Low Velocity Impact Behavior of Glass Fibre-Reinforced Polyamide

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Abstract. The low velocity impact behavior of composites made of polyamide (PA) as matrix and glass fibre as reinforcement has been investigated. The assessment of the impact behavior has driven the need to perform tensile tests to determine the elasto-plastic behavior of the composites. The specimens were manufactured by injection molding techniques for the experimental tensile testing. ABAQUS/EXPLICIT for finite element modeling is employed in order to predict the impact behavior of glass fibre-reinforced polyamide. The determinations of the impact force history and elasto-plastic structure deflection are the most important objectives in impact engineering structures design.

Keywords: Mechanical Composite, PA66, mechanical characteristics.

1 Introduction

Fibre-reinforced composites are widely used in many engineering applications such as automobile and aerospace due to their light weight, high strength and stiffness, resistance to chemical and environmental agents, design freedom and manufacturing advantages. During their manufacture, maintenance and service life, this Fibre-reinforced composites may suffer different damage, of which low velocity impact is considered as one of the most important and dangerous, because it can induce internal damage in the form of delamination, matrix cracking, local permanent deformation, debonding and fiber breakage, leading to a significant strength reduction of the structure.

Numerous investigations dedicated to the problem of the impact behavior of composite materials are performed by several authors such as (Wali et al. 2011), (Dhakal et al. 2012) and (Yang et al. 2013). The published results show that the impact resistance of composite structures depends, in a complex way, on the properties of composite structures (material, thickness, laminate stacking sequence in

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case of laminated composites), properties of impactor (mass, velocity, energy, shape of impacting head) and experimental setup (clamping conditions of the test specimen) (Giangiacomo et al. 2012). In addition, research has shown that composites are capable of absorbing energy and dissipating it by various fracture and elastic processes when subjected to a low velocity impact (Cantwell and Morton 1991).

A number of investigations were conducted to assess the impact on thermoplastic composites reported in the works of (Xu et al. 2011) and (Simeoli et al. 2014). Glass fiber-reinforced polyamide (PA66) is one of the most widely used thermoplastic composites in the engineering industry and the security imposes to perform impact behavior. Therefore, it becomes necessary to know the behavior of this composite material which is very sensitive to elasto-plastic impact promoting high levels of strain, leading to failure and damage.

Despite increased use in engineering applications, few published work on the impact behavior of polyamide short fiber-reinforced thermoplastic composites is found. The fracture toughness and impact behavior of a range of glass-fibre-reinforced polyamides of high fiber content, which were promoted as potential metal replacement materials, are examined by (Akay et al. 1995). The compressive behavior of Nylon 6 and Nylon 66, on wide range of strain-rates, was investigated by (Benaceur et al. 2008) using Hopkinson bar tests. A localized low velocity impact experiments and simulations were conducted by (Mouti et al. 2010, 2013) on glass fiber-reinforced polyamide automotive product to investigate typical flying stones impact scenarios.

The purpose of this paper is to predict the behavior of an elasto-plastic glass fibre-reinforced polyamide structures under low velocity impact. The mechanical elasto-plastic model of glass fibre-reinforced polyamide materials for different glass fibre volume fractions is then modeled basing on experimental tensile tests. The model is implemented into the commercial finite element code ABAQUS/Explicit to predict the Low velocity impact behavior of circular glass fibre-reinforced polyamide. Numerical results, including contact force and displacement of the composite plate subjected to low-velocity impact, are calculated.

2 Experimental

2.1 Materials

Two commercial polyamide 66 with 30 wt.% of short glass fibre (HERAMID A NAT with 30 wt.% glass fibre, provided by RADICI GROUP) and natural polyamide 66 (A HERAMID NAT) were used to produce molded glass fibre-reinforced composites with 00, 10, 20 and 30 wt.% .They were designed as PA66_00, PA66_10, PA66_20 and PA66_30, respectively. The specimens were made by injection molding (Figure 1).

Fig. 1 Molded samples

2.2 *Tensile Tests*

Mechanical testing consisted of tensile tests. The tensile tests have been carried out using an Instron Electropuls tensile testing machine with crosshead speed of 1 mm/min (Figure 2). The jaws used for attachment of the test specimens are

