ANALYSIS OF FAILURE IN COMPOSITE FLEX BEAM BY INTRODUCING FOD AND KNIFE CUT

Vaibhavi D[1], T Rangaswamy[2], Kavya S[3], Suresh[4]

[1,3,4]*ME Scholar, Department of Mechanical Engineering, Bangalore University, Bangalore, Karnataka, India, 560001*

[2]*Professor, Department of Mechanical Engineering, Government Engineering College, Hassan, Karnataka, India, 573201*

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ABSTRACT - *Flex beam is a critical, dynamic and integral part of the tail rotor blade of a helicopter that eliminates the need of bearings at the connecting junction of tail rotor blades and small deviation in its normal behavior could lead to catastrophic failure of the helicopter. The rejection rate of the flex beam is around 49% per year and it is due to defects such as foreign object debris, air gap, and change in fiber orientation. In this context an attempt has been made to evaluate the mechanical properties such as stiffness, flexural strength and interlaminar shear strength of flex beams. Flex beams are fabricated with simulation of defects such as release film (foreign object debris) and knife cuts, using hand layup process. Testing involves computed tomography scan, ultrasonic C-scan, differential scanning calorimetry, stiffness, and flexural and interlaminar shear strength tests. Stiffness, flexural and interlaminar shear strength values obtained are compared with the theoretical one and found that they have good agreement with each other. From the results it can be concluded that flex beam with release film is rejected whereas the same with other defect is accepted as it gives satisfactory stiffness and strength values.*

***Keywords**: Flex beam, Foreign object debris, Helicopter tail rotor blade, Fiber orientation change, Flexural strength.*

1.INTRODUCTION

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials. Increasingly enabled by the introduction of newer polymer resin matrix materials and high performance reinforcement fibers of glass, carbon and aramid, the penetration of these advanced materials has witnessed a steady expansion in uses and volume. Composites are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity. Unlike conventional materials (e.g., steel), the properties of the composite material can be designed considering the structural aspects. A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the *reinforcing phase* and the one in which it is embedded is called the *matrix*. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers etc. A Flex Beam is a dynamic part which is an integral part of the Tail Rotor Blade of a helicopter [1,7]. It is a critical part as it balances the torque produced y the main rotor blade. Flex beam is designed to provide required stiffness in the flap and lag deformations of the blade and also acts as a pitch change mechanism [2]. As small deviations in the behavior of flex beam could lead to catastrophic failure of the helicopter, the design, fabrication and analysis of the flex beam becomes significant. Each prepreg tape is having a width of 11.5mm and is mad of R glass UD material. Hub region consists of Carbon BD prepreg and R glass BD prepreg. The layers are arranged as per the layup sequence sheet provided by the production department along with route book. The rejection rate of flex beam is around 49% per year and it incurs huge loss to the organization as the cost of a flex beam is around 21 lakh [7]. Some of the reasons for rejection are Foreign Object Debris (FOD), change in fiber orientation and air gap [6]. In this context an attempt has been made to evaluate the mechanical properties of flex beams by simulating the fore mentioned defects.

2 FABRICATION OF COMPOSITE FLEX BEAM [2,7]

2.1 Lay up

Lay up as we know is the process of laying up the layers of prepregs one upon the other according to the route card. The prepregs are cut into simple shapes and laid up on the tool. The orientation of the fibers are also specified by the designer, usually the layers are put together in the angle of 0^0, 90^0, $\pm45^0$ to give the ultimate strength to the component. The prepreg layers are laid on the tool cavity and extra materials are trimmed off to give the exact shape of the tool.

2.2 Vacuum Bagging

Vacuum bagging is a process of providing flexible elastomeric, Nylon film on the outer cover of composite component, which can be sealed to create vacuum as shown in Fig. 1. This process is very important because to ensure that any air entrapment, gas entrapments are present in the stacked layers are removed. Vacuum bag applies uniform pressure over the stacked layers and this indeed ensures proper compaction. Vacuum bagging also ensures proper adhesion between layers and also between tool and the stacking. Vacuum of 0.8 Bar is applied and the bag has to be made leak proof, any presence of leakage in the bag will lead to failure of the part during curing process. 0.05 Bar for 5 minutes leakage pressure is acceptable, any leakage greater than that is not acceptable. After the bagging is done intense care is taken so that the bag doesn't get damaged.

