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Experimental And Finite Element Analysis Of Mechanical Response On Unidirectional Glass Fibre Epoxy Laminate

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Abstract : Research in low velocity impact loading of composites is aimed at reducing the degree of damage in order to improve the damage tolerance. A number of approaches have been used to improve the impact damage resistance and tolerance of composite materials. These include control of fiber/matrix interfacial adhesion, laminate design and through the thickness reinforcement. One of the techniques of arresting delamination is providing through-the-thickness reinforcement like stitching. The objective of this work is to understand the influence of stitching on the impact of the laminate. In this paper, the drop weight impact properties of stitched and unstitched glass fibre epoxy laminate are compared experimentally and the damaged specimen are assessed using back lighting photographic technique. A detailed comparison between the stitched and unstitched laminates experimentally confirmed that the stitching effectively suppressed the out of plane impact damage.

Keywords: Stitched laminate, drop weight impact

1. Introduction

In terms of structure, materials can be divided into four basic categories: metals, polymers, ceramics, and composite materials. A composite structure is a material composed of two or more phases combined in a macroscopic scale, whose properties are superior constituent materials, acting in an independent manner. In other words, a composite is a combination of at least two different materials both chemically and geometrically.

Composites are materials of choice for light-weight structures due to their excellent weight/strength and weight/stiffness properties. Composite structures may be subjected to low-velocity impacts. Many parameters are involved in impact problems (the projectile mass, velocity, kinetic energy, the shape of the end of the projectile, the span of the target, boundary conditions) and this induces very different target responses depending on their specific set of interactions. Under the dynamic loading of the material, these unseen damages can become larger and even cause the loss of the material. Because of this, on a layered composite build, foreseeing the damage caused by the impact is

very important on design and usage. Though composites have excellent mechanical properties over conventional metallic materials, their use in advanced technological applications has been limited due to their poor translaminar properties.

Catastrophic propagation of delamination in various composite structures is of serious concern. Delamination can occur in composite materials due to various scenarios like low velocity, high strain rate and ballistic impact. Such impacts may occur during fabrication, normal maintenance operations or during service conditions. Such damages are not detectable to the normal eye (the damage being in a subsurface region or being too small to be visible to the naked eye), which adds to the critical nature of low velocity impact damage. Delamination is of major concern because there is significant loss of stiffness and compressive strength of the composite material. On the other hand, during routine maintenance activities and during operation, composite components may be subjected to repeated impact at localized sites. The resultant damage may seriously impair the subsequent mechanical performance of the composites. Thus, it is appropriate to investigate the effects of impact on structural composite materials. One of the techniques of arresting delamination is providing through-the-thickness reinforcement like stitching of the fibre.

2. Experimental Procedures

2.1. Materials

The material used as fibre is unidirectional glass fibre and the resin used is epoxy LY 556 in the fabrication of the composite material. The hardener used is HY 951. Epoxy and hardener are mixed in the ratio 10:1.

2.2. Preparation of specimen

The specimen dimension for drop weight impact testing as per the standard ASTM D5628 – 96 is 89x89 mm and 5mm thickness.

2.2.1. Unstitched specimen

The unstitched specimens are fabricated for the stacking sequence (0/45/-45/90)s. It is done by hand layup process first and then it is compressed at 5 bar pressure and 70°C temperature for 5 minutes in the compression molding machine as shown in Figure. 1.

Figure. 1 Compression Molding of the laminate

2.2.2. Stitched specimen

The stitched specimens are fabricated for the stacking sequence (0/45/-45/90)s. In this process, a stack of plies consisting of nominally in-plane fibres is penetrated and bounded together by the stitch thread and selvage thread. Stitching is done by polyester and cotton yarn. Figure. 2 illustrates the stitching pattern. Stitching direction is perpendicular to the fibre direction 0° surface layers of the laminate. The volume fraction of stitch thread material is about 0.4%. In order to reduce fibre distortion in the interior of the laminate, a modified lock stitch is adopted for stitching by easing the tension of the stitch thread. The stitch space and the stitch pitch is both 3 mm. The stitched plies were impregnated and molded by Resin Transfer Molding (RTM) method as shown in Figure. 3. Finally it is compressed at 5 bar pressure and 70°C temperature for 5 minutes in the compression molding machine.

Figure. 2 Cross section of the laminate along the stitch thread

Figure. 3 Resin Transfer Molding (RTM) of the Stitched laminate

2.3. Drop weight Impact testing

Standard test Method for Impact Resistance of a composite laminate by means of a drop weight is ASTM D5628 – 96 [2]. A drop weight impact test is performed on the fabricated laminate. Damage is imparted through out-of-plane, concentrated impact using a drop weight with a hemispherical striker tip. The damage resistance is quantified in terms of damage size and type of damage in the specimen. The result is stored in terms of load, velocity and displacement as the function of time. The damage resistance of the laminate depends upon specimen geometry, layup, impactor geometry, impactor mass, impact force, impact energy, and boundary conditions. The damage response parameters can include dent depth, damage dimensions and through-thickness locations, as well as the force versus time curve.