Fig. 2 Instron Electropuls tensile testing machine

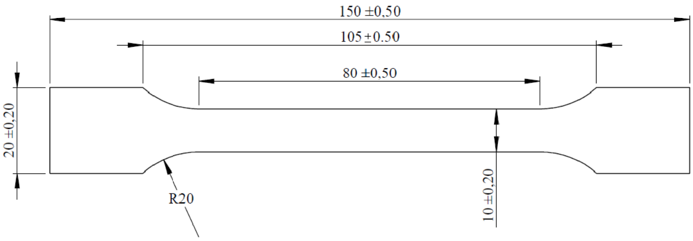


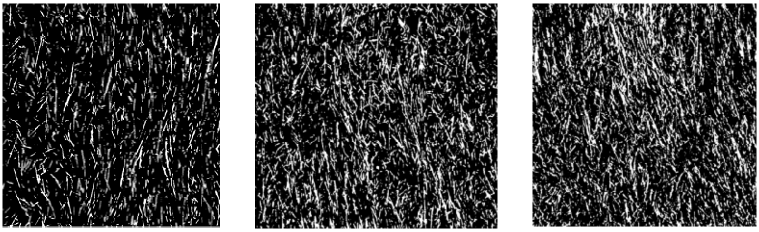
Fig. 3 Shape and dimensions of the specimen, according to ISO 527-2 standard

controlled pneumatically, 4 bars. Three specimens of each composition were tested and the average value reported. Strains were measured with a RUDLPH laser extensometer. Markers (white color and width 3 mm) are placed in each test specimen for measuring the deformation in the active area during the tensile test. Specimens had the shape and dimensions reported in Figure 3, according to ISO 527-2 standard. Tensile testing was carried out in air at 20°C and 50% relative humidity.

2.3 Analysis of fibre Length Distributions

The fibre orientation distribution in a material sample was examined by using the X-Ray microtomography machine (Skyscan 1172). The local variation of the anisotropy from the shell to the core of the molded tensile sample is captured and information about the local average fibre orientation angle is observed.

Figure 4 shows that the orientation of fibers in assemblies is moderately influenced by the processes used to manufacture the samples. Fibre content-images for specimens used in tensile tests is examined and illustrated in figure 5 to evaluate the global anisotropy .Figure 5 shows that, the amount of homogeneously distributed fibers is greater.



PA66_10 PA66_20 PA66_30

Fig. 4 Microtomography of reinforced PA66 (sagittal scanning in the test specimen middle)

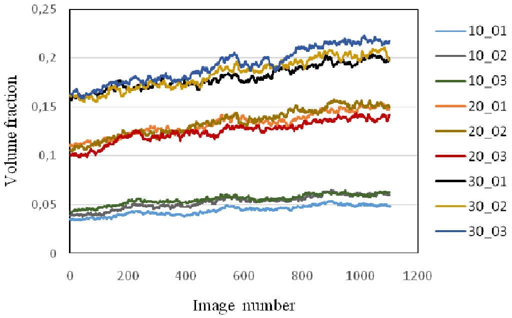


Fig. 5 Fiber content-images for specimens PA66_10, PA66_20, PA66_30

3 Results and Discussions

3.1 *Quasi-static Characterization*

Tensile test data was captured for different weight fractions: 0, 10, 20 and 30 wt%. For each material tested, three specimens were used. The degree of repeatability was found excellent in all cases. For example, in tensile tests of PA_00 at a strain rate of 1 mm/min, this repeatability is illustrated in Figure 6. The medium curve of three tests is chosen for all polyamides tested.

Tensile test data was then used to plot stress strain relations. Data captured from the testing machine and the laser extensometer was plotted in Figure 7. Figure 7 shows Stress-strain curves of natural PA66_00, PA66_10, PA66_20 and PA66_30. These results are in good agreement with literature (Ghorbel et al. 2011).

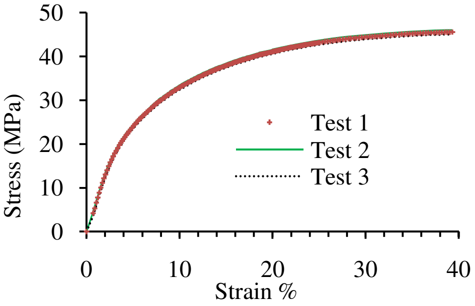


Fig. 6 Repeatability of simple tensile test of PA66_00

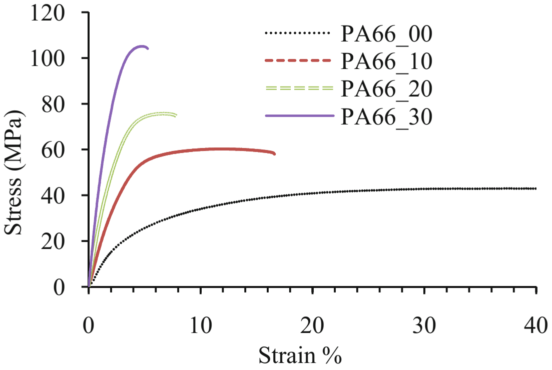


Fig. 7 Uniaxial stress-strain curves of PA66_00, PA66_10 , PA66_20 and PA66_30

The increasing of the fiber content has the effect:

- An improvement in elastic modulus
- An increase in tensile strength
- A reduction in fracture strain. The materials behavior changes from ductile to brittle behavior.

