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Effect of Temperature and Reinforcement Volume Fraction on Impact Energy of Hybrid Polypropylene Matrix Composites

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Abstract: In this study, impact damage characterization was performed on E-glass and Polypropylene (PP) film reinforced polypropylene matrix hybrid composites through compression molding. E-glass fiber volume fractions of 0.10, 0.15, and 0.20 were used. The low velocity impact test was carried out at different temperature of -20 ºC, -10 ºC and 30 ºC (ambient temperature). The flexural test was conducted on the specimen before and after impact, in order to find the flexural strength of the specimen. The Acoustic emission (AE) test was carried out to find the extent of damage occurred inside the specimen due to impact. It was found that absorbed impact energy increases with increase in temperature and also with increase in fiber volume fraction of E-Glass. But, there is a percentage reduction of flexural strength before and after impact. The result from AE test indicated that mostly, matrix cracking appears in the specimen.
Keywords: Thermoplastic resin, impact behavior, acoustic emission, compression molding.

1. Introduction

The composite materials are used in wide variety of automobile and aircraft applications due to their low weight, high strength and stiffness property. But, it is also important to study about the behavior of composite material under the impact loading, because the impact damage causes reduction in stability and strength of composite structure. The major damages that occur in the composite material are matrix cracking, fiber breakage and delamination[1].

The prediction of impact damage in composite structure is complex and different parameters, such as temperature[2], stacking sequences[3], fiber volume fraction[4], energy level[5], fiber layup[6] and methods of preparation of composites. To study about the localized damage without destroying the specimen, low energy impact test is performed, namely, ballistic impact test and low velocity drop weight impact test. Failure analysis for predicting the threshold of impact damage can also be performed using numerical simulation.

Alcock et al[7-9] in series of their investigations studied about the performance of self reinforced polypropylene (PP) matrix composites. PP has its own advantage that, it is recyclable material. The All-PP composites were prepared by PURE technology in which co-extrusion process at high compaction temperatures were maintained[10]. The mechanical properties show variation for different layup techniques such as weave architecture, unidirectional and woven tape. All-PP composites posses excellent resistance to falling weight impact and can compete with glass or natural fiber reinforced polymer matrix.

Extensive research work has been carried out on the hybrid composite material. Mallick et al[11] found that hybrid composites have superior impact characteristics based on flexural and charpy test. Seong et al[12] studied the impact energy absorption characteristic of glass fiber reinforced hybrid composite by instrumented charpy impact test method. Also the impact behavior of hybrid composite plate (glass- carbon-epoxy) was investigated. An energy profiling method, showing the relationship between impact energy and absorbed energy, was used together with load deflection curve to determine the perforation threshold of hybrid composite plate[6]. It was found from series of work on hybrid composites that efficient way of improving the impact energy of composite structure is to hybridize it with high strain to failure lamina. Hence it was decided to hybridize the all-PP composite.

The present work was aiming at investigating the influence of temperature and different fiber volume fraction on impact damage when E-Glass and Polypropylene (PP) fiber reinforced with polypropylene hybrid matrix composites subjected to low velocity impact test. Also to find the damage occurred in the composite during impact loading through Acoustic emission test.

2. Experimental Work

2.1 Materials

The chopped E-glass fiber of 0.4 mm diameter and 0.6 mm long and polypropylene thin film of 15 µm thickness were used as the reinforcement. The homopolymer polypropylene granules were used as the matrix phase. The properties of the materials are shown in the Table 1.

Table 1 Properties of the matrix and reinforcement material

Material	Type	Tensile strength (MPa)	Melting point (°C)	Strain to failure (%)	Density (kg/m^3)
Glass (Reinforcement)	E-glass	350	800	4.8	800
Polypropylene (Reinforcement)	15 µm thickness film	450	200	7	732
Polypropylene (Matrix)	Homopolymer granules	450	175	7.5	2580

2.2 Specimen Preparation

The composite laminates were prepared by the compression moulding process. The fabrication setup is shown in the Figure 1. The E-glass fiber, PP film and PP granules were taken in the measured volume fraction and then placed in the mold. They were compacted into the laminates by the application of heat and pressure. The materials were placed in a mold, which was positioned between the platens of a 50 kg hot press. After the desired compaction temperature was achieved and held for consolidation, the press was rapidly cooled. Pressure was maintained inside the mold throughout the process. The temperature inside the mold was monitored externally using thermocouples.