Fig-1: Vaccum Bagging

2.3 PRECOMPACTION IN AUTOCLAVE

Precompaction process is the process where the resin and fiber in composites hardens. This is done with the help of Autoclave. In Precompaction the component is cured partially, so that the layers will compact and post curing is done to obtain increased strength from a resin. If an epoxy resin is allowed to cure only at room temperature, its ultimate strength is rarely achieved. Post curing will increase two critical performance properties of an epoxy – chemical resistance and heat resistance. Normally in composite manufacturing curing will be done in the Autoclave. Autoclave is a closed vessel and adiabatic type, here usually maximum of 5-6 bar pressure is used for the proper compaction of laminates for uniform resin flow and temperature is based on type of reins used in composite. Vacuum is maintained to remove the gases that are developed during the curing process and to apply uniform pressure on the component. A typical autoclave is shown in the Fig. 2

Fig-2: Autoclave

2.4 Press Curing

A hydraulic press as shown in Fig. 3 is a mechanical machine usually used for curing of composite parts. The constructional features of this machine consist of two hot platens i.e. upper and lower platen.. The whole machine is controlled and monitored with the help of programmable logic controller (PLC). A programme for curing will be preloaded into the PLC which makes the curing of parts possible in a systematic way.

Fig-3: Hot platen press

2.5 Demoulding & Trimming

After curing in press, the Flex Beam is removed from the mould/ tool by separating top mould from the bottom mould. This process is known as demoulding. Wooden spatula is used for removing the completed part from the bottom mould. Extra material is trimmed off from the flex beam using hacksaw cutting machine

Defects stimulated in Flex Beam

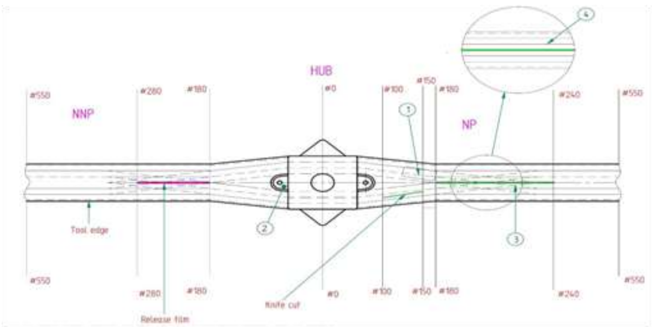

Fig-4: Schematic design of Flex beam

In Flex Beam, FOD (release film) was included on the NNP side and two knife cuts were made on the NP side as shown in Fig.4. The details of the defects simulated are as in Table 1

Table-1: Details of Defects Simulated

Sl No.	Type of defect	Location	Dimensions (l*b*t) in mm
1	Release film	#180 to #280 (NNP)	100*11.5*0.12
2	Knife cut	#100 to #150 (NP)	55*1*5
3	Knife cut	#180 to #240 (NP)	60*1*5

3. RESULTS AND DISCUSSION

Testing of flex beam involves ultrasonic C-scan test, CT scan, stiffness, flexural and interlaminar shear strength test. The results of these tests are discussed below

3.1 C SCAN

C scan shown in Fig. 5 is based on the ultrasonic principle and used to detect hidden (internal) defects. The sound signal with a frequency above 20000 cps is referred as ultrasonic sound. The principle of ultrasonic examination is based on transmitting a sound signal of ultrasonic nature through the object which is under test and receiving the transmitted signal. If the sound signal passes through the component without much attenuation the component or test specimen can be cleared as defect free whereas if the signal does not pass through the component it indicates the presence of defect. C scan can be defined as mean for data presentation, which provides a plane view of the test component and discontinuation. The type of defects that can be identified from C scan are debonding, delamination and FOD's. The major limitation of C scan method is that the depth of defect cannot be identified.


