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Effects of temperature and impactor nose diameter on the impact behavior of PA6 and PP thermoplastic composites

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Abstract

In this study, the effects of temperature and impactor nose diameter on the impact behavior of woven glass-reinforced polyamide 6 (PA6) and polypropylene (PP) thermoplastic composites were investigated experimentally. Impact energies are chosen as 10, 30, 50, 70, 90, 110, 130, and 170 J. The thickness of composite materials is 4 mm. Impact tests were performed using a drop weight impact testing machine, CEAST-Fractovis Plus, and the load capacity of test machine is 22 kN. Hemispherical impactor nose diameter of 12, 7, and 20 mm were used as an impactor. The tests are conducted at room temperature (20°C and 75°C). As a result, the PP composites of the same thickness absorbed more energy than PA6 composites. The amount of absorbed energy of PP and PA6 composites decreased with temperature.

Keywords

Impact behavior, thermoplastic composite, temperature effect, effects of impactor diameter, E-glass

Introduction

Fiber-reinforced laminated composite materials have been widely used in engineering application such as aerospace, wind turbine, and marine industries. The greatest

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advantage of composite materials over conventional metallic materials is their high strength to weight ratio. However, composite materials are very sensitive to impact loads. Lack of reinforcement through the thickness makes them highly susceptible to the transverse impact loading resulting in damages such as matrix crack, delamination, and fiber breakages.[1] Moreover, these failures, resulting in the reduction of stiffness and compressive strength, sometimes may not detectable to the eyes. Therefore, many researchers show interest in studying to understand the impact behavior of composite materials. A large majority of researchers conducted studies on thermoset matrix composites.[2–11] Icten et al.[12] investigated the effect of impactor diameter on the impact response of woven glass–epoxy laminates. Four different impactor nose diameters such as 12.7, 20.0, 25.4, and 31.8 mm were used. They noted that the projectile diameter highly affects the impact and compression after impact response of composite materials. Sikarwar et al.[13] have subjected composite materials that made of glass/epoxy using compression molding technique to impact loading. The ballistic limit and energy absorption capacity of the laminates were obtained. The effect of fiber orientation and thicknesses on ballistic limit and energy absorption of the laminates were studied. The values obtained from analysis were compared with experimental results and good agreement was found.

On the other hand, studies on thermoplastic matrix composite materials are very low compared with thermoset matrix composites. Arikan and Sayman[14] investigated single and repeated low-velocity impact behavior of glass fiber/epoxy thermoset composites and glass fiber/polypropylene (PP) thermoplastic composites. Impact energies of 20, 50, 80, and 110 J for single impact and impact energy (E_i) of 50 J for repeated impact were chosen. They found that the resin type is a significant parameter for the repeated impact response of the composites. Vieille at al.[15] compared the response of TS-based (epoxy) and TP-based (PPS or PEEK) laminates subjected to low-velocity impacts. They have investigated damage mechanisms and damage modes of carbon/epoxy, carbon/PEEK, and carbon/PPS composites for various E_i levels using C-scan inspections and microscopic observations.

Carrillo et al.[16] have compared the ballistic performance of aramid fabric/PP composite laminates and plain-layered aramid fabric targets. They found that adding a thermoplastic PP matrix increases the ballistic limit and perforation threshold energy of laminated composite targets when compared to the layered aramid fabric targets with similar areal density, resulting in less aramid fabric needed to obtain the same level of protection. They noted that the improved ballistic performance of laminated composite targets is due to the fact that the thermoplastic matrix enables energy absorbing mechanisms such as fabric/matrix debonding and delamination, which are not observed in aramid fabric systems.

The aim of this study was to investigate the temperature and impactor nose diameter effects on impact response of glass-reinforced PP and polyamide 6 (PA6)-laminated plates. Two different impactors with 12.7 and 20 mm impact nose were used. Impact tests were also performed at room temperature (20°C and 75°C) for impactor nose with a diameter of 12.7 mm. The variation of maximum contact load between the impactor and

Table 1. Mechanical properties of the thermoplastic composites.

