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Impact Properties of Composites Reinforced by Textile Product

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Abstract

The role of textile reinforced composites subjected to impact force is a vital dynamic trait with respect to composites performance. The effects of impact testing parameters; specimen particulars and impactor factors have a strong bearing on the impact property studies of textile composites. The evaluation of the effects of such impacts is highly complex due to the heterogeneous and anisotropic nature of the textile composites, which is further complicated by the impact parameters. The report mainly discusses the influence of impact test parameters and textile reinforcement along-with matrix, interface effects, impact failure modes and major evaluation techniques for impact damage analyses such as ultra scanning and retention of strength after impact.

Keywords: Textile preforms, impact force, impact parameters, failure modes, evaluation

1. Introduction

Textile structures have long been known as prime reinforcement for composite applications due to their unique properties such as easy handling, shapability and structural complexity [1]. Textile reinforced composites have great potential in high performance applications because of their high in-plane specific strength and high in-plane specific stiffness. Behaviour of composite materials to low velocity impact loading has gained importance as it emulates real world situations, for instance, impact events such as tool drops and contact with other materials, which can cause significant internal invisible or major visible damages to composite structures. For textile reinforced composites this low velocity transverse impact has been identified to be one of the most common forms of loading event that results in failure mode which can adversely affect the structural integrity of the composite structure [2]. Although a clear opinion does not exist, still impact phenomenon has been classified based on the impactor velocity into low (impactor velocity upto 0.25 km/s), medium (0.25-2 km/s), ballistic (2-12 km/s) and hyper velocity (above 12 km/s) [3]. Cantwell and Morton [4] define low velocity impact as upto 10 m/sec considering different impact testing techniques while Abrate [5] terms low velocity impact for impactor speed less than 100 m/sec. According to Olsson [6], definitions of low velocity impact on composites is either the situation when the duration of impact is same as that of the time required for the flexural and shear waves to reach the boundary conditions (impactor of small mass with higher velocity) or when the impact duration is much larger than the time needed for the flexural and shear waves to reach the boundaries (impacts caused by heavier masses at very low velocities).

2. Low velocity impact parameters

The impact behaviour of composite materials subjected to low velocity impact is influenced by the impactor issues and specimen particulars [7]. The impactor parameters mainly impinging impact behaviour are impactor material, mass, shape, incident impact velocity, incident impact energy, impactor shape, drop mode and angle of impact.

A dropped tool on a composite panel during maintenance may not always impact the panel with a relatively blunt shape such as a hemisphere. Lee et al. [8] conducted low-velocity impact tests on simply supported sheet moulding compound (SMC) laminates with conical, flat, hemispherical, and semi-cylinder impactors on specimens of 2.4mm thickness at an initial impact energy of 54.5 J. They found that flat and hemispherical impactors produced similar failure mechanisms and energy dissipation levels. The semi-cylindrical impactor produced a vertically propagating crack. The local indentation induced by the flat and hemispherical impactors resulted in an increase in energy dissipation compared to the semicylindrical impactor. Local penetration was observed from the conical impactor which resulted in the lowest dissipated impact energy. They also found that the type of failure mechanism induced by the impact affected the energy dissipation capacity of the specimen.

The effect of impactor shape on the impact response of thin woven carbon/epoxy laminates has been investigated [9]. The specimens were impacted at initial impact energies of 4J and 6J using steel hemispherical, ogival and conical impactors, all 12mm in diameter. The specimens impacted by the conical impactor absorbed most energy as a result of local penetration. The hemispherical impactor produced the highest peak force and lowest contact duration as expected. Only the hemispherical impactor at an initial impact energy of 4J produced barely visible impact damage (BVID) whereas the other impactor shapes produced permanent indentation and penetration.

Drop weight perforation studies [10] on glass fibre CSM-vinyl ester composite laminates have shown that the work of fracture increased with increasing loading rate (impact velocity). It was inferred that this increase is related to the rate-dependent fracture properties of the glass fibres. Increasing the loading rate effected increase in fibre failure stress and as a result, the stored elastic energy. This in turn increased crack bifurcation and the formation of a larger damage zone during impact. Further, it was found that work of fracture determined on single-edge-notch bend samples correlated well with the drop-weight impact perforation data.

