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Fatigue Life Behaviour of Woven GFRP Composite Laminates with Impact Damage

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Abstract: Composite materials have become viable alternative to metallic structures in aircrafts and automotive sectors. These structures prone to impact and fatigue loads. The objective of this paper is to investigate the effect of low velocity impact and tension-tension type fatigue on woven glass fibre/epoxy polymer composite laminate. The impact damage and fatigue life is inter-linked in this work. The laminates were prepared by hand layup process having a thicknesses; 2mm. The specimens were subject to low-velocity impact at different energy levels (7.85, 15.7 and 23.54 Joules). The fatigue test was conducted for both impacted and non-impacted laminates, by keeping the stress ratio,R value at 0.1 and frequency at 3 Hz. The results indicate that the impact velocity is very much influential on the fatigue life of composite laminate. Further the results indicate that the fatigue life of the 2mm thick impacted laminates was drastically reduced. A comparative study is also attempted to understand the behavior of impacted laminates subjected to fatigue loading.

Keywords: Low velocity impact, Composite Laminates, Fatigue life prediction.

I. INTRODUCTION

Composite material signifies the two or more materials are combined on a macroscopic scale toform third material. The most advanced composite material is polymer matrix composites. Epoxy, polyester, etc. are some of the reinforcements. Glass, graphite, aramides etc., are some of the fibres. Glass and epoxy are most used PMC's because it has more strength to weight ratio, low cost, high chemical resistance.Composite materials however have some limitations say tensile and compression properties, fatigue life, impact response, Residual strength etc... Perhaps the most significant among these is the behaviour of fatigue when the impacted laminates are subjected to fatigue loading for safety and reliability of structures. The impact damage may occur accidently at the time of manufacturing, fall of tools on its life time, from flying debris etc. from past decades several work is going on the impact related to the residual strength, tensile and compressive properties etc.The parameters like height of fall, impact mass, impact velocity, type of impactor etc. and also number of impact failure properties like, matrix and fibre damage, inter cracking, laminate splitting, deboning, delaminating, pull-out of fibre etc. [1-5].

Due to the practically impact damaged components are can't see with our naked eyes, but there is some effect on the structure for after some long time. So it is very essential to predict the damage on the material surface. From long ago investigations is going on the fatigue in the laminates after impact loading is done. Low velocity impact will much influence on the fatigue life and consequent reliability of the affected structure [6-10]. Pre impact fatigue behaviour is still unlikely to be fully understood even for a material which the fatigue response in undamaged laminates is known [11-13].   For such conductions fatigue life is predicted at different loading conductions is necessary. Fatigue is nothing but applying the cyclic load on the work. The current paper talks about the fatigue life of woven glass fibre/epoxy polymer composite laminates with impact damage it include the delamination and crack growth due to the combined effect of impact and fatigue.

II. EXPERIMENTS

A. SPECIMENS

The tested material was woven glass fibre epoxy matrix composite laminates of EP3 grade produced by ICP (India) Pvt. Ltd., Bangalore, of thicknesses, 2mm. The Composite laminates were fabricated by wet hand lay-up technique. E-glass plain weave roving fabric, compatible to epoxy resin is used as the reinforcement. Araldite LY 556 epoxy resin with HY 951 grade room temperature curing hardener with diluent DY 021 mix was employed for the matrix material. The choice of hardener depends on the pot life, curing temperature and heat resistance required. The hardener HY 951 was added to araldite LY 556 and araldite DY 021 at room temperature. [15].

B. IMPACT TEST

The tests were performed using an instrumented falling weight testing machine with no energy storage device. The maximum impact energy is limited by the adjustable falling height and the fixed mass, 15.6 kg, of the impactor [16]. The impactor mass together with the height of drop determines the energy of impact. With an increase in mass and height the potential energy of the dart will increase and thus on releasing the tool holding assembly the potential energy is converted to kinetic energy. [20]

The test is done in accordance with ASTM D 3029 standard a batch of rectangle, a thin (150 mm × 50 mm side, 2mm thick)[18] specimen is clamped on a fixture with a rectangular slots. The dart has a hemispherical head of 10 mm radius. The piezoelectric load cell is placed at the other extremity of the calibrated cylindrical rod that constitutes the dart, at which the pushing mass is connected. A fixed impactor mass of 15.69 N [17] with the dart was released from varying heights; 0.5, 1.0 and 1.5 m. The vertical guides of the impact tower were lubricated frequently to minimize any friction generated during the descent of the impactor.

