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Effect of environment on torsional fatigue test of composite material

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Abstract
The effect of environments on natural composite materials specimens (polyester and peel of egg reinforcement) with 43% volume fraction in torsion test was investigated. A torsional fatigue system has been designed and manufactured; also the effect of three parameters temperature, relative humidity and twisted angle on number of cycle to failure was studied. Special mechanism to get alternating rotation from a motor that rotates in one direction was manufacturing. The twisted angles of rotation were (25^o, 15^o, 12.5^o, 10^o, 6^o, 4.5^o, and 3^o). The heat treatment and relative humidity used in this work are (T=27C^o, T=48C^o, and T=67C^o) and (40%, 60%, and 75%) respectively. The results showed that the major parameter that effected on the number of cycle to failure of torsion fatigue test for composite materials was the angle of twist which decreases the number of cycle when it increases. Also, the increasing temperature and relative humidity conditions caused reduction in cycle number of failure where the maximum reduction of cycles for the specimen occurred at (T=48C^o, and relative humidity= 75%).

Keywords: Composite material; Torsion fatigue; Environment.

1. Introduction

The composite materials have a long history of usage and their beginning was unknown. However, all historical records contain references to some forms of composite materials [1].

Fatigue is the tendency of materials to crack and then finally fracture under repetitions of stress or strain at a level considerably less than the ultimate static strength of the material. Fatigue is an important subject because it is the largest cause of failures in metals. Fatigue failures are often catastrophic and often occur suddenly and without warning. The applied cyclic stress state may be axial (tension-compression), flexural (bending), torsional (twisting), or a combination of these [2].

Static torsion tests and fatigue torsion tests were carried out on quasi-isotropic by M. Bruggeman et al. [3]. Carbon epoxy laminates consisting of 16 plies with different stacking sequences were used in order to determine the influence of the stacking sequence on the value of G12. The results were compared to those obtained by CLT (Classical Laminate Theory). The axial displacement was also monitored during the fatigue tests because this parameter seems to be more sensitive than the evolution in designing the torsional fatigue behavior. D. McClaflin, et.al [4] investigated the torsion strain-life behavior of the solid and thin-walled tube specimens and found that fatigue life to be the same for both types of specimens. Also, suggested that, the reduction of weight of 50% will be found by replacing the cross-section from solid to tubular for shafts with pure torsion, while the torque capacity will be maintained and life of fatigue. Combined tension and torsion loading was investigated by N. H. Yang, et al. [5] to eight layers (E-glass composite shafts) with fatigue and monotonic to find the effects of combined loading on failure. From experimental result, the fatigue damage was found to be depended on the failure plane; a fatigue failure was considering the cyclic energy and mean in the experiment fatigue. The experimental result gives good correlation with damage models. H.Q. Xue et al [6] gives a comprehensive investigation depend on the mechanism of damage under torsional fatigue of D38MSV5S steel in high cycle. A fatigue torsional test was carried out at 20 kHz ultrasonic fatigue device. The results were compared with the conventional torsional fatigue test device at 35 Hz as to whether of discrepancy due to the effects of frequency between two results. All of the fatigue results were carried out up to 1010 cycles at 25Co. Toshio Ogasawara et al. [7] studied the feasibility of CFRP as a future flex beam material. The behaviors of unidirectional GFRP and CFRP torsion with same resin matrix were studies. The nonlinear torsional was observed 0.5 % from the shear strain. Tension / torsion fatigue were also evaluated for unidirectional CFRP and GFRP laminates. The life of fatigue was found at 10% reduction of torsional stiffness, to compare the degradation of stiffness of GFRP with that of CFRP. The results show that, the CFRP is preferable for material of helicopter beam.

The aims of the present work is to design and build a torsional fatigue device and study the effect of environment (heat and moisture) on torsional fatigue for natural composite materials specimens.

2. Experimental work

2.1 Materials

Natural composite materials (polyester and peel of eggs reinforcement) were used in this research. The peel of eggs which is a biomaterial having 95% of carbonate of calcium in the calcite form and organic materials as 5%, such as (SiO_2, Al_2O_3, S, Cr_2O_3, MnO, Cl) **(**Raul et al. [8]). The peel of eggs are brown eggshell and has a density (1370 kg/m^3), at the beginning washed the peel of eggs by water to remove the small particles and membranes, then dried it by sun.