Complete response of composite plate under drop weight impact was proffered by a single factor called Impact parameter λ [11], illustrated by the equation (1) given below.

$$\lambda = \frac{(\alpha_p K^{2/5})(V_o M^3)^{1/5}}{h^2} \qquad (1)$$

Where, α_p is unit laminate thickness parameter, K is Hertz-Sveklo factor, V_o is impact velocity, M impactor mass and h height. Maximum impact force, co-efficient of restitution and time of contact during impact phenomenon can be determined in terms of this impact parameter λ.

When the velocity is varied but the mass of the impactor is constant, the maximum impact energy E_{max}, imparted to the composite increases with time and reaches a constant value i.e., the kinetic energy of the impactor, given by the equation (2) below.

$$E_{\max} = \frac{M V_o{}^2}{2} \qquad (2)\ [16]$$

In order to optimize the impact phenomenon, an estimation of energy loss E_{loss} (3) during impact has been given [12] as follows

$$E_{loss} = \frac{M}{2} * (V_i + V_r) * (V_i - V_r) \qquad (3)\ [17]$$

where V_i and V_r are the impact and rebound velocities. Further it was observed that rather than the total impact energy, impact force history was much more relevant measure for direct composite material characterization. Also the static indentation tests were known to represent the lower limit of impact velocity.

Based on the kinetic energy of the impactor, Cantwell and Morton [13] have ascertained the energy values of impact threats for composite structures that can arise from different causes at several places of the aircraft due to various types of risks, as detailed in the below table 1.

Table 1

Section / Area		**Impact Risk**	**Impact Energy (J)**
Upper wing skin	Inboard (near fuselage)	Falling tools	4
		Aircraft lifting equipment	20
		Refueling by gravity	20
Lower wing skin	Outboard	Falling tools	4
	Outboard + Inboard	Hail impact	30-35
	Outboard	Loading of pylons	16

3. Effect of Textile Reinforcement

Fibres being the principal load-bearing element of the composite structure contribute significantly for its strength and stiffness. Generally high performance fibres and specifically carbon, polyaramid (Kevlar) and glass fibres are extensively used for composite applications. Amongst them carbon fibres have the highest strength and stiffness followed by Kevlar and glass. The elastic modulus of the high performance fibre in the composite is usually much higher than that of the matrix, hence under low velocity impact situations, fibres appear to be rigid, further incipient damage is more matrix and interphase dominated [14]. Nevertheless, the type of fibre, reinforcement geometry, layering sequence and the fibre volume fraction (Vf) have been reported to have a strong influence on the low velocity drop weight impact performance of the composite material.

Fibre´s ability to store energy elastically (work of rupture) corresponding to the area under the stress-strain curve is the fundamental parameter influencing the low velocity impact response of the composite reinforced with it [4]. Reinforcements with high-strain to failure fibres such as ultrahigh modulus high density polyethylene (UHMHDE) and Polyaramid fibres like Kevlar 49 are known to impart high resistance to impact damage [15].

Under low velocity drop weight impacts, carbon fibre composites are known to have lower resistance to impact damage. Carbon fibres, being most brittle, show poor resistance to impact damage compared to glass [16] and Kevlar reinforced composites [17]. Studies on Carbon/Epoxy composites indicate that maximum load increases with impact energy upto 20J beyond which it is almost constant and these laminates will not be able to withstand dynamic peak load beyond 3.6kN. Also the energy to maximum load and defection at maximum load increase with energy beyond 20J for Carbn/Epoxy laminates [18]. Relative comparisons of impact performance of high performance fibre reinforced composite suggest that Kevlar reinforced composites excel carbon reinforced composites.

Studies on glass fibres reinforced epoxy composites report that the maximum impact force is an increasing function of Vf and it increases more than 100% when Vf increases from 0.1 to 0.7. The maximum deflection of the composite plate decreases with increase in the Vf. Even the time of contact of the impactor with the laminate is continuously decreases with increased fibre volume fraction of the thermoset composite under impact [19].

The instrumented impact test plot (Figure 1) on glass reinforced polypropylene thermoplastic composite showing the dependence of fibre initial modulus on the fibre content illustrate a non-linear trend, although in this case also the maximum modulus is in the 40–50 fibre weight % range. Impact properties are reported to increase initially with glass content but drop off when the glass fibre weight content is increased beyond 40 %. At higher fibre content the impact properties decreases significantly and approach the unreinforced polypropylene performance at the highest fibre weight content of 73 % in the composite [19].