Fig-5: Ultrasonic C Scan

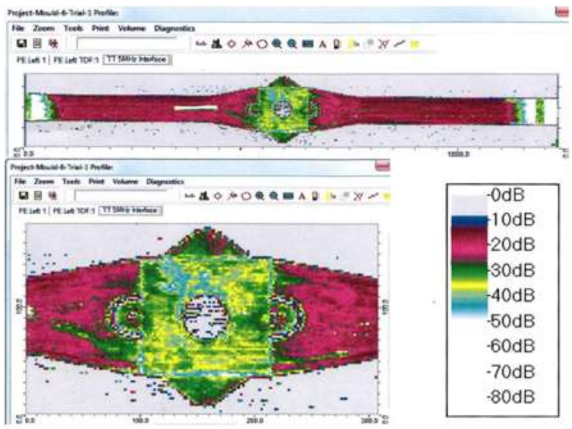

Fig.6: C Scan Plot

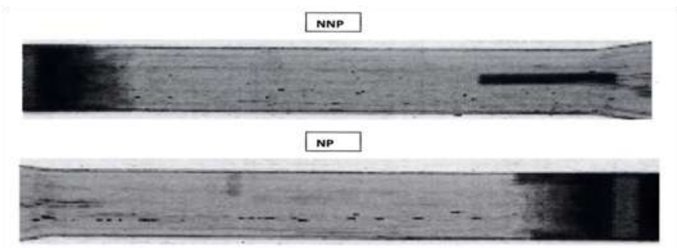

Fig-7: C Scan (grey scale) Plot

The detailed analysis of C scan plots was done for flex beam trial 1 and it concludes that the defects can be easily identified with C scan. The white colour object in Fig.6 on NNP side indicates release film while several small white dots on NP side represents air pockets. The graph reads that good section of flex beam will be shown with blue and pink colour whereas the sections which are not acceptable and considered as defects will be shown with other colours. Each colour has a definite dB as shown in Fig. 7 shows the grayscale view of the flex beam.

3.2 CT Scan

A CT scan, also known as computed tomography scan, makes use of computerprocessed combinations of many X-ray measurements taken from different angles to produce cross-sectional (tomographic) images (virtual "slices") of specific areas of a scanned object, allowing the user to see inside the object without cutting. The main advantage of CT scan is that it is not restricted by the shape or composition of the object being inspected, however the width of the specimen is limited to 0.5 m.

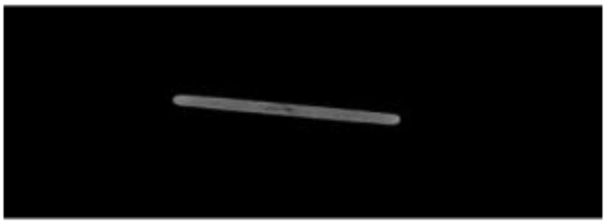

Fig-8: CT Scan Image with Release film

In Fig.8, the black colour that is seen in the cross sectional image of the flex beam indicates the presence of release film.

3.3 Stiffness Test

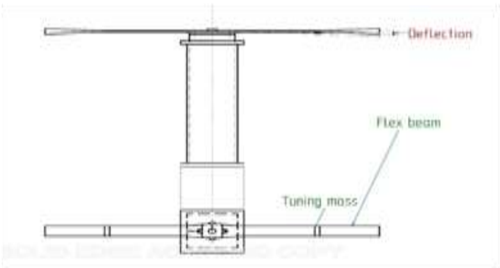

Fig-9: Stiffness Test

Stiffness is defined as the ability of body to resist deformation. It is the rigidity of body or the extent to which it resists deformation in response to applied force.