This reinforcement was mixed with polyester resin which has a density of (1135 kg/m^3) before mixing it with a hardener. The volume fraction used in this research was 43%.

2.2 Torsion device (formation of mechanism)

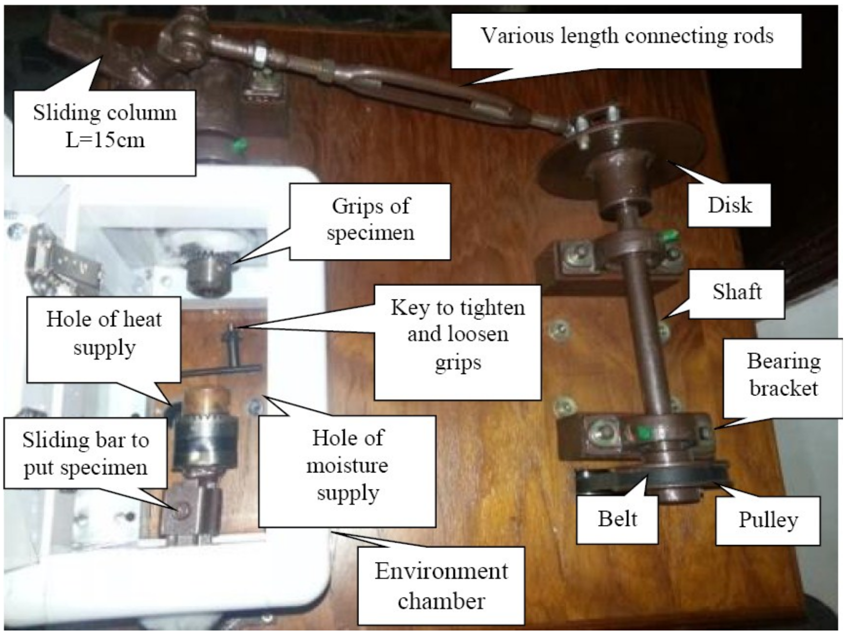
A mechanism was designed and built to convert one direction and constant of of motor of alternative rotation speed and allow changing its value; the system consists of the following parts:

1- Pulley. 2- Shaft. 3- Disk with slide slot. 4- Bearing bracket. 5- varaible length connecting rod 6- Sliding column. 7- Grips of specimen.

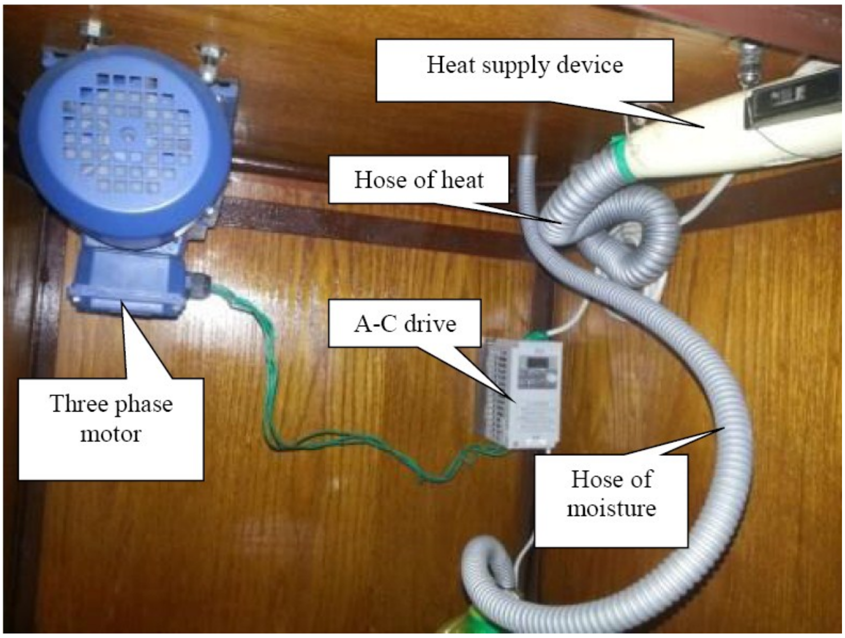
Initially, the mechanism was manufactured and set on temporal table and the system rotated by tentative motor to determine final dimension of each piece in mechanism as illustrated in Figure 1.

