Design & Development of Fatigue Test Setup for Composite Laminate

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Abstract— Fatigue results in failure materials subjected to completely reversed or cyclic loading. An important consideration for design is ultimate strength of the epoxy glass-fiber composite laminate. Hand Lay-up technique was employed for composite fabrication of Epoxy and E-Glass Fiber. Epoxy resin and hardener were mixed using the ratio of 2:1 parts by weight. The entire setup includes motor, gearbox, cam and shaft assembly, springs, plates, grippers, flat needle roller bearings, sliding channel. The tension fatigue test of composite specimen is measured by applying constant frequency of 3Hz. Moreover the specimen and design considerations are as per ASTM standards. Unidirectional glass-fiber epoxy specimens with 0°, 45°, and 90° are used as samples for test. For demonstration of machine functionality, the measured results of few test have been compared with numerical methodology. This types of machines are very expensive hence simplicity and overall cost are important considerations in this system.

Key words: Fatigue, Epoxy Glass-Fiber Composite, Reversible Loading

I. INTRODUCTION

Fatigue is the weakening of a material caused by repeatedly applied loads. In this process permanent structure change occurs in the material produced by repetitive loading. The laminates manufactured by hand layup process. Failure of composite occurs in three stages i.e. crack initiation, crack propagation, fracture [1]. The working parameters on which we based these design is ultimate tensile stress of laminate for 0, 45, 90 orientations obtained experimentally [2]. To avoid the failure due to thermal stresses the frequency of machine is limited to 3Hz [3]. The fatigue test are performed as per the ASTM D3479M standard [3]. Rotary motion is transformed to reciprocating motion by cam, efforts are made to calculate the jump speed of the cam to prevent noise [4]. The methodology used is the correlation between S & N in high cycle region is obtained based on equation of the line (i.e. $y = b \cdot x + c$). Considering endurance strength at (Se=0.5Sut) and for composite material stress amplitude about (0.7Sut) at which 10^3 cycles starts.

II. THE FATIGUE TEST MACHINE

In this section short description of tensile fatigue machine is proposed. The main feature required for performing the test are stiffness of springs and jump speed of cam. By using eccentric cam and parallel springs in combination a harmonic force with amplitude 890 N can be obtained. To satisfy the test requirement the layout presented in fig 1 is adopted.