The impactor nose is hemispherical with a diameter of 12.5 mm. The weight of impactor is 12.967 kg. The boundary condition is clamped. The impactor is dropped under gravity assisted free fall

condition from three heights viz. 550 mm, 650 mm and 750 mm.

2.4. Assessment of Impact damage

The damaged specimen is visually inspected to assess the damage occurred such as matrix cracking, flaking of matrix, and fiber breakage etc. The extent of the damage is measured by exposing the impacted laminate against a bright light source from behind the damaged plate. The damaged area is mapped on to a graph sheet and the damage area is measured. Damages of all types scatter the light and thus make the damaged area opaque. The perpetrated portion of the plate allows the light to pass through and that particular portion is bright. The experimental

Specimen	Drop height (mm)	Velocity (m/s)	Damage force (N)	Peak deformation (mm)	Peak energy (J)	Peak force (N)	Total energy (J)
Unstitched	750	3.836	41.649	4.953	17.415	527.142	41.185
	650	3.571	36.103	4.458	15.587	502.275	39.862
	550	3.284	35.524	4.428	15.329	482.513	35.894
	75	3.836	26.	6.001	11.	367	23.

The data from the impact test system is stored for each sample in terms of load, velocity and displacement as function of time. Overall 4,932 data points are collected over the impact duration. Data collection is triggered by means of velocity detector just before the drop weight impacts the specimen. In the current study, the impact phenomenon is characterized in terms of peak load, absorbed energy and damage area. Energy absorption in composites is mainly through two modes: elastic strain energy and through various damage modes. As composites are brittle in nature, there is no associated plastic deformation. The absorbed energy is calculated as the

composite plates are subjected to back lighting photographic techniques and damage area is identified with area bound by opaqueness

3. Results and discussion

The impact forces increases with increasing drop height for both stitched and unstitched laminate. It is further observed that the impact force by unstitched laminate is always greater than the stitched plate. It could be due to high stress induced in the stitched points which absorbs some amount of impact force. Table.1 shows the comparison of both stitched and unstitched laminate by experimental results for various test conditions.

Stitched	0		133		284	3.39	735
	650	3.571	22.457	5.770	9.451	329.311	22.560
	550	3.284	20.416	5.442	9.414	288.968	21.012

Table. 1 Impact response of stitched and unstitched laminate

difference of total energy absorbed by the specimen at the end of the impact and the energy at peak load. Dynamic response of stitched and unstitched laminate is compared by plotting load and energy curves as functions of time. Figure.4 represents plots of force vs deformation responses of stitched and unstitched laminate at 3.836 m/sec. This velocity level is chosen to represent the general trends in the response, though it is possible to plot these curves for all the velocity levels. The slope of the load time plot increases with increases in impact velocity. Peak load increases as the velocity increases.

At higher energy levels, the curve shows oscillations, which indicate the onset and propagation of damage in the laminate. This indicates that there is very little impact in the laminate. At 30 J impact energy, there is qualitative indication of damage by small oscillations in the load after peak load has been reached. With further increase in the impact energy, the load drops become more evident. At 30 J, the first indication of penetration is evident at the impact location by means of cracks along the dent circumference and the tensile split of fiber tow on the back surface. The dent depth increases further at 31 J with the damage size increasing on the back surface with a through penetration. For unstitched laminate, it was observed that in plane damage area was more compared to stitched ones. On the other hand, in the case of stitched laminates, stitching contains the damage within the grid location. Visual observation of the failed stitched laminate indicates that damage area is highly localized.

Figure.4 Force vs Deformation responses of stitched and unstitched laminate at 3.836 m/sec

Table. 2 gives the comparison between stitched and unstitched values of the impacted damage area of the composite plate for the various test conditions. As the impact energy increases, the damage size increases rapidly for unstitched laminates (Figure. 5). For unstitched laminates, damage spread is conical, with the maximum damage on the back surface. However, for the stitched laminates, propagation of delamination front is arrested at the stitched location and the damage spread through the thickness in cylindrical fashion. However, it should be noted that the damage is very much localised due to the interlocking of the fabric,

resists the splitting of the lamina. It increases delamination strength.

Specimen	Mass (kg)	Drop height (mm)	Initial kinetic energy (J)	Damage area (mm ²)
Unstitched	12.967	750	1443.53	2117.3
		650	1250.97	1679.6
		550	1057.97	1523.6
Stitched	12.967	750	1443.53	350.33
		650	1250.97	339
		550	1057.97	319

Table. 2 Damage areas of stitched and unstitched laminates subjected to different impact velocity

Figure.5 Damage area (mm²) vs Drop heights (mm) for stitched and unstitched laminates

4. Conclusion

The impact forces have been evaluated experimentally by drawing a graph between force vs

deformation for both stitched and unstitched laminates. The peak force of unstitched laminate is more than the stitched laminates. Damage area of unstitched laminate is 83.46% higher when compared to the stitched laminate which was observed for the damage plate of 750 mm height. Stitching of the laminate will further improve the delamination resistance, as the stitching helps in containing the damage within the grid location. Spread of damage is cylindrical in the case of stitched laminates whereas it is more likely to be conical in unstitched laminates.

5. References

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