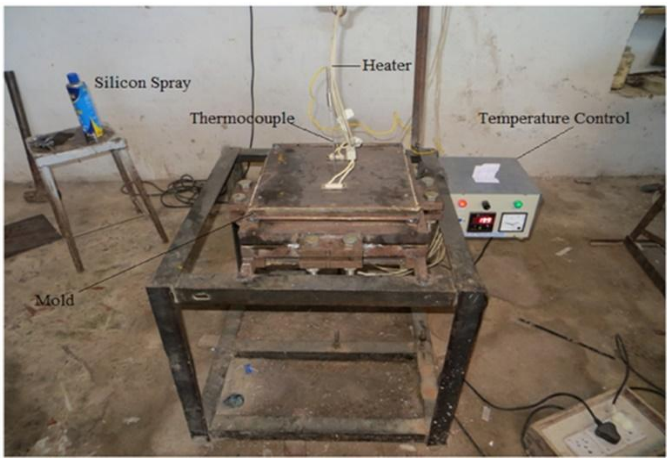

Figure 1 Fabrication setup

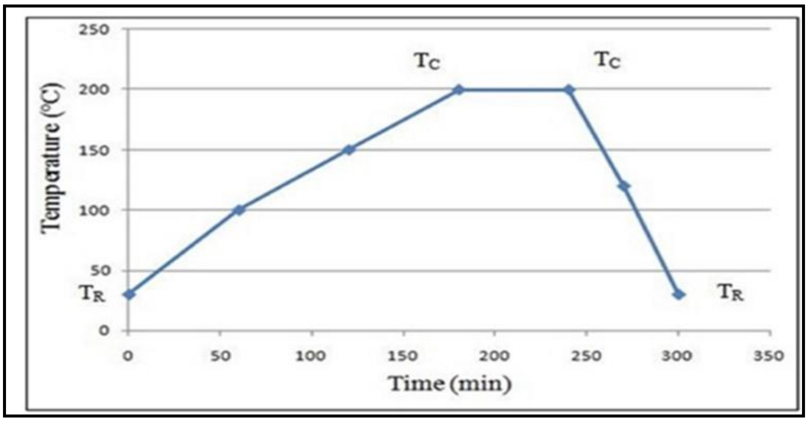

Figure 2 Time-Temperature profile during fabrication of composite

Figure 2 shows the time-temperature profile for the fabrication technique in which the material system was placed in the hot press at the release temperature (T_R) of 30 ºC. Initially, no pressure is applied at this release temperature and hence it doesn't affect the orientation of the laminate placed in the mold. At the starting of compaction temperature (T_C) of 200 ºC, the full pressure was applied, until the specimen was cooled to T_R. The entire cycle takes the duration of 300 min from the insertion to the removal of laminate from the mold. The time taken to heat the specimen from T_R to T_C took approximately 180 min. Then the laminate is left for the compaction for the duration of 60 min. The temperature is then reduced from T_C to T_R took nearly 30 min. After removing the laminates from the mold, they were cut into the testing specimens as per the ASTM standards.

2.3 Flexural Test

Three point bending test was conducted to find the flexural strength of the composite material. Using UTM (Instron) three point bending test was carried out on the specimens until the failure occurred. In the test, the sample was placed between two metallic supports and a load was applied at the centre of the sample. The load is generally applied at the centre. The effect of temperature on the flexural strength in normal and post impacted specimens was studied.

2.4 Impact Test

The low velocity Fractovis plus impact tester was used for conducting the impact test. The impact tester machine consists of the environmental chamber in which specimens were cooled using the liquefied nitrogen. The solenoid valve is connected with the environmental chamber in order to regulate the required temperatures. Impact test was carried out at the following temperatures, -20 ºC, -10 ºC and 30 ºC. The pneumatic clamp of force 500 N used to clamp the specimen during impact tests was housed within the environmental chamber. The specimens were impacted at a velocity of 2.5 m/s by using the hemispherical shape striker of size 15 mm.

