.41578	12264	38.01507	10264	28.75434	7012	24.39942
17538	109.375	20084	42.23309	10259	39.66109	8071	29.14297	5002	25.01052
15012	112.8347	17023	43.75	8906	41.01563	6086	29.62091	3113	25.89442
12591	116.879	15049	44.916	5069	46.88867	4088	30.01246	1328	27.5625
10357	121.5408	10016	48.99292	3197	52.31193	1054	31.23377	1086	28.13994
7615	129.2614	6074	54.51153	1775	60.15625	/	/	/	/
5001	140.6156	4665	57.67045	1169	68.93698	/	/	/	/
2570	160.6674	2055	68.69555	/	/	/	/	/	/

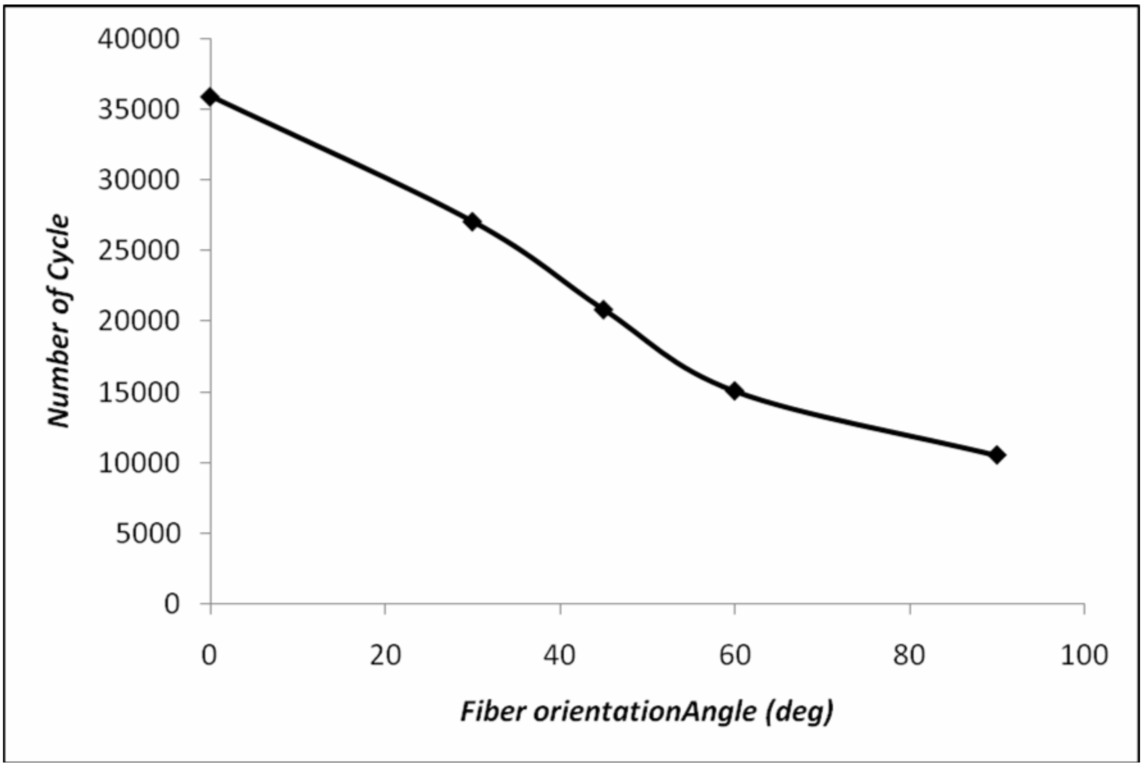


Fig.6. Number of Fatigue Cycle with Various Fiber Orientation Angle.