3D textile preforms which include orthogonally woven, multi-axial warp knitted, multilayered woven-interlocked and stitched preform composites provide best impact performance, attributed to the third-direction fibres, which hinder crack propagation, increases the impact resistance and damage tolerance [17,18]

Effect of textile reinforcement in the low velocity impact behaviour is very important; it is evident that type of fibrous reinforcement, fibre fraction, its geometry, stacking sequence, fibre orientation and 3D preforms influence the impact behaviour of the composite.

4. Failure modes in textile composites subjected to low velocity impact

Mode of failures in composites is an important factor in damage analyses as it not only provides information on impact event but also about the residual strength of impacted composite. Even the interaction between failure modes is helpful in understanding damage initiation and propagation, which is also useful in modeling the impact behaviour of the textile composites. Fibre reinforced composite materials subjected to impact loads dissipate the imparted energy mainly through several interacting damage modes rather than simple deformations [18].

Cantwell and Morton proposed a pine tree damage pattern and a reversed pine tree damage pattern for the impact-induced matrix cracks in thick and thin thickness laminated composites [4]. In the case of textile reinforced composites there is very little or no plastic deformation and impact energy is initially absorbed through elastic deformation till a threshold energy value. At and beyond the threshold energy value, impact energy is absorbed through both elastic deformation and creation of damage through various failure modes [18] as explained earlier. Of relevance to the present discussion is the work by Davies et al. [19], who showed that in carbon/epoxy composite laminates there is a threshold value of the impact energy below which delamination is not generated, given by the equation (4) below, where Pc is the threshold load, E and v are the equivalent inplane modulus and Poisson ratio, h is the laminate thickness, and G_{IIc} is the critical strain energy release rate. The model indicates that the square of the critical force threshold is proportional to the cube of the laminate thickness. Above that threshold, delamination occurs suddenly, affecting an area that increases slowly with increasing impact energy..

$$P_c^2 = 8\pi^2 E h^3 G_{IIc} / 9(1 - \nu^2) \quad (4)$$

Dorey [25] gives a simple equation for the impact energy (E) required for fiber failure and for penetration,

$$E = \sigma^2 wtL / 18E_f \quad (5)$$

where σ is flexural strength, E_f is flexural modulus, w is width, L is unsupported length, and t is specimen thickness.

5. Evaluation of Impact Damage in Textile Composites

Even when no sign of impact damage is observed at the surface, matrix cracking and delamination can occur beneath the impacted surface, which inturn affect the performance of the composite. Hence evaluation of impact damage becomes critical in these situations and for the same various evaluation techniques are available to assess the damage after impact, which can be broadly classified into destructive and non-destructive evaluation tests.

Destructive techniques generally involve microscopic investigations and impact damage tolerance studies based on residual strength parameters such as tensile, compression and flexural strengths. Microscopic studies have been tried for characterizing the impact damage by visual image analyses and fractographic studies. Chai and Babcock [18], using the shadow moire technique, performed optical measurements on composites subjected to low-velocity out-of-plane impact. Epstein et.a1, [19] used dynamic moiré interferometry to measure the deflection of impacted composite plates.

6. Conclusion

Impact parameters influencing the impact performance include impactor size, shape, weight, velocity and kinetic energy, size and thickness of the specimen, type and span of specimen support. From the reinforcement point of view, work of rupture of the fibre is considered as most important in influencing the low velocity impact properties of the composite, the other factors being type of the fibre, fibre volume fraction, preform geometry, stacking sequence and fiber orientation. Textile composites under impact demonstrate different modes of failure through several interacting damage modes amongst which delamination failure is considered most decisive.

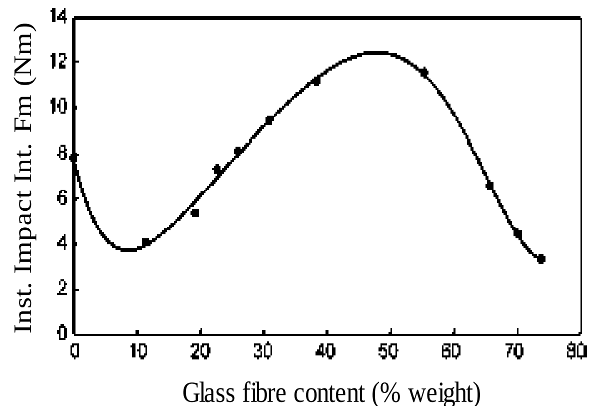

Figure-1 Instrumented impact hehaviour versus Fibre content [19]

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