2.5 Acoustic Emission Test

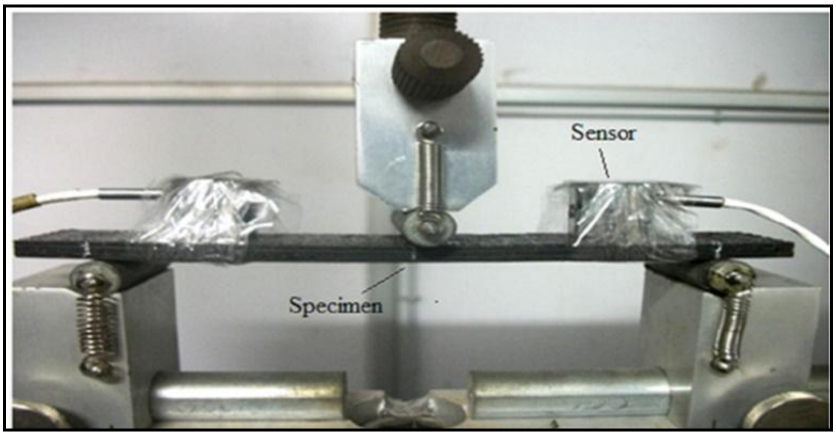

Figure 3 Flexural Testing with AE Sensor

In order to predict the damage in the specimen, Acoustic Emission (AE) tests were performed using a flexural testing machine with AE sensors as shown in the Figure 3. The two R15 D piezoelectric transducers, attached to the specimen surface using high vacuum grease as a couplant and fastened with tape, generated the signal. The signals reach the main unit from the transducers through PAC 2/4/6 G/A pre-amplifier. UTM was switched ON and the flexural load was applied. Various AE parameters such as amplitude, counts, energy, rise, and duration were recorded during the test and analysis was performed.

3. Results and Discussion

3.1 Impact Test Result

Impact test was carried out for specimens at the temperatures (30 ºC, -10 ºC, and -20 ºC) as discussed in sec. 2.4. Figure 4 shows that the absorbed energy in the composites increases with increase in temperature and also with increase in the fiber volume fraction of E-glass. Absorbed energy is inversely proportional to residual strength. Hence the residual strength decreases.

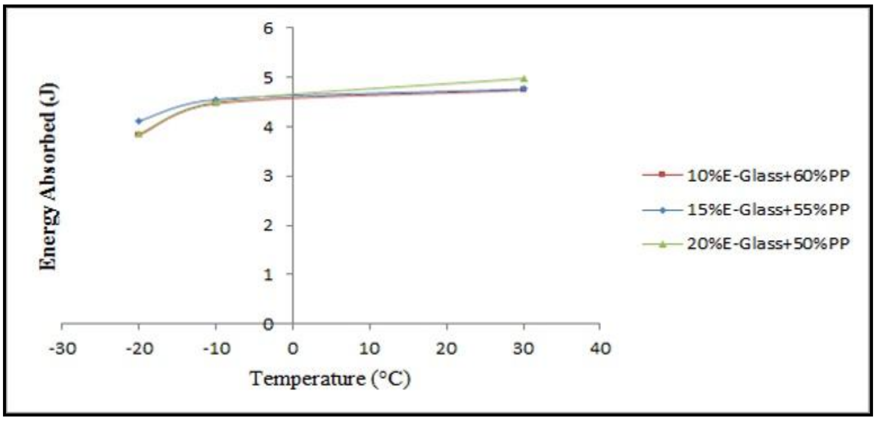

Figure 4 Variation of Energy absorbed with Temperature

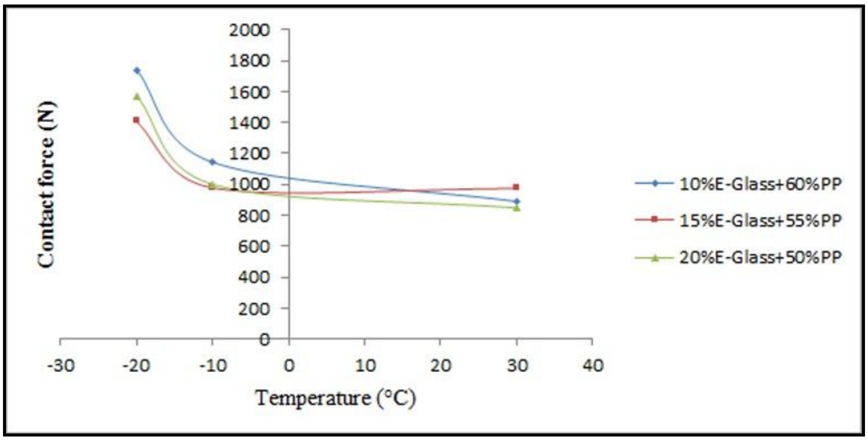

Figure 5 Variation of Contact force with Temperature

Figure 5 shows the variation of contact force with temperature. It can be observed from the figure that the contact force decreases with increase in temperature. The percentage reduction in contact force for the impacted specimens at -10 ºC and -20 ºC compared at ambient temperature (30 ºC) are 20% and 40% respectively.

