OPTIMAL LAYUP SCHEMES WITH SELECTIVE DISPERSION OF CORE/SHELL MICROPARTICLES IN PLY INTERFACES OF GLASS/EPOXY COMPOSITE LAMINATES FOR LOW VELOCITY IMPACT

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Abstract: The overall objective of the investigation presented in this paper was to study the effect of selective dispersion core/shell microparticles (CSP) within the different ply interfaces on impact damage behaviour of glass/epoxy laminates. These laminates were fabricated with the 30 g/m\textsuperscript{2} CSP particle areal weight per interface. A series of impact experiments were done with instrumental drop tower device at impact energy of 7.8 J and impactor velocity of 2.4 m/s, which is within a practical low velocity impact range. The analysis of the impact load, contact duration indicates that the presence of CSP particles in the bottom layers has a more pronounced effect on the impact performance improvement as compared to the top layers. In the case of selective dispersion, the presence of particles in the middle plies slightly degrades the performance when compared to the selective dispersion of particles only in top or bottom plies.

Keywords: Glass/epoxy composite laminates, Impact behaviour, Optimal layup scheme, Core/shell particles, Selective Dispersion

Introduction

Composite materials are being used extensively in aerospace, automotive, and marine industries to build lightweight and cost-effective structures. Their usage is also gaining momentum in orthopaedics and spacecraft applications. Composites are well established for its high specific strength and high specific stiffness, which make them a desirable choice for weight critical applications [1-4].

One of the major drawbacks of laminated composites is their vulnerability to impact [5-6]. Aircraft composite structures are often exposed to impact damages from hailstones, tools dropped during maintenance or manufacturing, collisions by service vehicles, foreign objects thrown up from the ground or debris stones from the runway propelled by the tires [7]. These low velocity impacts can create internal damages within the laminated composites which often cannot be discovered by visual inspection and eventually can grow under the applied loading. These damages result in drastic reduction in the residual strength in tension, compression, shear and bending, and to some extent, affect the fatigue and vibration characteristics of the laminates [8-9].
A simple and inexpensive technique for the toughening of composite materials consists of selectively toughening the matrix resin between the plies by using thermoplastic or rubber particles [10]. This technique appears to be the best practical method so far for improving the impact toughness of composites [11]. A new type of particles called core/shell microparticles has been successfully used to improve the impact behaviour of prepreg laminates [12-14]. In this study, selective dispersion of core/shell microparticles has been investigated to understand and arrive at an optimum layup schemes.

**Experimental Details**

The laminates investigated in this research were fabricated using GFE8 L530-7781 prepreg (refer Table 1 for its details) and about 6 to 9 samples were tested in each layup scheme.

| Sample code | Description                                      | Figure |
|-------------|--------------------------------------------------|--------|
| ORG0        | Original Laminate without particle dispersion     | 1a     |
| ALT-7ALL    | Particle dispersed in all 7 interfaces            | 1b     |
| ALT-3BTM    | Particle dispersed only in bottom 3 interfaces    | 1c     |
| ALT-3TOP    | Particle dispersed only in top 3 interfaces       | 1d     |
| ALT-5BTM    | Particle dispersed only in bottom 5 interfaces    | 1e     |
| ALT-5TOP    | Particle dispersed only in top 5 interfaces       | 1f     |

The chosen CSP particles have a soft rubber (PBA) core and a transparent shell of poly (methyl methacrylate) (PMMA) with an epoxy functional group grafted to the shell with the average particle size of about 160 µm. The structure and particle size distribution of the CSP particles has been explained elsewhere [7]. In order to distinguish the effect of particle dispersion in top layers and bottom layers, various layup schemes were worked out. Table 2 shows the various sample codes and its descriptions. Figure 1 illustrates the schematic of different layup schemes used, indicating the point of application of the impact load with tup. The Original laminates (ORG) has 8 layers and are fabricated without CSP particles. Altered laminates (ALT) were fabricated with CSP particles dispersed in 3 and 5 layers with two different configurations; particles dispersed only in top layers and particle dispersed only in bottom layers. All the impact tests were conducted on the GFE8 laminates at the incident impact energy of 7.8 J, which corresponds to the impactor velocity of 2.4 m/s. Dynatub Drop Tower Impact testing machine is used for the present experiments and the details of the impact-testing machine is explained elsewhere [6].
Results and Discussions

Figure 2 shows the maximal load values that the laminate of the various layup schemes withstand during the impact test. It is apparent from Figure 2 that, all the altered laminates irrespective of particle dispersion in 3 or 5 interfaces and top or bottom interfaces, exhibited higher maximal load compared to that of the ORG0 laminate. It can also be observed that the ALT-7ALL and the ALT-3BTM laminates show same maximal load. The other layup schemes such as the ALT-3TOP, ALT-5BTM and ALT-5TOP showed lower maximal load when compared to the ALT-3BTM. Hence, in terms of maximal load, the ALT-3BTM is optimal layup scheme as it withstands the same maximal load as that of the ALT-7ALL.

Figure 3 depicts the contact duration of various laminates with different layup schemes. In terms of the contact duration, the ALT-7ALL shows the lowest, followed by the ALT-3BTM. The contact duration of all the altered laminate with particles was better than the ORG0 laminates irrespective of the layup schemes.

Figure 4 represents the damage index (DI) for various layup schemes. This also indicates the same trend as the maximal load. The ALT-3BTM exhibited the least damage index of all the layup schemes, even better than the ALT-7ALL layup. This is primarily due the high elastic stored energy of the ALT-3BTM layup when compared to all other layup schemes. The damage index of the all layup schemes with particles indicated improvement when compared to that of the ORG0 laminates. It can be clearly deduced that in terms of maximal load, contact duration and damage index, that all the layup schemes
with particles incorporation (whether it is 3 layers or 5 layers; top layers or bottom layers) showed better performance than the ORG0 laminates. Hence, the presence of CSP particles had definite improvement on the GFE8 laminates irrespective of layup schemes.

The ALT-3BTM and the ALT-5BTM shows better maximal load, contact duration and DI than the ALT-3TOP and the ALT-5TOP respectively. Hence it can be deduced, that the presence of CSP particles in the bottom layers has a more pronounced effect on the impact performance improvement as compared to the top layers.

![Figure 2 Maximum load for various lay up schemes](image)

It can be understood that ALT-3BTM shows better impact response than ALT-5BTM in terms of maximal load, contact duration and damage index. Similarly ALT-3TOP shows better impact response than the ALT-5TOP samples. Hence, it can be said in the case of selective dispersion that the presence of particles in the middle plies slightly degrades the performance when compared to the selective dispersion of particles only in top or bottom plies.

![Figure 3 Contact duration for various layup schemes](image)
It has been explained in previous study [6], that the first damage in the laminate precipitated as the matrix cracks in the bottom face of the laminate. When the impact load is applied, the bottom layers will be in tension and the top layers will be under compression. This means incorporation of particle within the interlaminar regions between the layers subjected to tension exhibit superior resistance to impact load and damage.

Conclusions
The present study deals with identifying the optimal layup scheme and effect of selective dispersion of Core/shell particles in the interlaminar interlayers of the glass/epoxy composite laminates. The laminates were fabricated with Core/shell particles dispersed in all seven layers, top and bottom 5 layers and top and bottom 3 layers. The presence of CSP particles had definite improvement on the GFE8 laminates irrespective of layup schemes. In case of selective dispersion, the presence of particles in the middle plies slightly degrades the performance when compared to the selective dispersion of particles only in top or bottom plies. Incorporation of particle within the interlaminar regions between the layers subjected to tension exhibit superior resistance to impact load and damage.

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