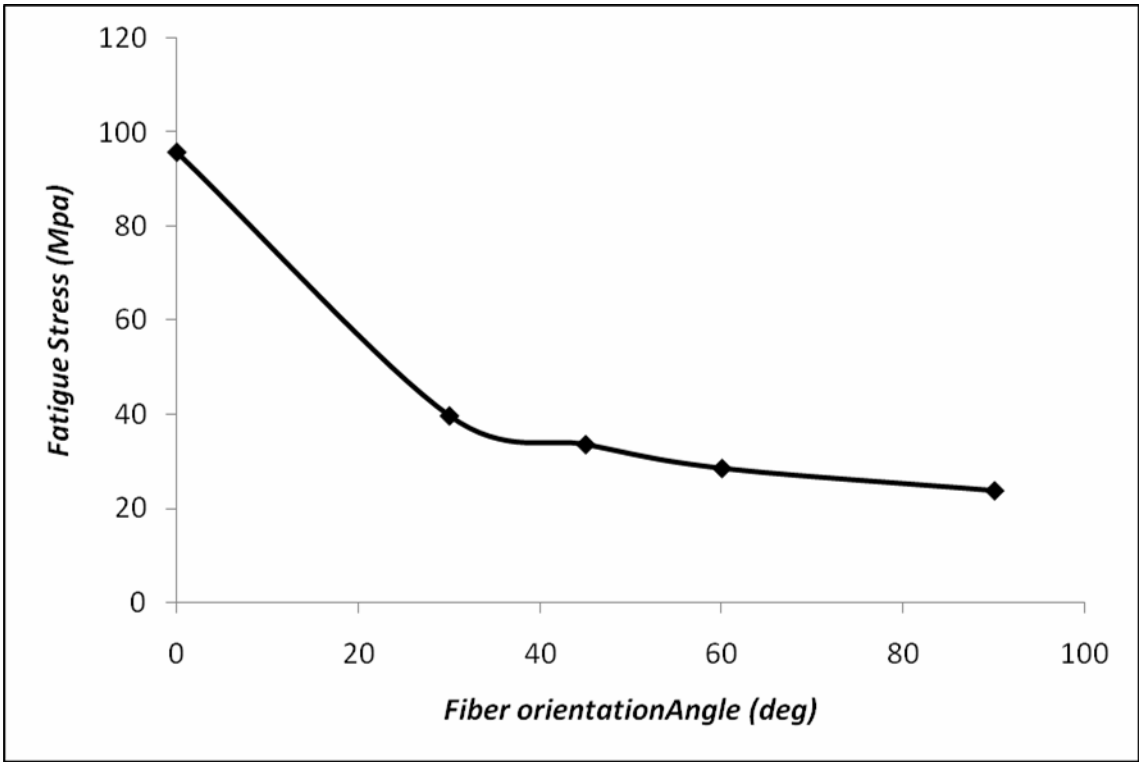


Fig.7. Endurance Fatigue Stress with Various Fiber Orientation Angle.

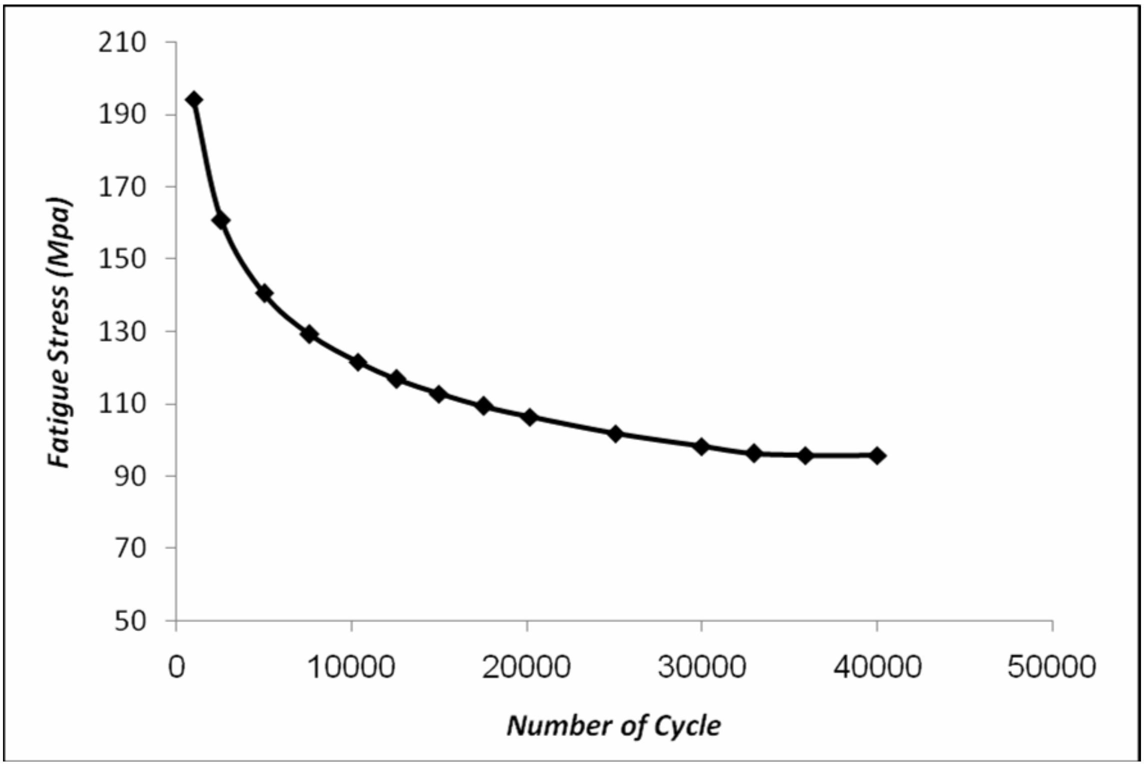


Fig.8. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (0^o).