3.2 Flexural Test Result

The flexural strength of impact specimen was calculated by subjecting it to three point bending tests. The variation of flexural strength with temperature is shown in the Figure 6. The figure clearly shows that the flexural strength of the composites increases with increase in temperature as well as the fiber volume fraction of the E-glass.

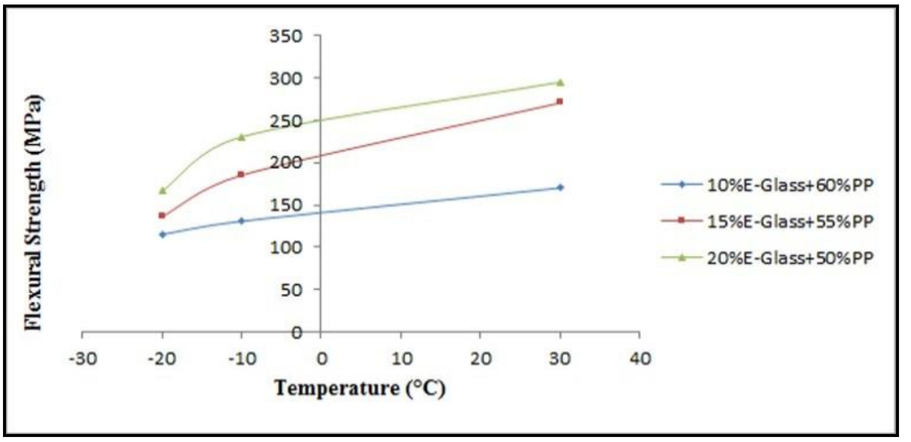

Figure 6 Variation of Flexural strength with Temperature

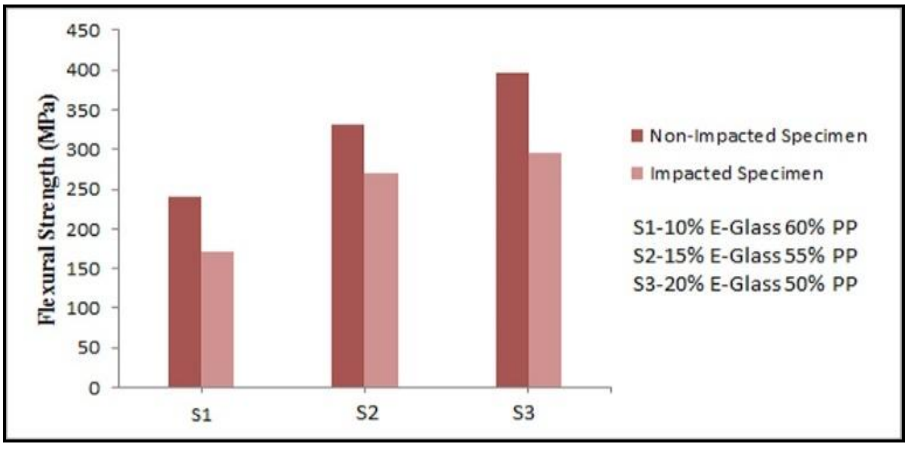

Figure 7 Variation of Flexural strength before and after impact at 30 ºC

Figure 7 shows the variation of flexural strength before and after impact at 30 ºC. It indicates the capacity of specimen to withstand the bending load after and before impact load is applied. The percentage reduction in flexural strength of the specimen before impact compared with after impact for samples S1, S2 and S3 are 28%, 18% and 25% respectively at 30 ºC. Composite with 15% E-glass (Sample S2) shows lesser variation of flexural strength of impacted & non- impacted specimen compared to other two composites (Samples S1 and S3).