After that, final dimensions were fixed and stand was built to carry the all system with auxiliary devices as illustrated in Figure 2.

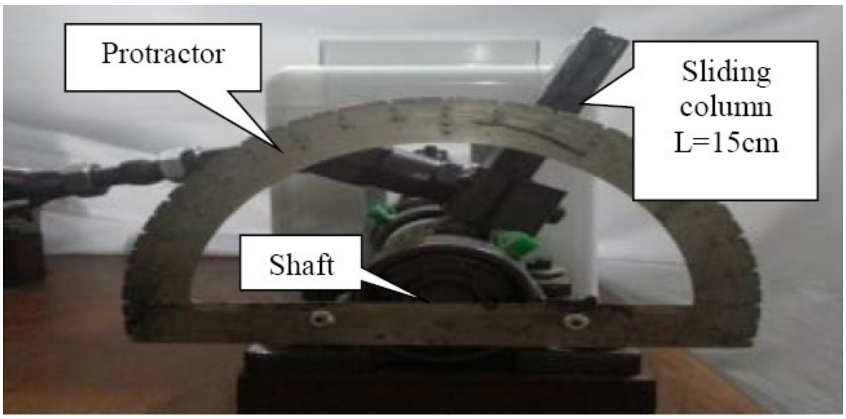
Figure 1. Prototype of rig of device.



(a)



(b)



(c)

Figure 2. (a) Main upper parts of system, (b) Main lower parts of system, (c) Protractor and second shaft.

The devices and measuring instruments used in the experimental work were:-

1. Electrical motor is used to supply movement to the mechanism. It is a Three phase motor which it's coil link in star manner is required to allow changing the number of revolution in one minute (from 0 to 1500 RPM).
2. A-C drive: It's an electric device change the phase from single to three phase but allow change the frequency of this current to change RPM of motor.
3. Moisture device: It's an electrical device which filled with water to convert it to moisture, It Contains a variable capacitance resistance to determine amount of moisture as in Figure 3.
4. Heating device: consists an electrical heater and feed delivery fan.
5. Speed changer: It used a frequency of Iraqi electrical current which equals to 50HZ,at this value, motor rotate at 1500RPM so that when reduce this value to 25HZ, motor rotate at 750RPM, by this method, the speed of the motor was determined.
6. Thermometer: It's consisting of thermocouple and a digital reader as show in Figure 4.
7. Hygrometer: It's consisting of moisture sensor and digital monitor to display the value of moisture content as in Figure 5.
8. Strain meter: It's consist of Programmable Logic Controller (PLC) to send electrical sign to computer, electrical circuit to link strain gauge with PLC and variable capacitance resistance to make first reading equal to zero and neglect resistance of wires as in Figure 6. Figure 7 shows the system arrangement with all devices of measurement

Figure 3. Moisture device.

Figure 4. Thermometer.

Figure 5. Hygrometer.

Figure 6. Strain meter.

2.3 Main steps of experimental work

1. The calibration of strain meter is very important to ensure all reading values of stress which read from computer are correct. The calibration was performed by applying value of torque and record value of Θ and volt which appear on monitor, and determine shear stress from equation (1)[9],

$$\tau = \frac{\theta R G}{L} \quad (1)$$

2. Specimens of natural composite material (polyester and peel of egg) were formed according to ASTEM standard F1717 [10], which it used in all experimental test and performed as shown in Figure 8.
3. Determinate the number of cycles and the shear stress that cause the specimen to be fractured.
4. Repeat the above steps under the effect of environment (heat and moisture), each one separately.
5. Draw S-N curve of all results.