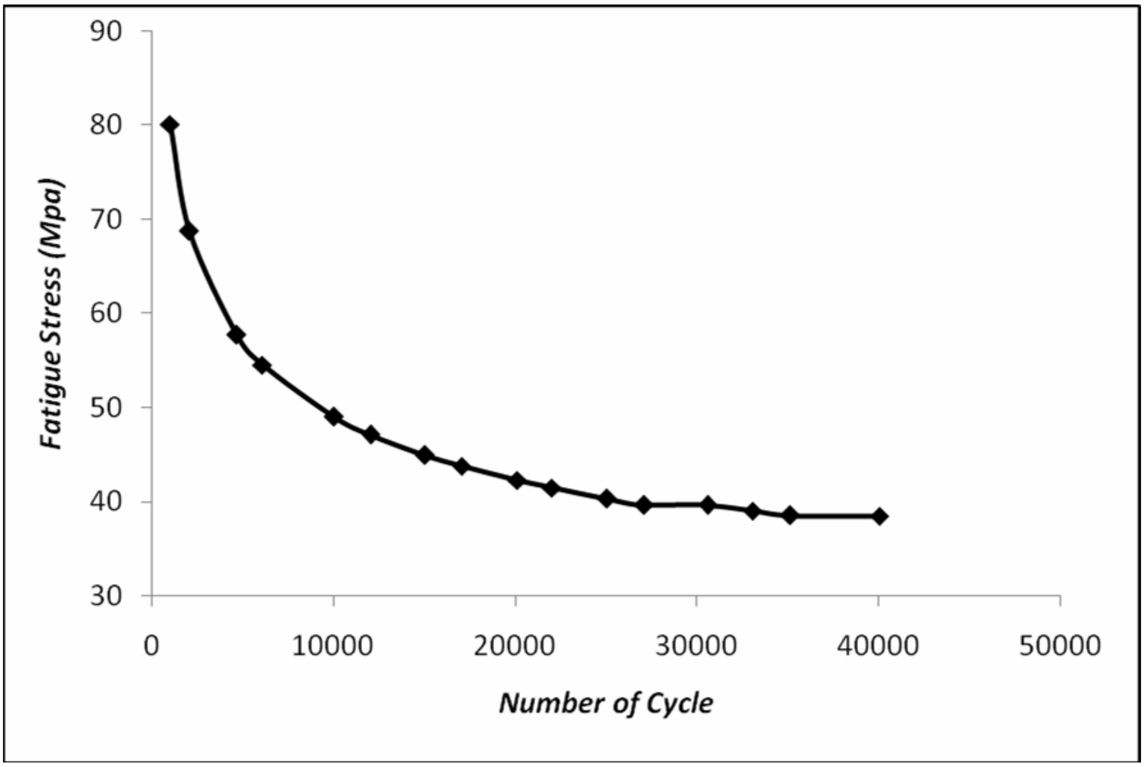


Fig.9. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (30^o).

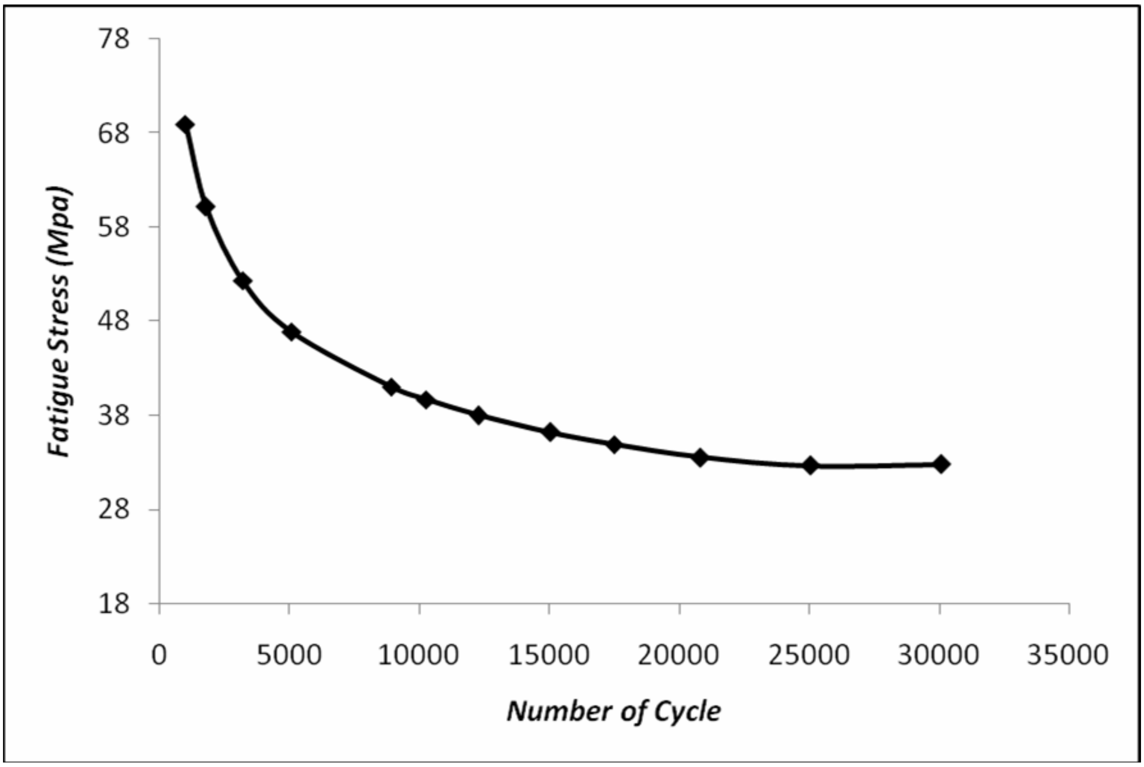


Fig.10. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (45^o).