	Mechanical properties				
	$X_{1\ T}$ (MPa)	$X_{2\ T}$ (MPa)	E_1 (GPa)	E_2 (GPa)	ν_{12}
PP	21	20	402	393	0.16
PA	21	22	406	391	0.17

PP: polypropylene; PA: polyamide.

the composite plate and the maximum deflection at the center of the composite plate versus E_i are shown subsequently. In order to determine the energy-absorbing capability, energy profiling method is utilized.

Materials and methods

The aim of this study was to compare the impact response of woven E-glass–reinforced PP- and PA6-based composites. Using a hot press, the thermoplastic sheets were manufactured by woven E-glass–reinforced PP- and PA6-based prepregs at 200°C. During the manufacturing process, the thermoplastic-based face sheets were retained for 1 h under 0.625 MPa pressure, followed by cooling at room temperature. The areal density of the woven E-glass fabrics used was 600 g/m^2. The composites consist of eight layers. The nominal thickness of both types of face sheets was 4 mm. Some mechanical properties of the thermoplastic face sheets are listed in Table 1. In Table 1, X_T and Y_T stand for tension strengths, while E_1, E_2, and υ_{12} for Young's moduli and Poisson's ratio in principal material directions, respectively. Shimadzu AG-X testing machine having a loading capacity of 100 kN was used for determining composite strength, Poisson's ratio and Young's modulus in principal material directions. A video extensometer was used to measure the elongation of the specimens during the tensile tests. The crosshead speed was chosen as 1 mm/min. Each test was repeated at least three times.

CEAST-Fractovis Plus drop-weight impact testing machine was used in this study to carry out the impact tests. A load cell having a hemispherical impactor nose with a capacity of 22 kN was used in the tests. The diameter of noses was 12.7 and 20 mm, respectively (Figure 1). Composite specimens with dimensions of 100 × 100 mm^2 were fixed by a pneumatic fixture with a 76.2-mm hole diameter. Tests at 75°C were made by thanks to a conditioning chamber integrated into the impact testing machine (Figure 2).

Results

Variation of the contact force between the impactor and the specimen versus deformation of the specimen at contact point for some critical E_i values for thin and thick

Figure 1. Impactor noses.

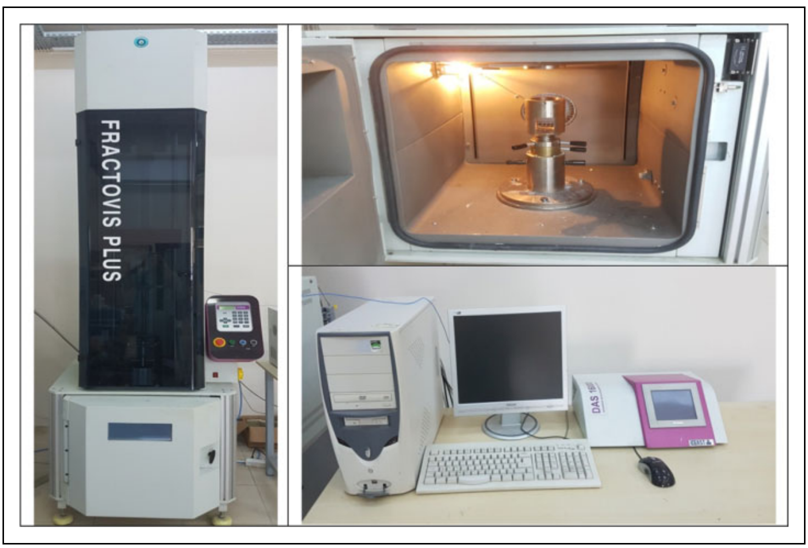

Figure 2. Impact test machine.

impactor noses is given in Figure 3. The contact force–deflection curves give absorbed energy (E_a) during the impact process. There are two basic types of the curve: closed and open. The closed curves imply that penetration does not occur, while the open curves