Table- 2 Tabular Column for stiffness test

NNP Side			NP Side
Sl. No	Load (kg)	Dial gauge reading (mm)	Dial gauge reading (mm)
1	0	39.5	39.94
2	5	31.6	32.33
3	10	24.97	24.73
4	15	17.6	17.35
5	20	9.09	10.93

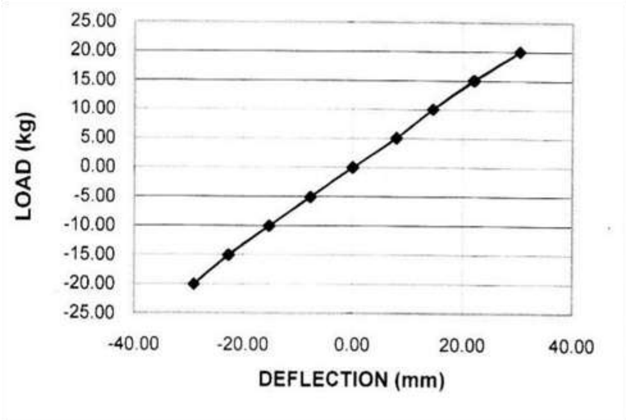

Fig-10: Graph of load v/s deflection

From the plotted graph**s**, slope i.e. stiffness was found to be 0.671 kg/mm for both the trials and hence the values are within the acceptable limits.

3.4 Flexural Test

Fig-11: Three point bending test

Three point bending test is used for the determination of using UTM as shown in Fig.11 and the standard used is ASTM D790. As per this standard, the length, width and thickness of the specimen are 140mm, 16±0.2mm and 4±0.4 mm respective.

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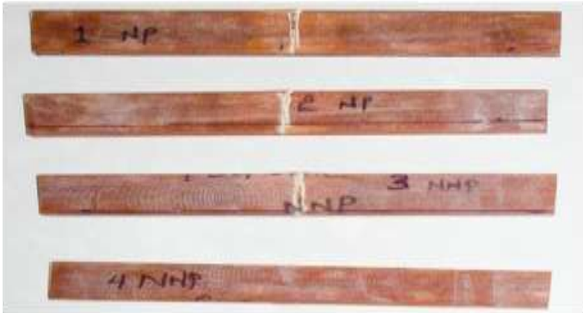

Fig- 12: (a)Flexural Specimens After Test

Fig-12: (b)Delamination Due to Release Film

Fig.12 (b) shows the delamination of the specimen 5 due to realse film

Table- 3: Flexural Test Results

Sl. No	Specimen dimension (l*b*t) in mm	Max. load in N	Flexural strength in MPa
1	140.73*16.26*4.42	2724.400	1286.462
2	139.72*16.53*4.43	2636.200	1218.959
3	140.85*16.58*4.40	2832.200	1323.504
4	140.82*15.80*4.33	2626.400	1270.537
5	140.83*16.31*4.43	1679.600	927.699
6	140.31*16.62*4.36	2724.400	1276.734

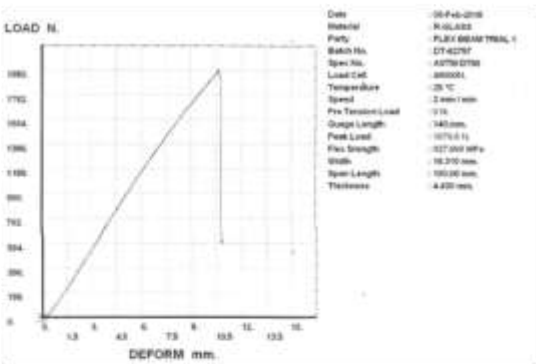

Fig. 13: (a) Flexural Test Graph for Specimen 5

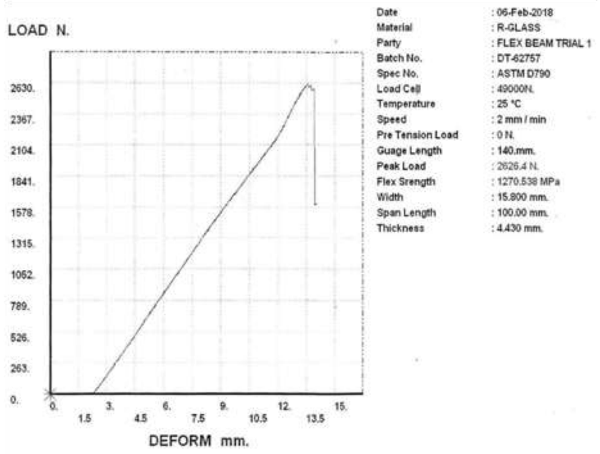

Fig- 13: (b) Flexural Test Graph for Specimen 4

The flexural strength obtained for all the specimens are above the acceptable limit except 5th specimen because this specimen contained release film and due to this FOD, the specimen could not provide desired flexural strength. If we look at the Fig. 13(a), rupture of the specimens has taken place well before 12mm and thus these specimens get rejected. Fig. 13 (b) is acceptable because it has both the flexural strength and deformation as desired.