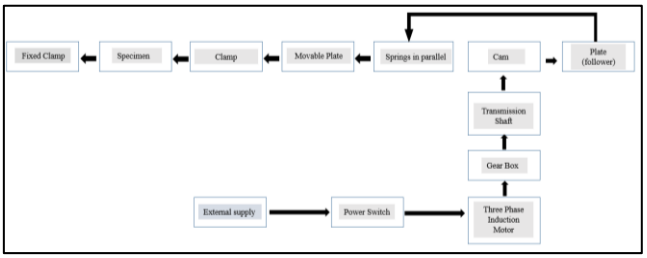

Fig. 1: The Fatigue Test Machine Layout

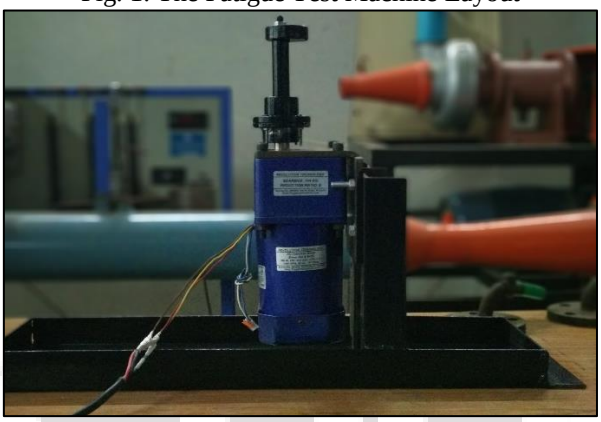

Fig. 2: Cam - Motor Assembly

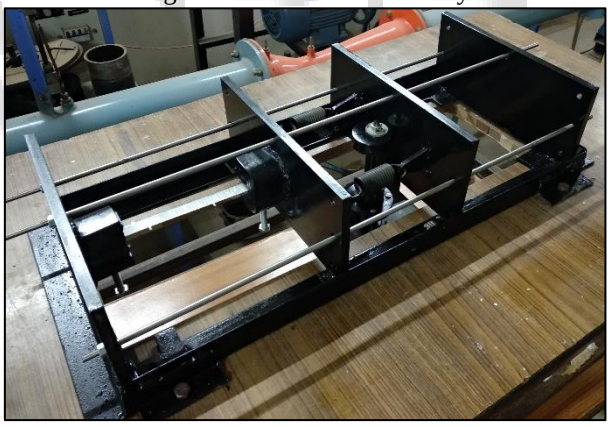

Fig. 3: Experimental Setup

Geared motor is used to transmitt torque to the cam via transmission shaft (fig 2). By eccentric cam and plate (follower) mechanism the force is transmitted harmonically through the springs to the plate attached with the clamp. Clamp is connected to te speciment and other side of the clamp is rigidely fixed to the plate (fig 3). Needle bearings selected FT 2010N perform the role of antifriction surface between plate and channel and make it noise and wear free.

A. Design of Components

1) Motor Torque

Output speed of the motor is 1440 rpm, which is to be reduced to 180 rpm, hence motor with compound gear train is used to transmit torque.

a) Specifications

AC Induction motor. 360W, 230/415 VAC, 3-Ph, 1.5 A

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1440 RPM, 50Hz, 0.5Hp
Gear ratio for compound drive used is 8
Output speed of motor= 1440/8 = 180RPM
Torque transmitted by 0.5 Hp motor

$$T\ (Nm) = \frac{P*60000}{(2*\pi*N)}$$

Maximum torque transmitting capacity of three phase induction motor = 22.27Nm.

2) Cam Design & Analysis

Analysis of a rigid eccentric cam involves the determination of the contact force, the spring force and the cam shaft torque for one revolution of the cam a circular disc cam with the cam shaft hole drilled off centre is known as an eccentric plate cam.

Material	Diameter	Width	Eccentricity
Mild steel	50mm	10mm	7.5mm

Table 1: Cam Dimensions

$F = 2Ke + P - me\omega^2$

Mass of follower m= 2.147 kg, Eccentricity e= 7.5mm, Stiffness k= 3.81402 N/mm,
Pre load P= 0,
Jump would begin when, F=0,

$$\omega j^2 = \frac{(2Ke + P)}{me}$$

ωj = 59.606 rad/sec. Nj= 569.19 Rpm

3) Design of springs

The results of tensile test conducted for 0, 45, 90 degree orientations are used as design inputs for designing the force transmitted by the springs. The deformation is to be constant to 15 mm. On varying stiffness of springs force transmitted to the specimen can be changed.

Sr. No.	No. of Layers	Orientation	Mechanical Properties	
			Peak load(N)	Tensile Strength (MPa)
1	2 Layers	0^0	10535	553.018
		45^0	764.4	42.490.
		90^0	653.66	33.393

Table 2: Tensile Strength for Different Orientations of Fiber

Material selected for spring: Stainless Steel 304, it provides excellent corrosion resistance, no surface treatment is required, can be used in temperature of up to 300°C,strong directional properties, higher tensile strength, easily available.

Sr.No	C	d	D = d x C	n	ID	OD	Free Length	Total length	k	Ke=2*k	Force	Torque
1	8	2	16	18	14	18	36	72	1.90701	3.81402	57.2103	1.43026
2	5	1.2	6	21	4.8	7.2	25.2	39.6	4.01714	8.03429	120.514	3.01286
3	6.95	3	20.85	18	17.85	23.85	54	101.7	4.36274	8.72549	130.882	3.27206
4	7.1	3	21.3	15	18.3	24.3	45	93.6	4.91044	9.82088	147.313	3.68283
5	4	1	4	20	3	5	20	30	6.86523	13.7305	205.957	5.14893
6	4.5	2	9	18	7	11	36	58	10.7148	21.4297	321.445	8.03612
7	5	2.6	13	17	10.4	15.6	44.2	75.4	10.7518	21.5035	322.553	8.06382
8	5	2.5	12.5	16	10	15	40	70	10.9844	21.9688	329.531	8.23828
9	5	2.7	13.5	16	10.8	16.2	43.2	75.6	11.8631	23.7263	355.894	8.89734
10	5.1	3.3	16.83	17	13.53	20.13	56.1	96.36	12.8594	25.7187	385.781	9.64453
11	6	6	36	15	30	42	90	174	16.2731	32.5463	488.194	12.2049

Table 3: Springs for Force Transmission

a) Finite Element Analysis

The validation of above mentioned springs was done using ANSYS software. Results obtained by experiment conducted were compared with the results from FEA.