C. FATIGUE TEST

For the fatigue test the specimen is prepared as per ASTM D3479 test STD it is shown in the fig2.1.Aluminum is used as tab is done at edges of the specimen by glowing. The servo hydraulic computer controlled Fatigue testing machine is used [19]. Two jaws are operated by hydraulically because it holds the specimen very rigidly and handling isalso easy.

The input values given for the testing as stress ratio R=0.1, frequency as 3Hz. The frequency is kept below 5Hz to avoid thermal effect on the specimen and it also reduces the fatigue life. The maximum load on the specimen is 60% to 70% of the ultimate tensile strength for the unimpacted specimen.The failure of the specimen is found by transmitting the light through specimen. [14]

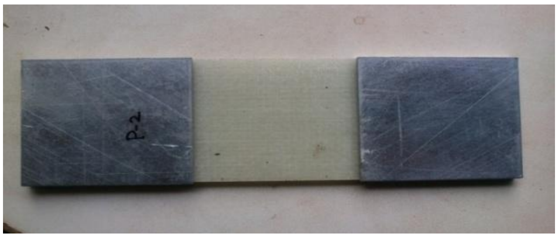


Fig.1 Specimen used for FATIGUE TEST

III.RESULTS AND DISCUSSION

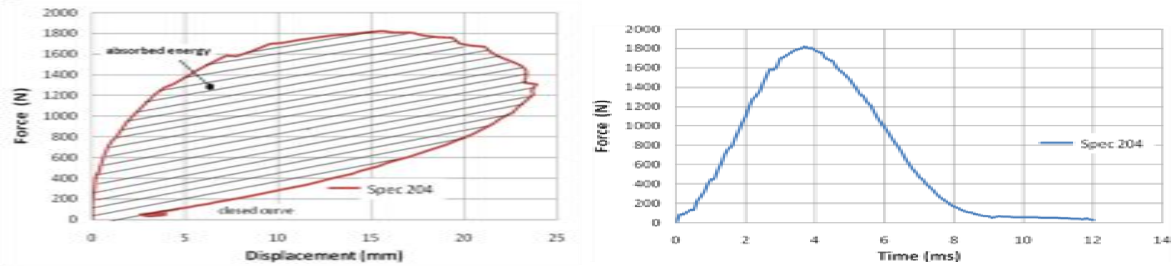
A. LOW VELOCITY IMPACT:

There has been a growing interest to use composite materials in structural applications on account of their extraordinary properties compared to conventional materials. Hence it gains high importance to predict their response to an impact loading. In this work, variation of impact parameters such as contact force, displacement, impact velocity, and absorbed energy versus time or deflection is examined in order to figure out damage process of woven fabric GFRP composites laminates in an impact event. The study is expected to be helpful in understanding the overall response of woven fabric composite plates under impact loading. For this purpose, a number of tests were performed under varied impact velocities ranging from approximately 3.132- 5.425 m/s. Therefore, in the following, energy profile of the woven composite, the load–deflection curves and the images of some damaged specimens are discussed.

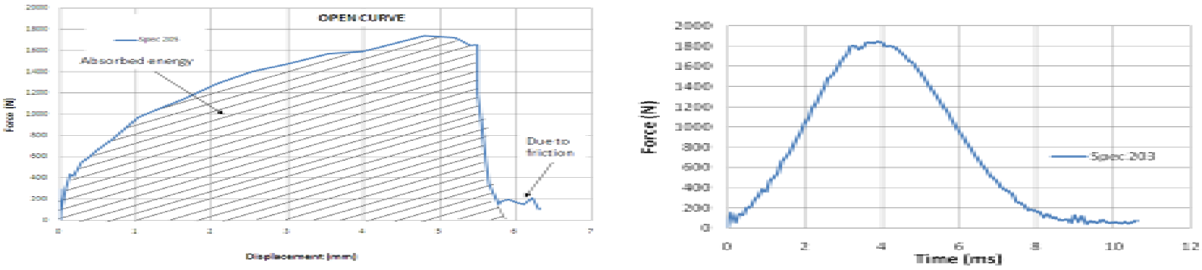
Graph represents the histories of force and deformation energy. Impact energy (Ei) and absorbed energy (Ea) are the two main parameters that are used to assess the damage process in composite structures after an impact event. Impact energy is the kinetic energy of the impactor right before contact-impact takes place while absorbed energy is the amount of energy absorbed by the composite specimen at the end of an impact event. Absorbed energy is calculated from force-displacement curves.