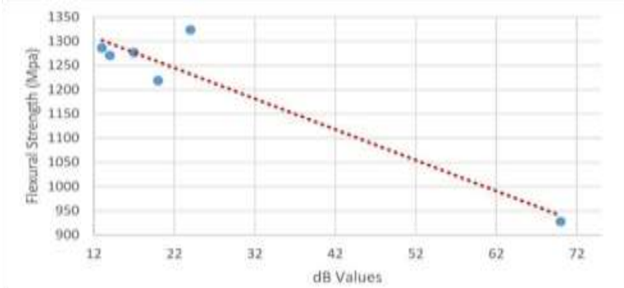

Fig- 14 (a) Flexural Strength vs dB Values

The Fig. 14(a) shows that Flexural strength is indirectly proprtional to dB values i.e as the dB value increases, Flexural Strength decreases and vice versa.

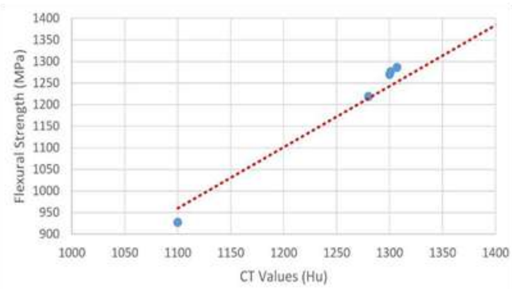

Fig- 14: (b) Flexural Strength vs CT Values

The Fig. 14(b) shows that Flexural strength is directly proprtional to CT values i.e as the CT value increases, Flexural Strength increases and vice versa.

3.5 Interlaminar Shear Strength (ILSS) Test

Three point bending test is carried out to determine the shear strength of the interply shear strength. The standard followed for this test is ASTM D2344. The standard length, width and thickness of the specimen are (40 X 12 ± 0.1 X 6 ± 0.3) mm respectively. The specimen ends rest on two supports that allow lateral motion, the load being applied by means of a loading nose directly centered on the midpoint of the test specimen.

Fig- 15ILSS Specimens After Test

Actual specimens for ILSS test are cut from NP side of the flex beam, the details of which are given in Table 4.

Table- 4: LSS Test Results

Sl. No	Specimen dimension (l*b*t) in mm	Max. load in N	ILSS in MPa
1	40.80*11.90*6.17	7957.600	81.285
2	40.46*11.98*6.16	8006.600	81.371
3	40.48*12.04*6.18	8261.400	83.272
4	40.45*11.99*6.16	8075.200	82.412
5	40.17*11.98*6.18	7928.200	80.313
6	39.90*12.08*6.18	8036.000	80.732

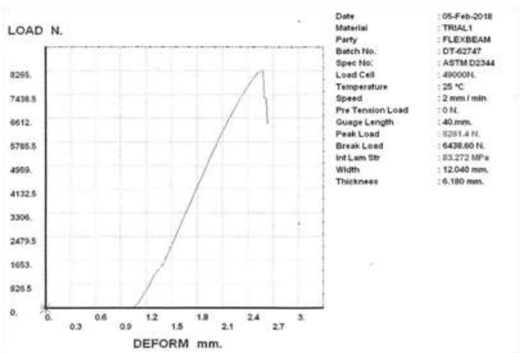

Fig. 16: ILSS Graph for Specimen 3

As ILSS values obtained for different specimens are above the acceptable value, thus it can be concluded that the flex beam will not fail when subjected to interlaminar shear loading.