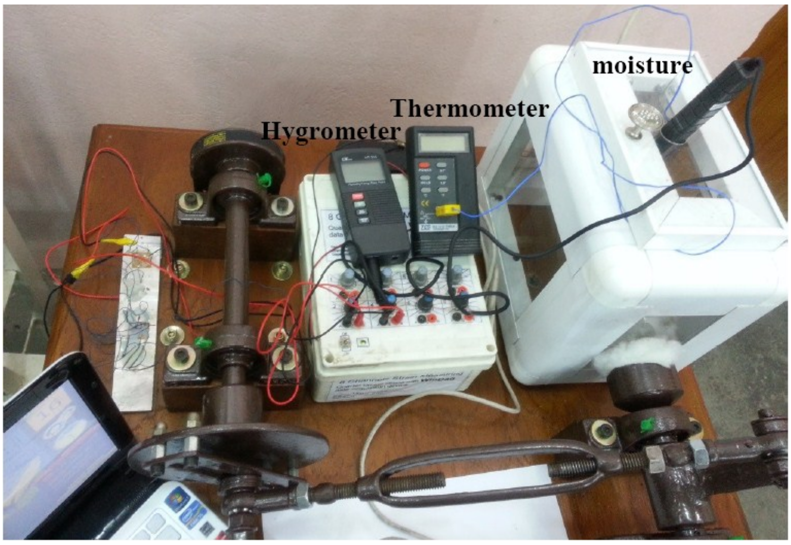


Figure 7. Torsion fatigue device arrangement.

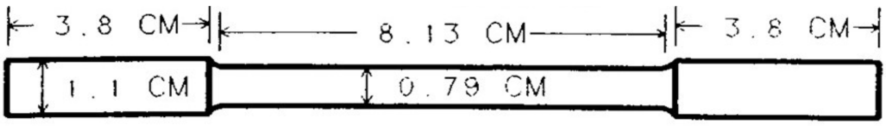


Figure 8. Specimen dimension (ASTEM F1717) [10].

2.4 Preparation of Specimen
1. At the beginning, manufacturing of molds casting of specimen consisting of rod brass owns internal diameter (15 mm) was done as shown in Figure 9.
2. Closure of one of the points of the mold and grease the mold by oil to facility eject of specimen to facilitate and minimize the effect of friction.
3. Mixing of materials by 80% polyester and accelerator stiffness and 20% powder of eggshells then fill the mold with mixture and leave it for a quarter of an hour and then opened the mold and reject the specimen and left to fully solidify as in Figure 10.
4. Pass the specimen on the operation of turning and cutting to get the final dimensions of the specimen according to ASTEM standard F1717which shown in Figure 11.

Figure 9. Cast mold of specimens.

Figure 10. Specimen after fully solidify.

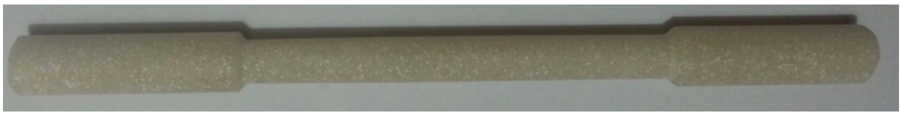


Figure 11. Torsion Fatigue specimen formation of polyester and peel of egg after turning and cutting.

2.5 Experimental parameters

Three parameters were studied (temperature T, relative humidity Ø and twisted angle ϴ). The twisted angles ϴ were = (25°, 15°, 12.5°, 10°, 6°, 4.5°, and 3°). Figure 12 shows the failure of specimen after torsion fatigue test.

After finishing of experimental tests, Von Mises equation was applied to determine the maximum stress [11],

$$\sigma = \sqrt{\sigma x^2 + \sigma y^2 - \sigma x * \sigma y + 3 * (\tau xy)^2} \quad (2)$$

where, σ: Maximum stress, σx: Stress in x direction, σy: Stress in y direction, τxy: Shear stress in xy plane now, $\sigma x = \sigma y = 0.0$

$$\sigma = \sqrt{3 * (\tau)^2} \quad (3)$$

Figure 12. Specimen fracture.

3. Results and discussion

3.1 Von Mises stresses

The values of Von Mises are illustrated in Table 1. From the table, the minimum and maximum ultimate stress are (26 and 221.7 MPa) respectively. That is because the increase of the twisted angle causes an increase in shear stress which will be increases ultimate stresses.