The experimental tests were performed on three specimens for a thickness; 2mm. Tests were performed two times at three energy levels determined by the falling height, namely 500, 1000 and 1500 mm. The corresponding values of the nominal impact velocities are 3.132, 4.429 and 5.425 m/s. From an energy point of view, Fig. 3.1 shows six curves of force versus displacement and force versus time of the dart at various levels of impact energy. This figure allows us to clearly detect the transition from rebound to perforation, in the perforation cases the curve ‘‘folds’’ onto itself toward decreasing displacement, while in the rebound cases the displacement is monotonically increasing. The transition case is shown by the fifth curve (corresponding to 1000 mm of falling height and 5.125 m/s of nominal impact velocity) thatevidences very little rebound of the dart after the maximum penetration has been reached.

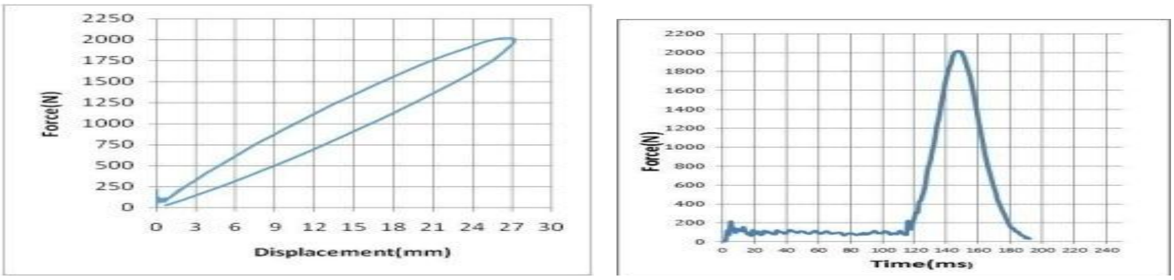
Fig. 3.1(i. iii, v) indicates the time histories of the dart displacement and force. Fig 3.1 (ii, iv, vi), indicates the histories of the force and time. The force history showed two thresholds, the first one at about 360 N, where the curve sharply changed its look and a deviation was visible, the second one was at 1260 N, where the curve sharply dropped down and then started again to grow but with a slope lower than the previous one. The first threshold is the indication of the first material damage. The second threshold occurs at the first lamina failure. The force versus displacement graph (Figures 3.1(i, v)) shows a closed loop. The area under the curve is the absorbed energy that was progressively transferred from the dart to the plate, when the saturation of the load carrying capacity of the plate was reached. The shaded area represents the energy absorbed by specimens during impact tests resulting in closed type curves. For specimens having rebounding, i.e. closed type curves, the absorbed energy can also be calculated from the initial kinetic energy minus the rebound kinetic energy using the initial and rebound velocities. Fig3.1 (iii) Indicates graphs for a case of perforation. Measurable ‘‘end of contact’’ time can be detected when the force between specimen and dart returns to null (Fig. 3.1(ii)). At this time the energy balance can be formulated and thus obtain the whole energy dissipated by the specimen in order to initialize and propagate fractures inside the material. Another measurable characteristic time can be defined when the dart velocity becomes zero, at this time the dart has reached its ‘‘maximum penetration’’.
Impact Velocity of 3.132 M/Sec for Specimen No. 1