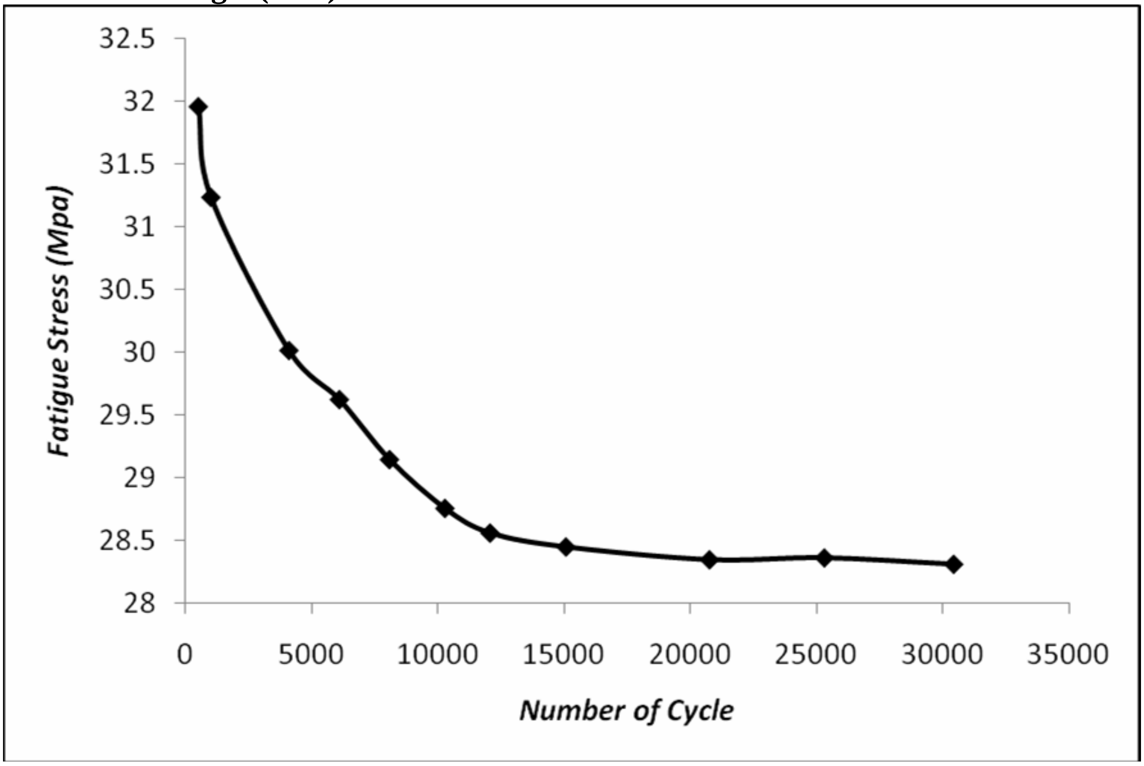


Fig.11. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (60^o).

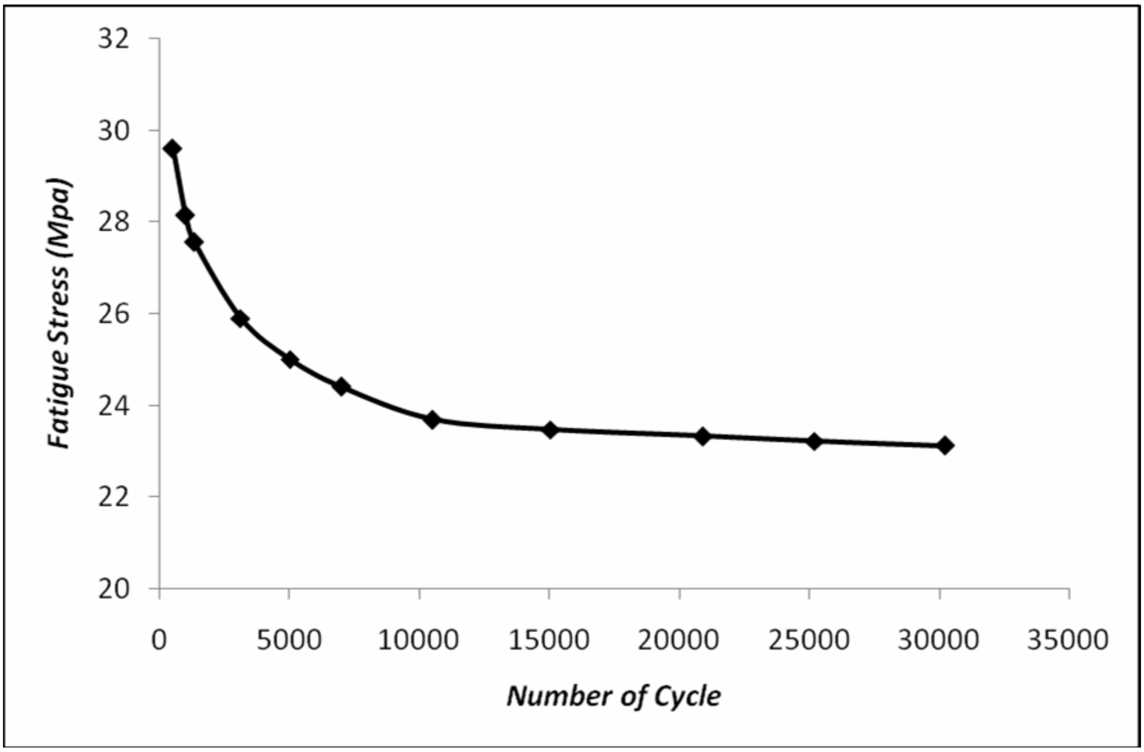


Fig.12. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Fiber Orientation Angle (90^o).