Sr.No	C	d	D = d x C	n	ID	OD	Free Length	Total length	k	Ke=2*k	Force	Torque
1	8	2	16	18	14	18	36	72	1.90701	3.81402	57.2103	1.43026

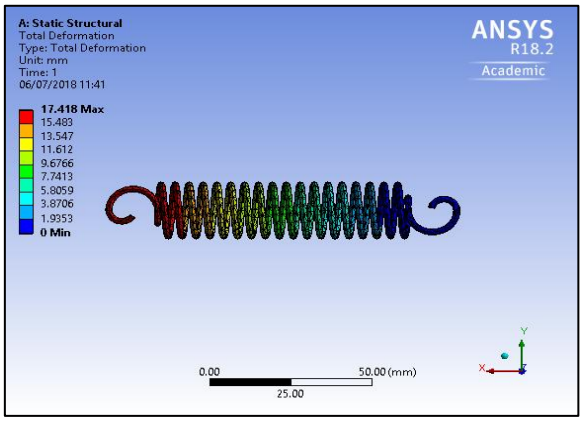

Fig. 4: FEA Analysis of Spring no 1

Sr.No	C	d	D = d x C	n	ID	OD	Free Length	Total length	k	Ke=2*k	Force	Torque
11	6	6	36	15	30	42	90	174	16.2731	32.5463	488.194	12.2049

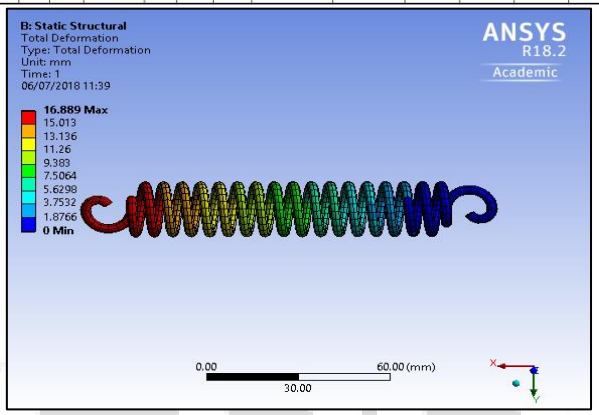

Fig. 5: FEA Analysis of Spring no 11

Sr.no	Spring	Analytical deformation	FEA (deformation)	Percentage error
1	Spring (1) low stiffness	15	17.418	16.12
2	Spring (11) high stiffness	15	16.889	12.59

Table 4: Comparison of Analytical & FEA Deformation of Springs

4) Testing

a) Limitations

1) Frequency of testing is constant to 3 Hz.
2) Transverse vibrations are induced in setup.
3) Specimen needed to fail completely, hence first failure evidence in difficult to notice.
4) Motor torque is restricted to 22.27Nm. Hence limiting the load to be transmitted to 890N

5) Test specimen

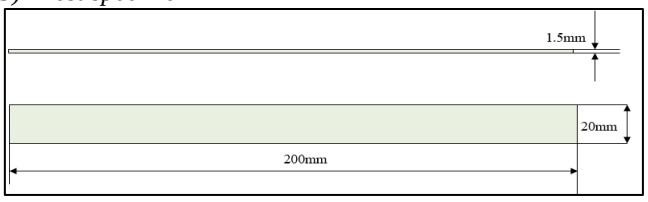

Fig. 6: Test Specimen Dimensions

B. Results

1) 90° Fiber Orientation

Stress ratio	Average number of cycles	S-N curve	Percentage error
0.8	120	80	33.33

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0.7	1376	1100	19.98
0.6	18764	15130	19.36

Table 5:

2) 45° Fiber Orientation

stress-ratio	Average number of cycles	S-N curve	Percentage error
0.8	130	99	23.846
0.7	1216	1050	13.65
0.6	15335	11017	28.157

Table 6:

3) 0° Fiber Orientation

Sr. No	Stress ratio	Time for failure	Life (cycles)
1	0.1	15 hr.16 min	10^6
2	0.1	15 hr. 22 min	10^6
3	0.1	15 hr. 5 min	10^6

Table 7:

III. CONCLUSION

The fatigue testing machine based on standard description has been developed. The machine is capable of doing fatigue test in different range of loads with constant frequency. The frequency of the machine can be varied by inducing a variable frequency drive. The machine is capable of transmitting load upto 890N. The developed machine is able to continue for long period of time. Fatigue life of 0°, 45°, 90° fiber orientation for various loading conditions is calculated.

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