CHAPTER 8
IMPACT BEHAVIOUR

This chapter deals with the impact behaviour of PU/E-glass composites by experimental methods. Impact absorption energy of PU/E-glass composites was evaluated using an instrument impact tester with computer interface, which was designed for the purpose. The crack initiation, crack propagation and the total impact absorption energies of PU/E-glass composites were studied experimentally as per ASTM D 256.

Composite materials have several advantages compared to conventional materials. They possess higher rigidity and specific resistance, good oxidation resistance and considerable flexibility in application. However, they often involve long manufacturing cycles, which usually mean high fabrication costs. In addition, their high sensitivity to damage is often a handicap in several applications. Thermoplastic matrix composites can normally surmount these obstacles by virtue of their casting facility. Long-fibre composites are attractive materials with high mechanical performance and their applications, especially in the automotive industry, are currently expanding. However, a limited approach to optimum design, based on existing production technology, necessitates a better understanding of their impact behaviour and damage tolerance.

Glass reinforced thermoplastic has many advantages compared to other materials such as injection molding composites, sheet-molding compounds, and sheet metal. FRP have been used in a variety of applications [132-136], although automotive components are their main area of application, e.g. as bumper beams, noise shields and battery trays. Thomason et al. (1996) reported the
effect of the length and the concentration of glass fibre on general mechanical properties of glass fibre reinforced polypropylene [136 -137]. Investigations with respect to scattering of the mechanical properties [138-140] and fracture behaviours were performed [141-144].

Schledjewski et al. (1994) performed the dynamic mechanical analysis of glass fibre reinforced PP and have tried to describe the stiffness of GMT-PP as a function of glass fibre content and temperature. Notch sensitivity and damage mechanism of glass reinforced PP were studied by other researchers [145-149].

Impact damage may severely degrade the strength and stability of laminated composite structures. For this reason the effect of low velocity impact on composite panels has received much attention in recent years. However, much work has not been carried out on high-rate Impact loading, and the effect of impact load on interfacial interaction of the glass fibre and PU.

Thus, the present work gains importance through investigation on the damage analysis; most of the impact parameters have been undertaken experimentally. This work was focused on qualitative and quantitative study of the low-velocity impact response of four different types of specimens with glass fabric reinforced plastics. The specimens were fabricated according to the manufacturer’s specifications. The specimens were impacted experimentally using an instrument impact tester with a hemispherical tip.
8.1 IMPACT SPECIMEN

The size of the test specimen was 250 mm X 75 mm X 2 mm as shown in Fig. 4.4, which was prepared as per ASTM D 256. The depth under the notch of the specimen is 10.2 mm (0.4 inches).

8.2 IMPACT RESPONSE

Low velocity instrumented impact tests were carried out on laminates made of glass fibre reinforced plastics. The tests were carried out using impact tester (Fig. 8.1), connected to a data acquisition system. The specimens were clamped in a square support, and were struck at their central point by a hemispherical bolt of diameter 5 mm, which was welded to a square MS flat, on which a load cell was mounted to measure the effective impact force. An LVDT attached to the bolt measured the impact penetration dept. The bolt with the flat moves in guide ways to impact the specimens. The variable weight drop hammer actuated the hemispherical bolt assembly. After the first impact, the impactor was seized and stopped to avoid further damage due to rebound. Two separate curves: a) force as a function of depth of penetration, and b) penetration time as a function of depth of penetration were generated by the data acquisition system. Three more types of curves for maximum impact force, total penetration time and depth of penetration for different types of laminates panels were manually plotted for the data obtained from the data acquisition device.
The initial velocities of the impactor were computed for different weights of the freely dropping hammer. The hammer hit the impactor that moved through a distance of 30 mm with higher velocity. The data acquisition system captured the impactor travel distance and travel time. The initial velocity \( v \) was computed by using the equation:

\[
v = \text{impactor travel distance} / \text{time taken} \tag{1}
\]

The impact energy \( U \) is computed by using the relation:

\[
U = \frac{1}{2} m v^2 \quad \text{where } m \text{ is the mass of the impactor} \tag{2}
\]
Fig. 8.2. a) Impact force, b) depth of penetration and c) penetrating time vs. impact energy of PU/E-glass composite specimens
The damage was initiated by the front layer failure in all the tests irrespective of the impact energy. While some of the specimens showed partial failure (no damage caused to the back-layer) others showed total failure. One set of typical experimental results in which distinctly both total and partial failures were observed at an impact energy of 23.4 joules is graphically presented in Fig. 8.2. Force vs. depth of penetration curves [Fig 8.2 (a)] exhibit similar pattern of behaviour in the two regions as identified in the curves: 1) steep increase and 2) zigzag pattern with net decrease in the slope. No ringing in the load cell was ensured before testing and hence the zigzag pattern in the impact behaviour is attributed to the structure behaviour.