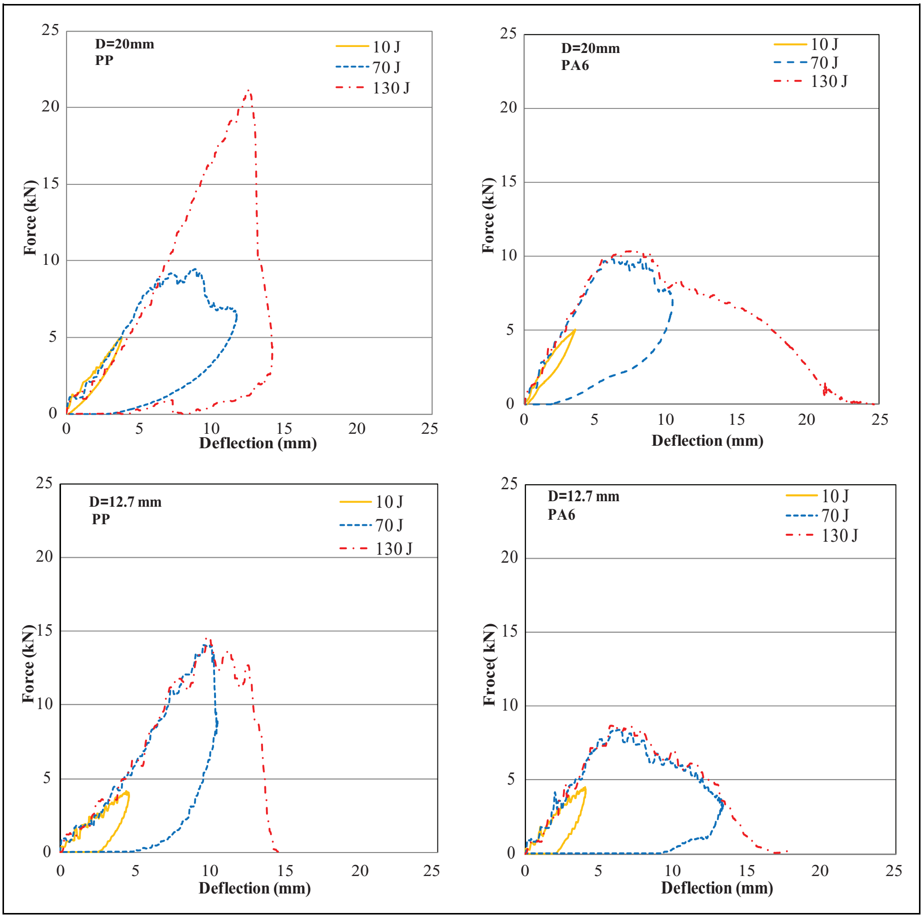

Figure 3. Force–deformation curves for thin and thick impactor noses.

indicate perforation. Both curves consist of ascending and descending sections. Two different cases are shown in Figure 3 in that the first one is the rebounding, which the curves for 10 and 70 J represent this case. The rebounding cases have two different trends. The contact force at the beginning of the curve increases with increasing deflection up to the maximum value for both. Thereafter, the deflection and the contact force values decrease in the first tendency. However, in higher E_i levels, the contact force reaches the peak value. Then, the contact force values decrease with increasing the deflection up to the maximum deflection value. Following this, the contact force again decreases with decreases in the deflection values for 70-J impact energies. This behavior may occur because of fiber breakage rather than the minor matrix cracks in composite specimens. The deflection–contact force curves in both rebounding cases are closed. If the descending section is completely a softening curve, the load–deflection curve should