Table 1. Results of Von Mises stresses.

Shear stress τ (MPa)	Ultimate stress σ (MPa)
128	221.7
93	161.1
70.8	122.63
51.6	89.4
36	62.4
24.6	42.6
15	26

3.2 Effect of temperature on number of cycles to fracture

Figure 13 shows the effect of angle of twist on number of cycles for natural composite material specimens (polyester and peel of egg reinforcement) with temperature effect at constant value of relative humidity (40%). From figure, the increasing of angle of twist causes a decrease in the number of cycles to failure because of the rising of twisted angle leads to an increment in shear stress which will reduce the life of sample. The increase of angle of twist from (3^o to 25^o) causes a decrease of number of cycles to failure (31035%, 35066%, and 45121%) at heat treatment (T=27C^o, T=48C^o, and T=67C^o) respectively. Also, the increment of temperature from (T=27C^o to T=67C^o) causes a reduction in the number of cycle by (72%, and 85%) for twisted angle (3^o, and 25^o) respectively.

Figures 14 and 15 show the same parameter as Figure 13 but the relative humidity are (60%, and 75%) respectively. Same behavior of Figure 13 will be found in Figures 16 and 17. The increasing of temperature from (T=27C° to T=67C°) causes decreasing the number of cycle by (57%, and 88%) for twisted angle (3°, and 25°) respectively for Figure 14 and (38%, and 77%) for Figure 15.

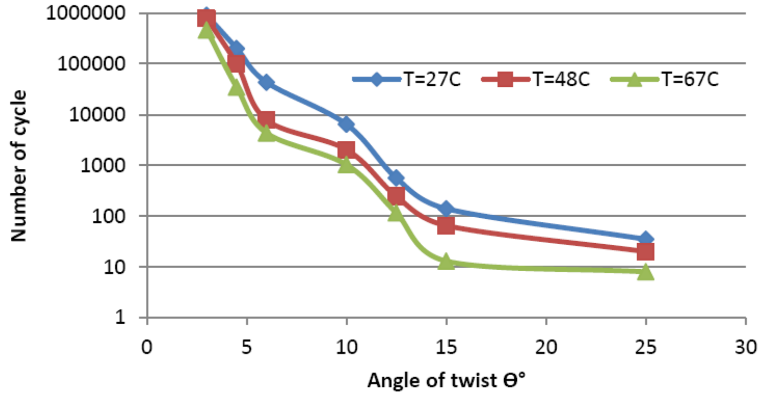


Figure 13. Effect of angle of twist on number of cycle with deferent temperature effect at 40% relative humidity.

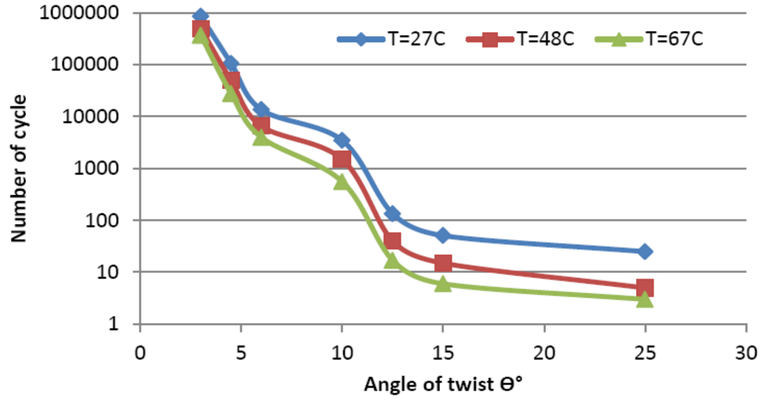


Figure 14. Effect of angle of twist on number of cycle with deferent temperature effect at 60% relative humidity.