In the first region, all the samples showed steep increase until maximum load ($F_{\text{max}}$) and the first major break on the load-displacement curves occurred at the onset of the failure process, i.e. impactor side face sheet cracking. Tensile failure is likely to occur when the face layer is thin and deflections are large so that high tensile stresses are developed in the face layer. The force attains maximum value at a deflection of 0.0004 m for both 16% PU/E-glass and 32% PU/E-glass samples, and at 0.006 m deflection for 5% PU/E-glass and PU samples. The motion of the face layer into the space formerly occupied by the core will not induce any transverse stresses directly or shear stresses at the lower surface of the face layers. The effect was much higher for bending-type load with the top face layers as the transverse direct stress formerly taken by the core might be transferred by transverse shear within the front layer to the surrounding support. The intact core immediately surrounding the damaged core experiences an increased transverse load since it acted as a fulcrum for the bending top impact layer. Another reason for the deformation of the front layer that occurred before its failure is the inability of the adjacent core to support the face layer as the core itself underwent damage [150]. The shapes of the curves indicate the occurrence of no fibre failure in the impactor side (fibre failure on the impactor side face sheet results in sudden drop in the curve) as visualized by the smooth transition of the curve without any sudden load drop. Visual examination
of the impacted samples reveals that the damage in the fibres was developed around the point of impact, which resulted in considerable strength loss. This is observed in steep decrease in Impact force in the curves. The presence of the core material, contributing to the local rigidity of the laminates structure at the impact point, masks the first fibre failure, making its identification difficult [147]. The trend in damage development is similar to the results reported elsewhere [143]; the fractured fibre zone size at the impact side surface continuously increases with energy up to a limiting value, which approximately coincides with the impacter diameter.

In the second region, the samples attained a higher peak load prior to the first major load drop, which is due to the tearing of the impact side layer. The curves show zigzag (several humps) pattern following \( F_{\text{max}} \) suggesting that there exists a multiple step failure mode during the impact. The curves show bilinear behaviour (valleys and humps) following an initial linear response. The valleys are due to reduction of the stiffness of the core caused by the onset of crushing. The interface of the fibre and the skin resist further crushing, which is manifested as humps. Further, valleys are due to the interface failure caused by debonding. This behaviour, which continues throughout the second region, probably means that the local rigidity, rather than the overall structural rigidity, is involved in the impact phenomenon. Both crushing and shearing of the fibre occur under the impact because the impacter diameter is larger than the fibre diameter. Core material being compressed under the blunt impacter is also constrained by the adjacent cells, which causes buckling failure of core. The core damage is represented as multiple load drops of smaller magnitude that occur throughout the loading history of the sample in the second region. The load distributed over a large portion of the composite skin creates more crack surfaces, reflecting a non-catastrophic failure.

In this region, total failure was observed in pure PU and 48 wt % glass/PU specimens and partial failure in 16 wt % glass/PU and 32 wt % glass/PU
specimens. The impact force was inadequate to break the back layer in partially failed specimens. The energy loss, which was slowly recovered, might be associated with the matrix deformation and the impact energy was completely absorbed. The behaviour of the samples in which total failure was observed was similar to the failure mechanisms that occurred in the first region but the load dropped gradually until no load condition. In this region only, the back sheet resisted the impact load. The hemispherical impactor created buckling failure of the fibres in the outer skin, which is a typical failure phenomenon observed in non-sudden failure. Visual examination of the totally failed specimens revealed fibre stretching and fibre separation following debonding in the outer skin, resulting in linear decrease in the impact load.

8.3 IMPACT FORCE

Experimental studies of the impact force history resulting from low velocity impact on laminates specimens have revealed that the impact force is a complex function of the depth of penetration. Maximum contact force experienced during the impact, $F_{\text{max}}$, as a function of impact energy is presented in Fig. 8.2(a). It can be observed that $F_{\text{max}}$ follows exactly the same trend (linear) for all the laminates panels. At a given energy level, the 32 wt % and 48 wt % samples exhibited higher contact forces, because of the higher rigidity of the PU skin. The contact force increased continuously with increase in impact energy, approached a limiting value corresponding to the performance of the face layer that was directly struck by the impactor. It can be concluded that face layer of higher rigidity does not necessarily guarantee a more efficient protection against fibre damage, although the increase in rigidity tended to give better support to the specimen structures. It also resulted in higher contact forces.
8.4 DEPTH OF PENETRATION

Fig 8.2 (b) shows the depth of penetration as a function of impact energy of all the four types of specimens subjected to low-velocity impact. Depth of penetration is highly dependent upon the type of the face layer. The laminates specimens experienced two types of failures at the same impact level and possessed very different permanent indentation depths.

At lower impact energies of 7.5 and 15 J, the impactor penetrated and sheared the face layers and crushed the matrix through some distance in all the cases. At 7.5 J the depth of penetration was nearly the same in all the cases. At 15 J the curves of all specimens show two deviations. The depth of penetration of PU face layer specimens was much higher than the PU face layer laminates structures. This behaviour shows that the PU face layer takes more impact energy than the PU face layer laminates structures. At 22.5 J, the PU face layer specimens completely failed but in the case of PU face layer specimens showed partial failure.

8.5 PENETRATION TIME

Fig 8.2 (c) shows impact penetration time as a function of impact energy. Penetration time increased with increase in impact energy but it decreased in the case of the specimens, which experienced total failure. Penetration time was higher in case of the specimens, which experienced partial failure because the stored energy was not enough to break the back layer. The back layer pushed the impactor backwards slowly. In case of total failure, the impactor sheared the face layer and back layer with minimum or no pushing backwards of the impactor. The impactor teared out the back layer, suddenly the force became zero and hence, the penetration time showed decreasing trend.
8.6 CONCLUSION

The impact response of PU/E-glass specimens' structures was studied experimentally. A modified instrumented impact tester was designed and developed with load cell, LVDT and the data acquisition system to capture the impact data and computed the impact properties of four types of specimens.

The following conclusions were drawn based on the experimental results:

- 48% PU/E-glass specimens have shown superior performance in terms of energy absorbing properties and strength due to the higher stiffness of glass front layer and back layer.

- Three modes of failures namely, PU layer failure, fibre failure and complete failure were observed predominantly.

- Face layer failures were due to flexural and shear stress at the point of impact. Specimen failure was due to shear strain and delamination between the fibre and the PU.