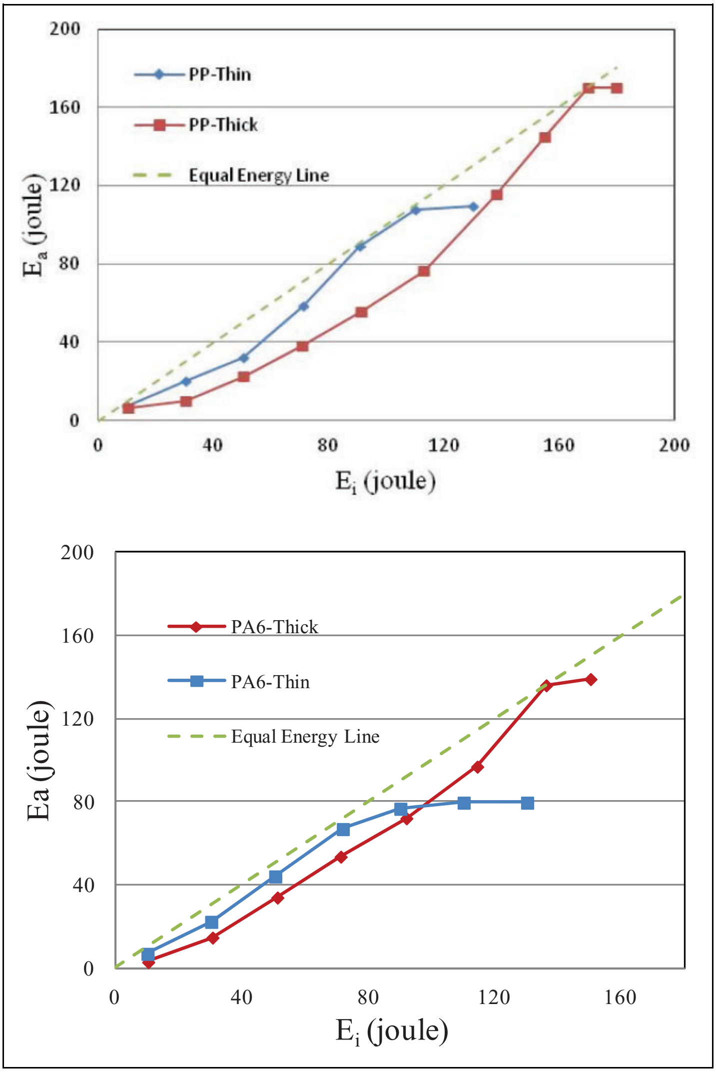

Figure 4. Variation of the E_a versus E_i for two impactor nose diameters. E_a: absorbed energy; E_i: impact energy.

be an open curve in that the impactor penetrates into the specimen for 130 J.[1,12] In the light of the abovementioned information, the maximum contact force increased when increasing the diameter of the impactor nose. The maximum contact force for PP is higher than that for PA6 for both impactor noses (Figure 3).

In Figure 4, variation of the E_a versus E_i for two impactor nose diameters, called energy profile diagram, is given by Liu.[17] Energy profile diagram gives information

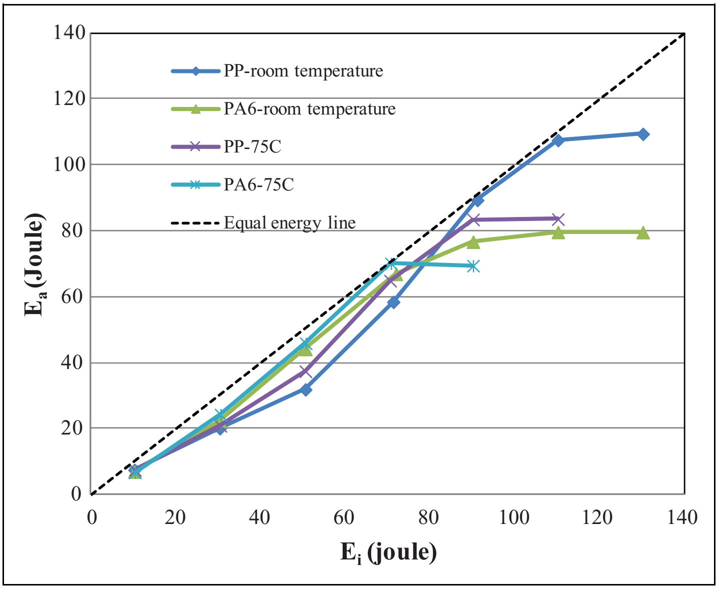

Figure 5. Variation of the E_a versus E_i at room temperature (75°C) for thin impactor noses. E_a: absorbed energy; E_i: impact energy.

about energy absorption process in an impact event, for example, penetration or perforation. Excessive E_i, the difference between the curve and the equal energy line,[1] is higher for the thick nose. The E_i causing penetration is nearly 170 J for thick noses in PP, while it is approximately 107 J for thin noses. Similar tendency occurred for PA6. It is 79 and 130 J, respectively. Figure 4 also shows that PA6 is more susceptible to impact load than PP. Penetration threshold of PP is higher than PA6 for both noses. Perforation threshold rises with increasing the diameter of impactor noses.