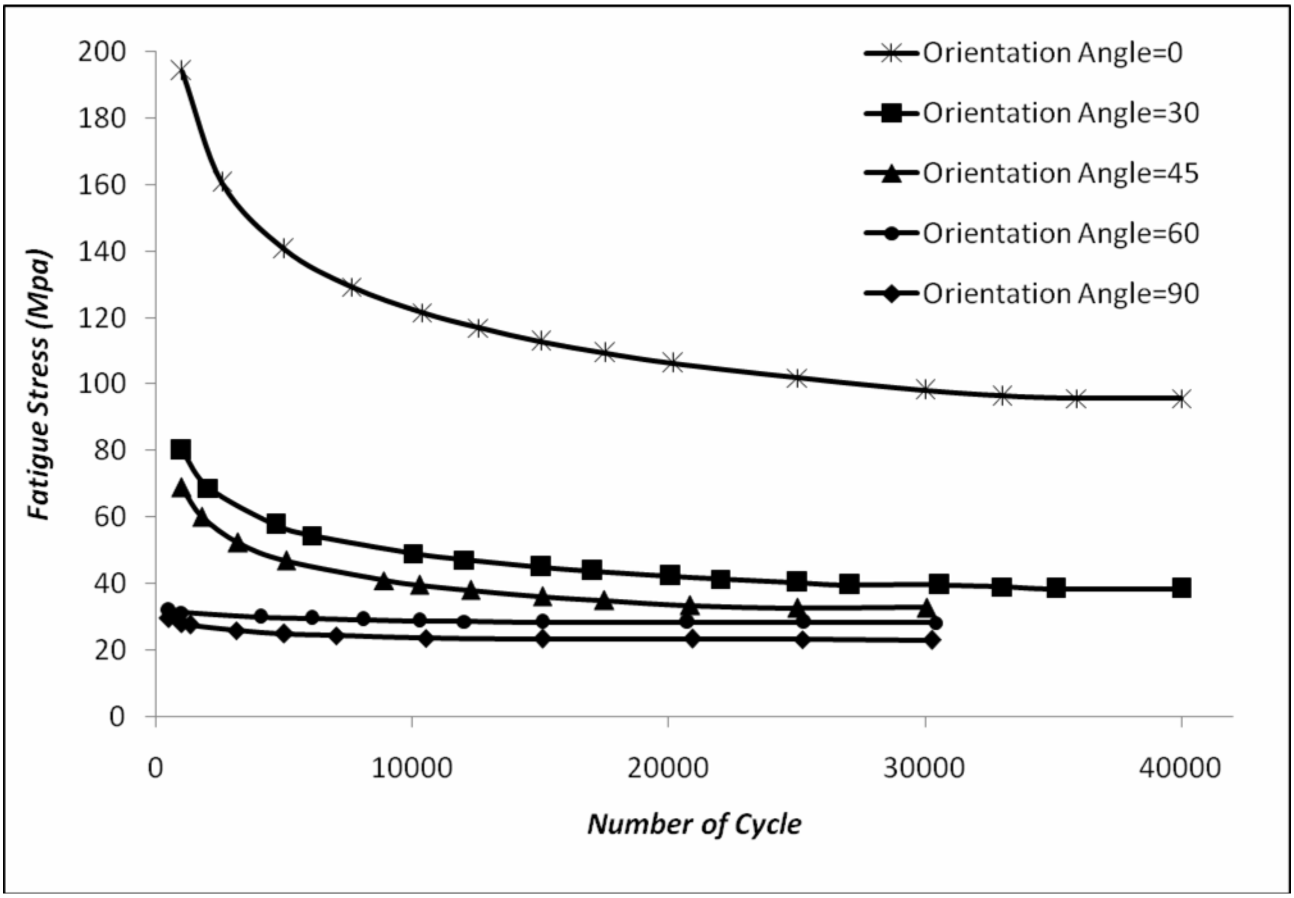


Fig.13. Fatigue Stress with Various Number of Cycle (S-N-diagram) for Various Fiber Orientation Angle.

Fig. 14 . fatigue shape of samples with Various Fiber Orientation Angle (Sample After Testing).