Graph 1: Impact Velocity of 4.429 M/Sec for Specimen 2



Graph 2: Impact Velocity of 5.425 M/Sec for Specimen No. 3



Graph 3: **I**ndicate graphs for a case of perforation

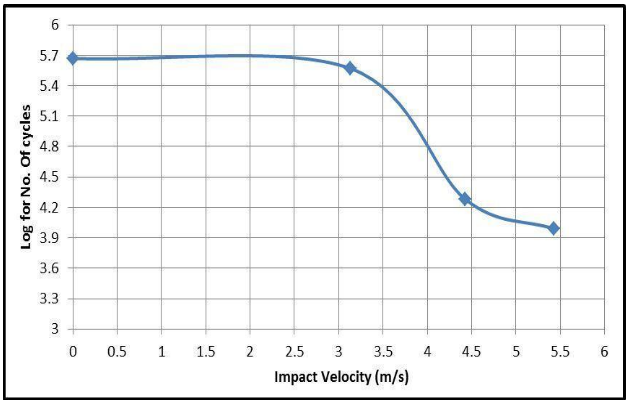
D. FATIGUE TEST
Graph 3 shows Log of cycle’s v/s Impact velocity (m/s) for fatigue life time curve, under Tension-Tension fatigue loading for 2mm thickness of woven glass fibre reinforced polymer composite laminates with and without impact loadings respectively. The impact damage decreases the fatigue life of the composite laminates. At the low velocity (3.132m/s) the impact damage has less effect on fatigue life compared to other velocities and so in the Log of cycle’s v/s Impact velocity curve. The fatigue life was determined for the laminates under impacted &unimpacted laminates of

2 mm thick woven glass fibre/epoxy polymer composite laminates low velocity impact of 3.132m/s, will not much effect on the fatigue life of the laminates at the impacted andunimpacted, there is small variation on the fatigue life compared to the other velocity's 4.429 & 5.425 m/s. The fatigue life at these impact velocities is very small, because which cause the fibre damage in the laminates during impact loading. Because there is very less damage on the fibre which will not affect much on fatigue life, the damage of fibre and matrix is more in 2mm thick laminates this will influence on fatigue life. The matrix and fibre damage is high in the 2mm thick laminates at 4.429 & 5.425 m/simpact damage then compared to 3.132m/s so this is not much effect on the fatigue then other two impact velocities.

Table 1: Summary of the calculated impact energy

Specimen no.	Thickness, mm	Mass, kg	Height of fall, m	Impact velocity m/s	Impact energy, joules	Max load, N	Energy at max load joules
1	2	15.69	0.5	3.132	7.85	1822.5	7.696
2	2	15.69	1.0	4.429	15.7	1755	13.01
3	2	15.69	1.5	5.425	23.54	2016	22.275

In each fatigue cycle the tensile fatigue load caused due to local buckling and displacement of the impact damage site. This was visible from front and back faces at the speed of fatigue cycling (3Hz). The amplitude of moment was in the range of 2mm.In the tension phase of fatigue cycle the crack has beenstarted from the impacted edge and after a few hundred cycles the cracks distributed to edges of the laminates. In later stages of fatigue test some of surface plies would delaminate from the damage plies and buckle during the tension phase of the cyclic loading. This delamination buckling would occur predominantly on the back face through occasional on the front face close to the impact damage site. The crack is incremented throughout the width of composite laminate. The crack was elongated there is a reduction in the stiffness of laminate. It would appear that matrix and Fibre failure increases gradually within the impact zone, it leads to the reduction in the stiffness.



Graph 4: 3 log of No. ofcycles v/s impact velocity (m/s) for fatigue life time curve, under tension-tension fatigue loading for 2mm thickness.

TABLE 2: Fatigue test results

Thickness of specimen (mm)	Specimen No	Impact velocity (m/s)	No. of cycles	Log for No. Of cycles
2	A2	0	4,66,852	5.669
2	01	3.132	4,58,208	5.661
2	02	4.429	19,077	4.280
2	03	5.425	9,710	3.987

IV. CONCLUSIONS

The investigation of the effect of low velocity impact and tension-tension type fatigue on woven glass fiber/epoxy polymer composite laminate has led to the following conclusions:

1) These impact tests have shown that the dynamic response of the laminates depends on the elastic properties of the fiber material.

2) The force versus displacement and the time versus force curves for each case have been drawn.
3) The laminate sustained the impact with delimitation onthe outer layer at an impact velocity up to 3.132 m/sec, whereas, at impact velocity of 4.429 m/sec, the laminates sustained catastrophic failure.
4) The experiments indicate that the impact damage has a significant effect on the subsequent fatigue life of the component.
5) At low velocity impact damage (3.132m/s) less effect on the fatigue life compared to other velocities & it is so in the log of number. Of cycle's v/s impact velocity curves.

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