In this study, the temperature effects on the impact characterization of laminated composite plates were also investigated. The impact tests were performed at room temperature (75°C), and the thin impactor nose was chosen. Three samples were tested and average values were calculated for each case. Variation of the E_a versus E_i, for different temperatures, is given in Figure 5. The E_a increases with increasing of temperature for the same E_i levels up to the perforation. In addition, the excessive energy decreases with increasing temperature for both composites. The perforation thresholds for temperatures at room temperature (75°C) are approximately determined for PP and PA6 as 107 and 83 J and 79 and 70 J, respectively. The reduction in the amount of energy causing perforation for PP and PA is approximately 22 and 11%, respectively. As a result, the PP is more sensitive to temperature than PA6.

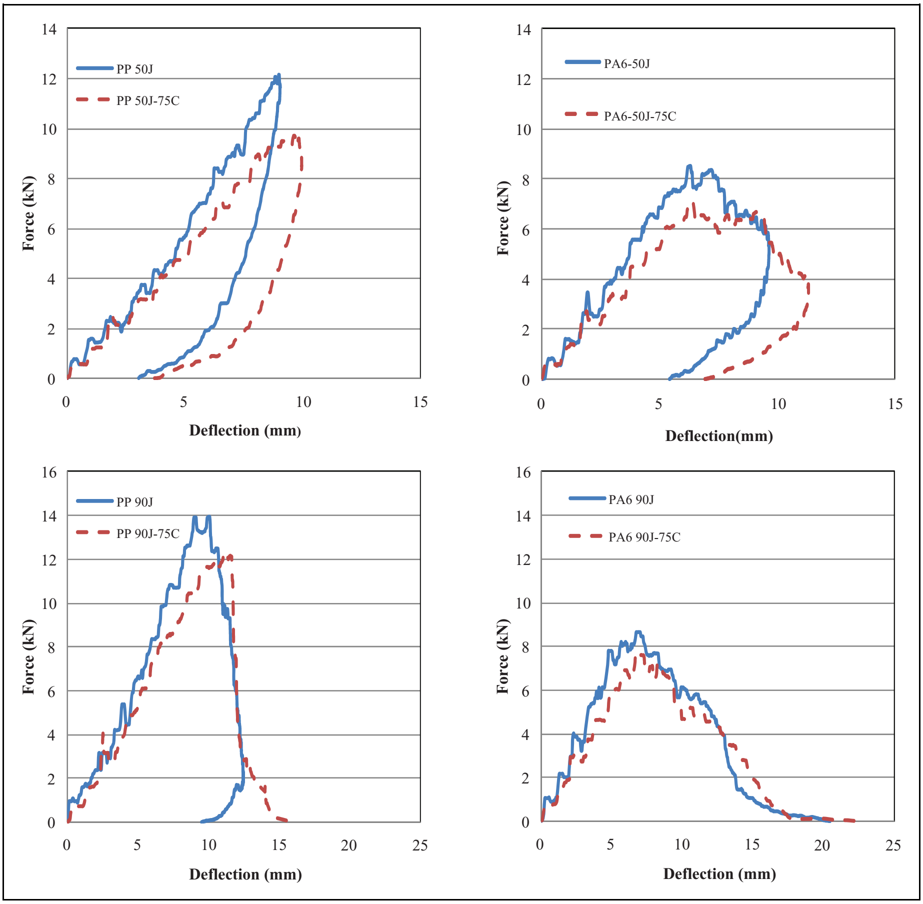

Figure 6. Force–deformation curves of impact tests at room temperature (75°C) for 50 and 90 J impact energies.

Force–deformation curves of impact tests at room temperature (75°C) for 50 and 90 J impact energies were given in Figure 6. The slope of ascending sections in these curves represents the bending stiffness. Increase in temperature for both composite and impact energies caused a decrease in bending stiffness. Similarly, maximum contact force decreased with temperature, while the maximum deformation increased.