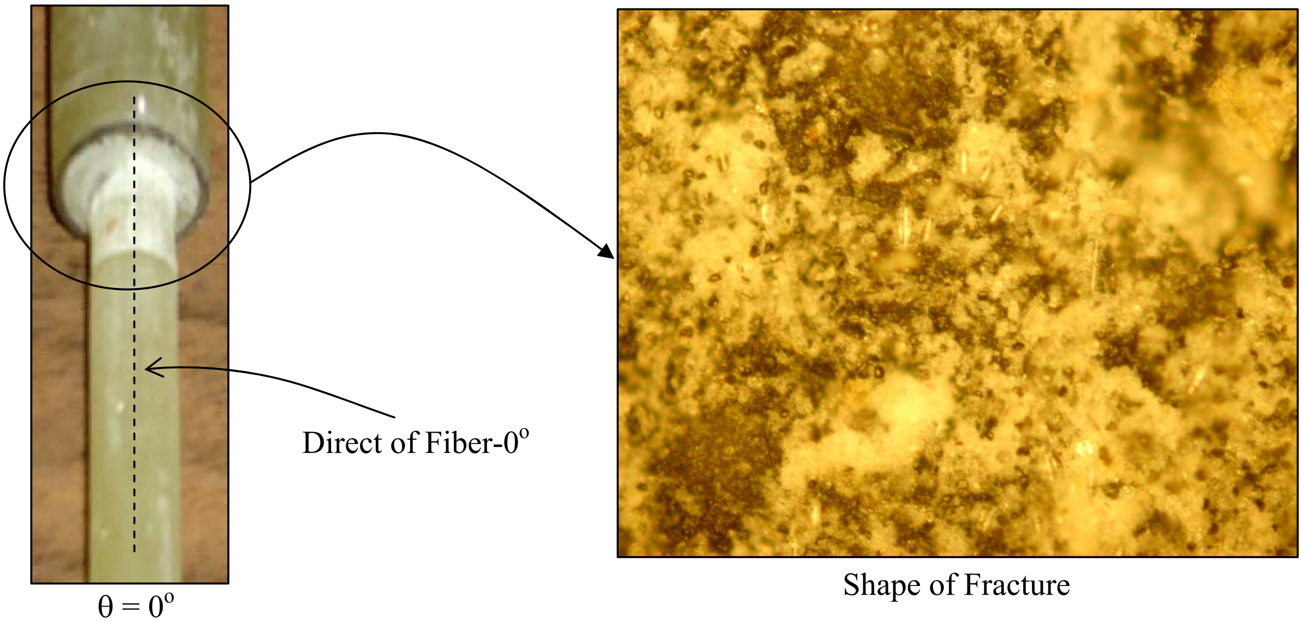


Fig.15. Optical Micrograph of Sample at angle (0°).

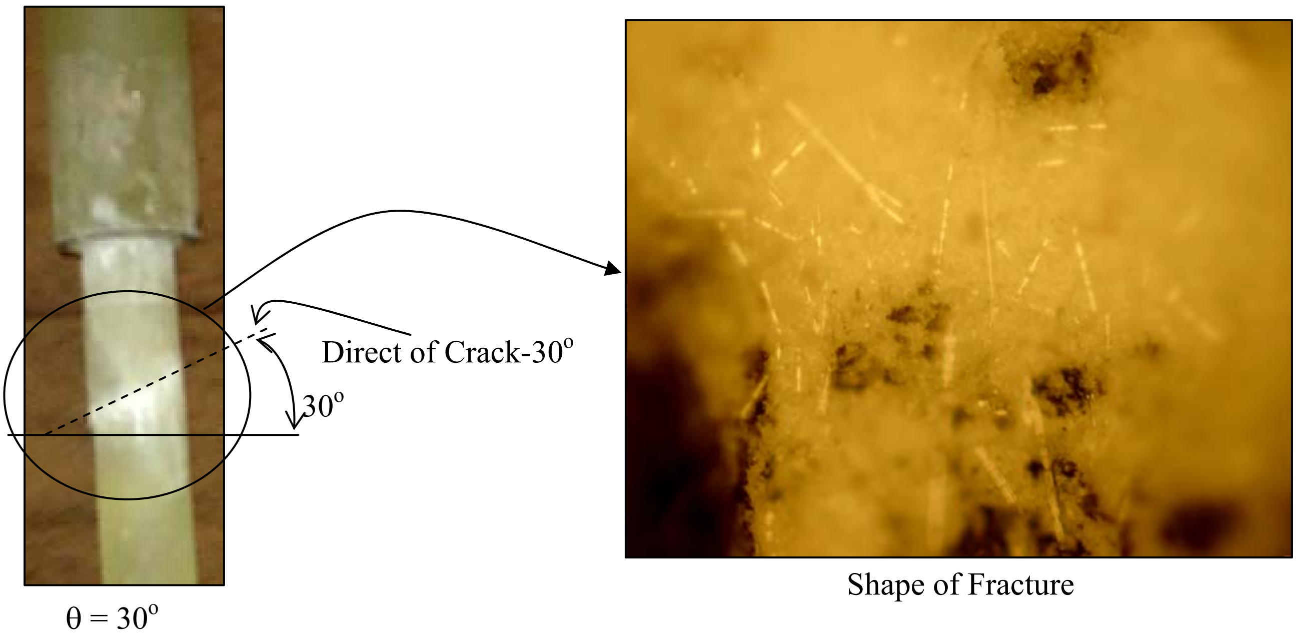
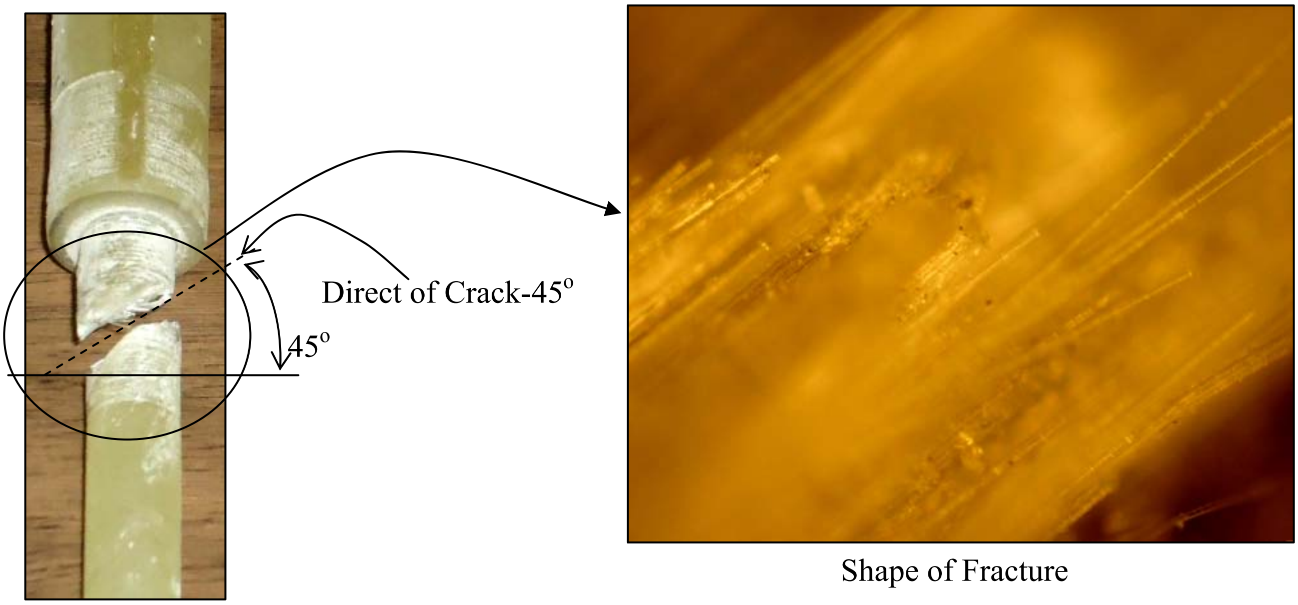