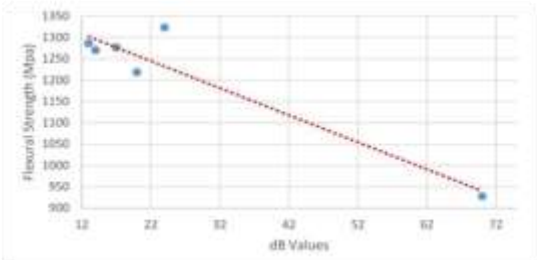

Fig- 17: (a) Flexural Strength vs dB Values

The Fig. 17(a) shows that Flexural strength is indirectly proportional to dB values i.e as the dB value increases, Flexural Strength decreases and vice versa.

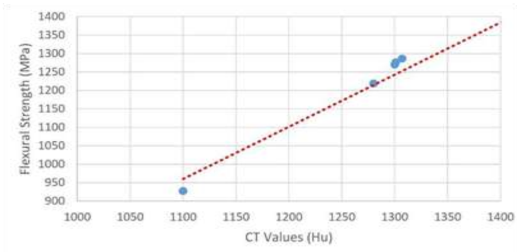

Fig- 17: (b) Flexural Strength vs CT Values

The Fig. 17(b) shows that Flexural strength is directly proportional to CT values i.e as the CT value increases, Flexural Strength increases and vice versa.

4. VALIDATION

4.1 Stiffness Test

Experimental stiffness value is obtained directly from the slope while the Theoretical stiffness is calculated using

$$K = F/ó$$

Table- 5: Tabular Column of Experimental and Theoretical Stiffness Values

Sl No.	Experimental value (Kg mm)	Theoretical value (Kg mm)	Error (%)
1	0.671	0.668	0.45
2	0.668	0.669	0.15
3	0.732	0.731	0.14

From the Table 5 it can be noticed that percentage error of stiffness is not more than 1% wish is acceptable

4.2 Flexural Test

The theoretical Flexural Strength is computed using the following formula [ASTM hand book],

$$F = 3PL/2be^2$$

Table-6: Tabular Column of Experimental and Theoretical Flexural Strength Values

Sl. No	Experimental value (MPa)	Theoretical value (MPa)	Error (%)
1	1286.462	1286.462	0.00
2	1218.959	1218.959	0.00
3	1323.504	1323.504	0.00
4	1270.537	1329.900	4.46
5	927.699	787.110	17.17
6	1276.734	1293.425	1.29

From Table 6 it can be conclude that for specimen 5 the percentage error is 17% which is not acceptable for flexural strength

4.3 Inter Laminar Shear Strength Test

Theoretical Inter Laminar Shear Strength is computed using the following formula[ASTM hand book].

$$F = 0.75*(P/ b*h)$$

Table-7 Tabular Column of Experimental and Theoretical ILSS Values

Sl. No	Experimental value (MPa)	Theoretical value (MPa)	Error (%)
1	81.285	81.285	0.00
2	81.371	81.371	0.00
3	83.272	83.272	0.00
4	82.412	82.000	0.500
5	80.314	80.314	0.00
6	80.732	80.732	0.00

From table 7, it can be noticed that percentage error is negligible for ILSS test

5. CONCLUSION

Flex beam is a critical, dynamic and integral part of the tail rotor blade of a helicopter and small deviation in its normal behavior could lead to catastrophic failure of the helicopter. In this project work property evaluation of composite flex beam is done and from the results obtained it can be concluded that

- There was no significant change in the stiffness value of all the flex beams. The values obtained were well within the acceptable range of 0.59 to 0.88 kg/mm.
- Except for release film, other simulations (defect) had no significant effect over the flexural strength value and their values were well above the minimum acceptance value of 1200 MPa. There was 22.69 % reduction in flexural strength due to release film i.e. flexural strength of 927.699 MPa was obtained.
- Simulations of knife cuts had no significant effect over the ILSS value and their values were well above the minimum acceptance value of 72 MPa.

Flex beam with release film is rejected whereas the same with other defect is accepted as it gives satisfactory stiffness and strength values.

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