The images of the several samples subjected to 50 and 70 J at 20°C and 75°C are provided in Figures 7 and 8, respectively. The nontransparent features of the PP and PA6 composites do not enable us to determine the overall damage areas and make an estimate about damage extent, including internal damages. However, as shown in Figures 7 and 8, the overall damage area of the impact tests that were performed at 75°C is larger than the impact tests that were performed at 20°C.

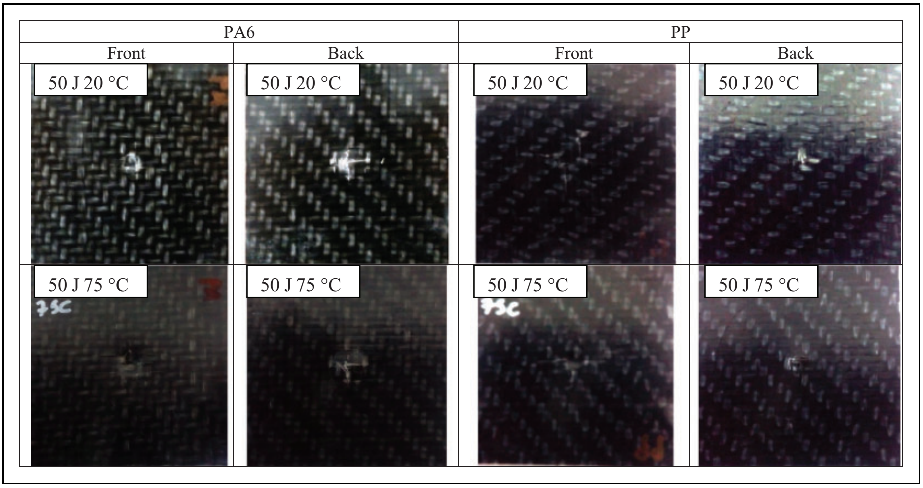

Figure 7. Images of the damaged specimens subjected to impact energies of 50 J at room temperature (75°C).

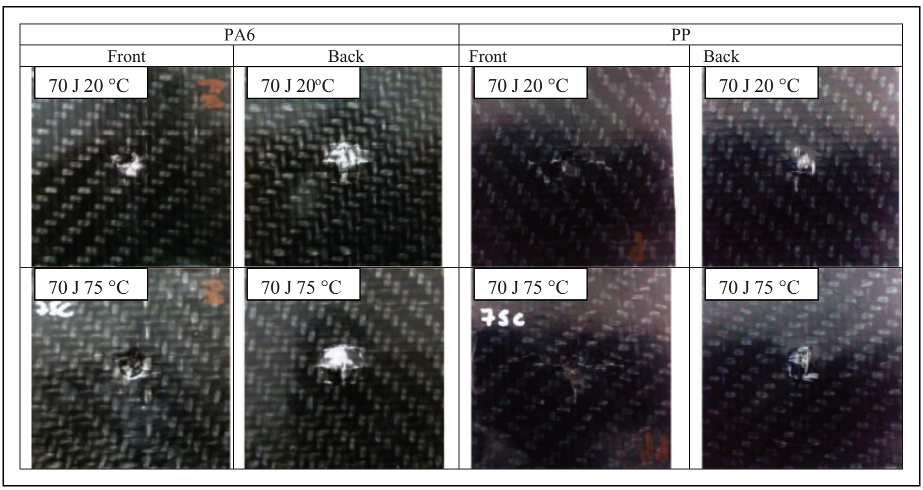

Figure 8. Images of the damaged specimens subjected to impact energies of 70 J at room temperature (75°C).

Conclusion

In this study, the effects of temperature and impactor nose diameter on the impact response of woven glass-fiber–reinforced PP and PA6 thermoplastic composites were studied experimentally. Impact tests were conducted for two different impactor noses and at two different temperatures. The concluded results can be summarized as follows:

1. For the same impact energies, the maximum contact forces are higher for thick impactor nose. The perforation happened in lower impact energies for the thin impactor nose.
2. Perforation threshold of PP is higher than PA6 at the same temperatures and impact energies. However, PP was more affected by the temperature increase.
3. Considering the energy profile diagrams and perforation thresholds given above, testing temperature affects the significant variation of impact response except for E_i of 10 J.

Declaration of Conflicting Interests

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