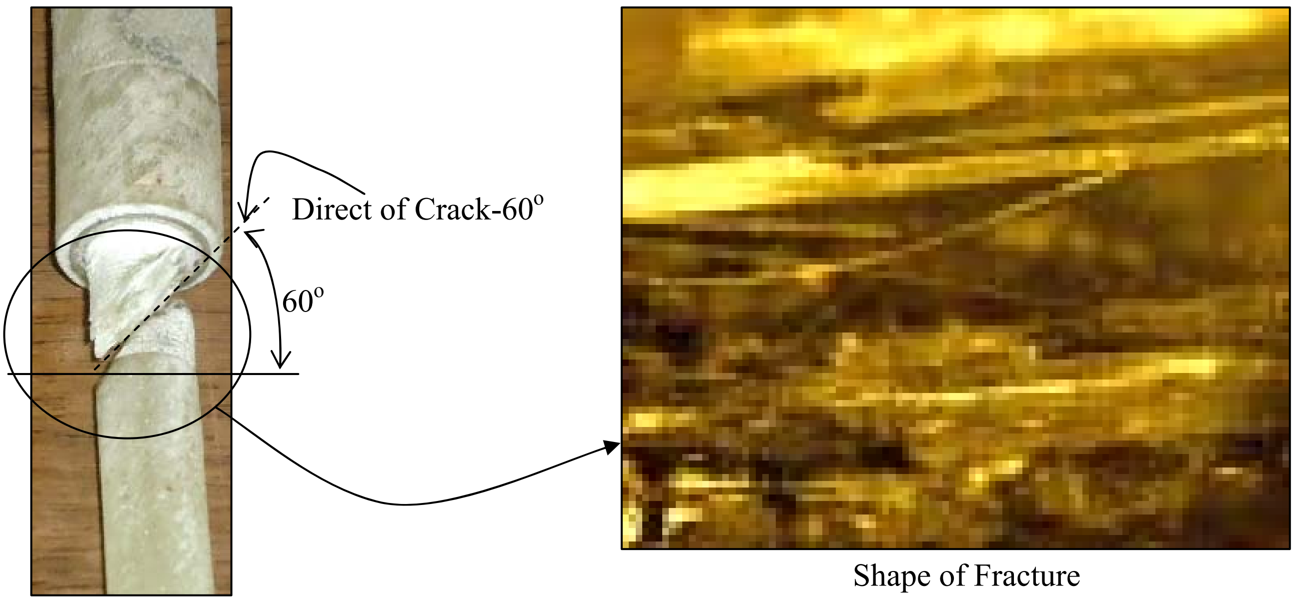
Fig.16. Optical Micrograph of Sample at angle (30°).