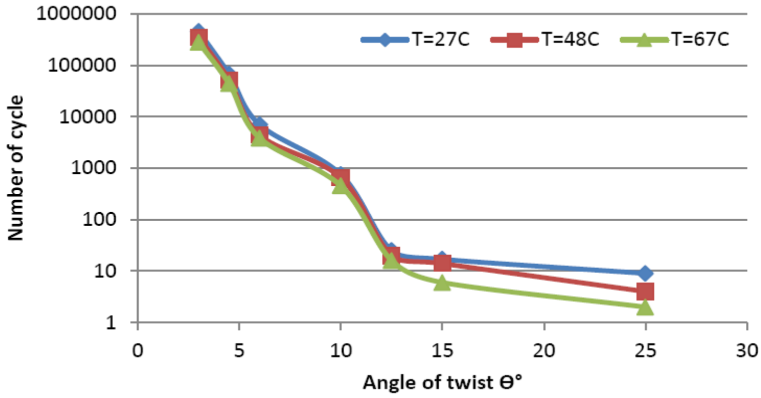


Figure 15. Effect of angle of twist on number of cycle with deferent temperature effect at 75% relative humidity.

3.3 Effect of relative humidity on number of cycle to fracture

Figure 16 shows the relative humidity and temperature effect on the number of cycles for natural composite material specimens (polyester and peel of egg reinforcement) at angle of twist= 3°. It can be seen that the increasing of relative humidity leads to reduce the number of cycles to failure due to the decreasing of the stiffness of the sample. The increment of the relative humidity from (40% to 75%) causes a reduction in the number of cycles (74%, 80%, and 75%) at (T=27C°, T=48C°, and T=67C°) respectively.

Figure 17 shows the same relations of Figure 16 but at angle of twist (25°). The increasing of relative humidity from (40% to 75%) causes a reduction in the number of cycles (49.6%, 55%, and 39.6%) at (T=27C°, T=48C°, and T=67C°) respectively.

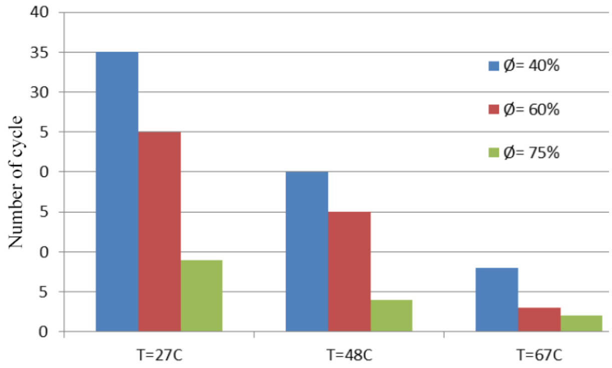


Figure 16. Effect of temperature and relative humidity on the number of cycle with at Angle of twist ϴ°=30.

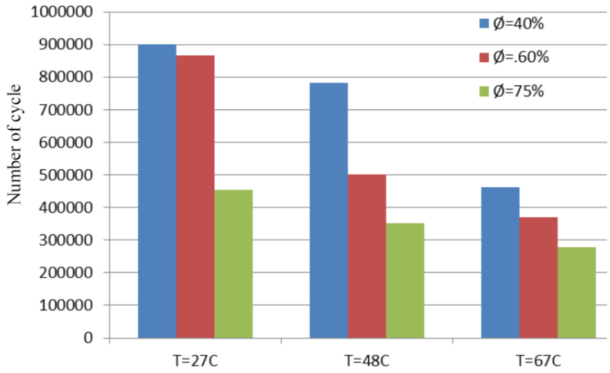


Figure 17. Effect of temperature and relative humidity on the number of cycles at an angle of twist ϴ°=250.

4. Conclusions

1. The angle of twist was the major parameter that effects on the torsion fatigue test for composite materials specimens on number of cycle to failure. The increment of the twist angle causes reduction in the cycle number of failure.
2. Increasing in the temperature of the specimen causes a decrement in cycle number to failure. This effect was shown clearly with increasing twisted angle compared with small twisted angle.
3. The increment of relative humidity leads to reduction in cycle number of failure.
4. The temperature effect in cycle number to failure of natural composite material was greater than effect of relative humidity.
5. The maximum reduction of cycles number to failure of the composite specimen under torsion fatigue test occurs at (T=48C°, and relative humidity= 75%).

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