3.3 AE Test Result

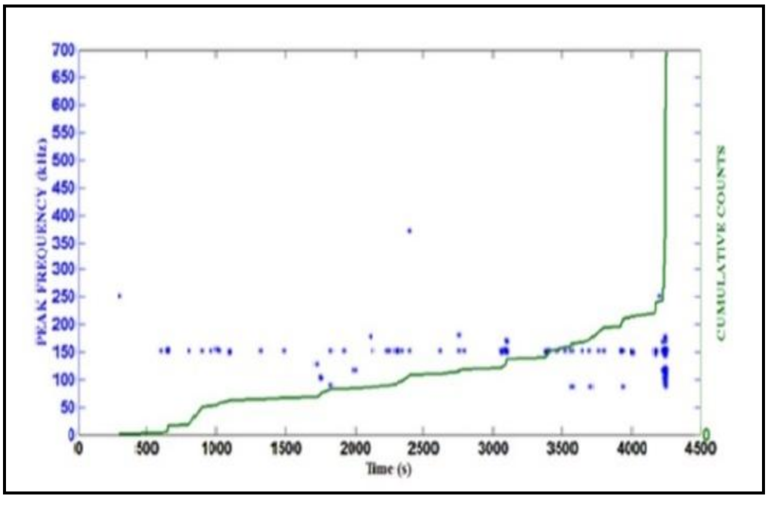

Figure 8 Time Vs Peak Frequency and Cumulative Counts for Non-impact specimen

The failure modes were detected in the composites from the AE test data. The AE test data parameters such as amplitude, peak frequency, duration and time were obtained. Based on the peak frequency, amplitudes and duration ranges, the different failure modes were characterized. From the AE test data acquired during three point flexural test, Time vs. Peak frequency and cumulative counts were plotted for non impacted and impacted specimens as shown in Figure 8 and Figure 9 respectively. Three ranges of frequency have been observed from the plot as 75 kHz to 155 kHz, 158 kHz to 200 and above 205 kHz. The failure modes in the composites were identified from these frequency ranges as follows.

1. The frequency range from 75 kHz to 155 kHz corresponds to Matrix failure.
2. The frequency range from 158 kHz to 200 kHz corresponds to De-lamination.
3. The frequency range above 205 kHz corresponds to Fiber breakage.

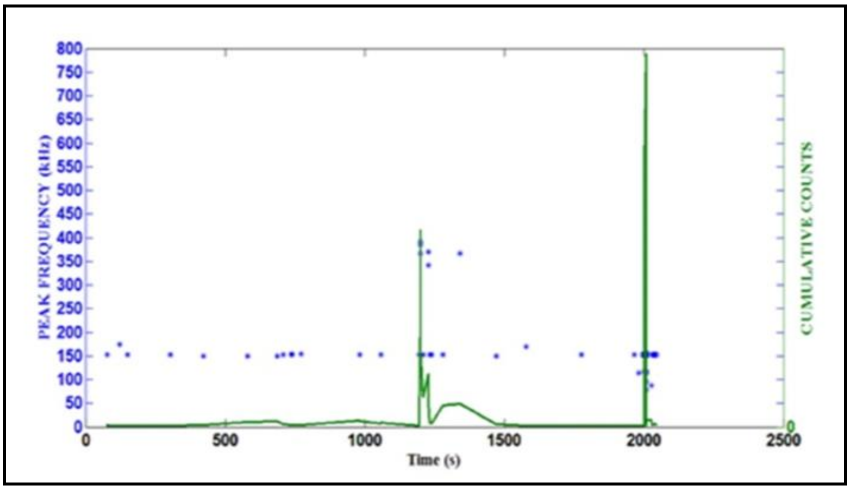

Figure 9 Time Vs Peak Frequency and Cumulative Counts for Impacted specimen

From the three different frequency ranges, various damages in the composites were predicted and presented as shown in Table 2. It was found that matrix cracking is the major damage that occurred in the specimen due to flexural stresses.

Table 2 Failure percentage in specimen

Specimen	Failure percentage (%)		
	Matrix cracking	**De-lamination**	**Fiber breakage**
Non -impacted	98.06	0.75	0.165
Impacted	93.856	0.502	5.54

4. Conclusions

The low velocity impact behavior and damage prediction of polypropylene matrix hybrid composite reinforced with different volume fractions of E-glass fiber & polypropylene film at low temperatures were experimentally studied. The flexural strength of the impact test specimen is less compared with the non- impact test specimen. Temperature has a significant effect on absorbed impact energy of the specimen. Less absorbed energy is seen in specimen impacted at lower temperature than at high temperatures. The absorbed impact energy is found to be increased with the gradual increase in the volume fraction of E-glass fiber. Three ranges of frequencies are observed from the Acoustic Emission results. The major impact damage occurred in the specimen is the matrix cracking due to flexural stresses.

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