Shape of Fracture

θ = 45°

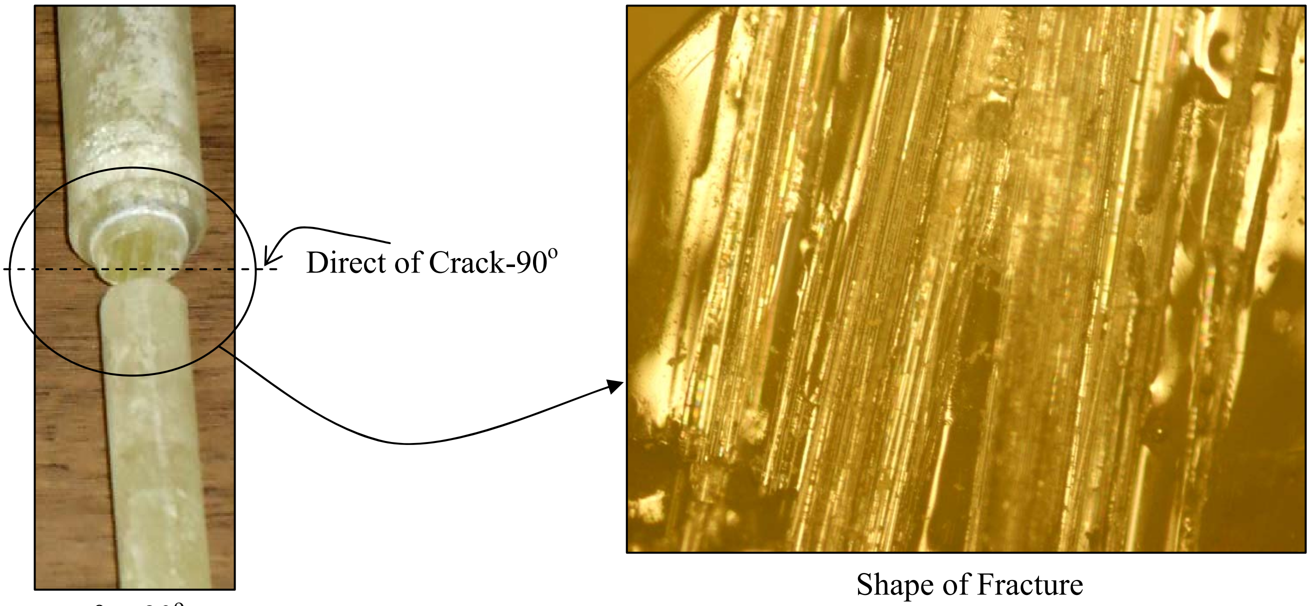
Fig.17. Optical Micrograph of Sample at angle (45°)



Shape of Fracture

θ = 60°

Fig.18. Optical Micrograph of Sample at angle (60°).



Shape of Fracture

θ = 90^o

Fig.19. Optical Micrograph of Sample at angle (90^o).

RESULTS AND DISCUSSION

The composite for the experiment were subjected to forces to the point of fracture and examined the strength fatigue as shown in **Figs. 6 to 13**. And **Tables 3 and 4**. and microscopically as shown in **Figs. 14 to 19**.

Tables 3 and 4, and **Figs. 7 to 13**. Shows the relation between the strength fatigue and number of cycles for various fiber orientation angle (0^0, 30^o, 45^o, 60^o, 90^o) of composite materials. From tables and figures shows that the fatigue strength of composite material decreasing with increasing the fiber orientation angle due to decreasing module of elasticity (strength) of composite materials.

Table 3 and **Fig. 6** . shown cycle number of fatigue with various fiber orientation angle (0^0, 30^o, 45^o, 60^o, 90^o) of composite materials. From table and figure shows that the number of fatigue cycle decreasing with increasing the fiber orientation angle, maximum at fiber angle (0^o) and minimum at fiber angle (90^o).

The micro-structural changes that result from fatigue damage can be shown in the **Figs. 14 to 19**. for various fiber orientation angle (0^0, 30^o, 45^o, 60^o, 90^o) of composite materials. Figures shows that the fracture surface of composite materials oblique (fatigue surface parallel to fiber direction) with the fiber orientation angle for fiber orientation angle (30^o, 45^o, 60^o,90^o) as in **Figs. 16 to 19**, for non-unidirectional fiber or load applied oblique on the fiber direction, becomes, the poor plane is parallel on fiber direction since the strength of composite material in fiber direction (perpendicular plane of fiber direction) greater than strength in perpendicular on fiber direction (parallel plane of fiber direction).

Fig. 15 . shown the fracture and micro-structural of unidirectional fiber, load supplied parallel to fiber direction. From figure shown that the fatigue surface perpendicular on the fiber direction, fatigue surface perpendicular to fiber direction, due to no load on the parallel plane to fiber direction.

CONCLUSIONS

1. The magnitude of fatigue strength and number of cycle of fatigue for composite material using in this research are found to lie between (95.7405 and 23.68721 *MPa*) and (35935 and 10508 *cycle*), respectively, for different orientation states of fibers.
2. The magnitude of fatigue strength and number of cycle of fatigue for composite material are decreasing with increasing fiber orientation angle, increasing with increasing the strength of composite material and decreasing with decreasing the strength of composite materials.
3. For oblique load on fiber direction, the surface fatigue of composite materials parallel of fiber direction and for unidirectional fiber, surface fatigue perpendicular on fiber direction.

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