3.2 Identification of the Hardening Law

The mechanical elasto-plastic model of glass fibre-reinforced polyamide composites for different glass fibre volume fractions must be modeled to accurately predict the low velocity impact responses. However, the least-squares method was used to fit the Stress/strain curves to the experimental tensile data points and the mechanical parameters of glass fibre-reinforced polyamide material are determined. The elastic-plastic material model was implemented in the commercial nonlinear finite element code ABAQUS/EXPLICIT for studying the impact behavior of polyamide.

The mechanical elasto-plastic model used during the identification phase is defined by

$$\sigma = \sigma_e + Q(1 - e^{-\beta.\varepsilon_p}) + K.\varepsilon_p \tag{1}$$

where σ_e is the yield stress, Q, β and K are the mechanical parameters of the elasto-plastic model and ε_p is the plastic deformation.

Finally, the comparison of the numerical approach with the experimental data shows the accuracy of the mechanical elasto-plastic model. Figure 8 shows that the numerical approach is in good argument with the experimental result for PA66_20 material. This approached law is used in next section when studying the impact behavior of glass fibre-reinforced polyamide.

Table 2 shows the values of the mechanical parameters for the glass fibre-reinforced polyamide during the identification phase.

Table 1 Identified mechanical parameters of the reinforced polyamide

	PA66_00	PA66_10	PA66_20	PA66_30
Yield stress $_e$ (MPa)	15	25	30	34
E (MPa)	1100	2350	4200	6000
Q (MPa)	23.5	35.1	47	72.6
β (MPa)	30	144	198	198
K (MPa)	72	83	103	135

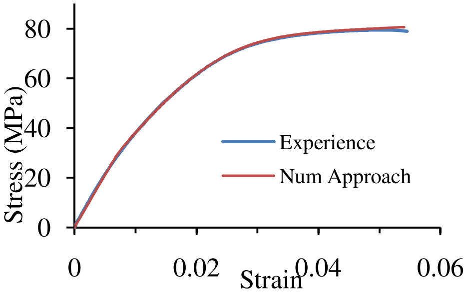


Fig. 8 True Stress/strain curves for PA66_20

3.3 Finite Element Modeling and Validation of Impact Model

✓ Finite element modeling

Various procedures can be used in ABAQUS for modeling the elasto-plastic impact phenomena. The accurate modeling requires an appropriate selection of contact modeling, element type, resolution method and number of element in plate thickness. The determinations of the impact force history and elasto-plastic structure deflection are the most important objectives in impact engineering structures design. For studying the impact ABAQUS 6.10 version is used. A clamped circular plate impacted at its center by a cylindrical impactor with hemi-spherical nose is considered. The plate with radius R=60mm and thickness h=1mm is made of aluminum alloy. The initial velocity of impactor is V_0 (Figure 9).

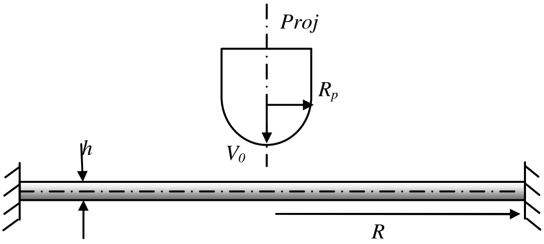


Fig. 9 Cylindrical projectile impacted circular plate

The presence of the rotational symmetry axis, can simplify the three-dimensional impact problem in an axisymmetric problem. The problem can thus be analysed using 2D axisymmetric model. The plate was meshed using the structured meshing technique and 6000 4-nodes per elements with reduced integration (CAX4R in ABAQUS). The impactor mesh consisted of 433 4-nodes per elements (CAX4R in ABAQUS).

✓ Validation of the contact model

Given that the impact model needs reliable data for simulation, we need to validate the mechanical properties and the contact law introduced into numerical model. For that, a comparative study between the numerical predictions and experimental response found in literature is established. The plate material is assumed to be an isotropic and homogeneous, and the elastic, perfectly plastic material and the Von Mises yield criterion, J_2, is employed same as in the work of (Chen et al. 2007). In this section, the deformable impactor is assumed to be elastic. For the validation, the mechanical properties of both impactor and plate are illustrated in Table 2.

The impactor velocity predicted by the present numerical model and the result obtained by experimental data tested through LDA technique (Chen et al. 2007) are plotted in Figure 10. One can note from this figure that the impactor velocity is in good agreement with the experimental test.

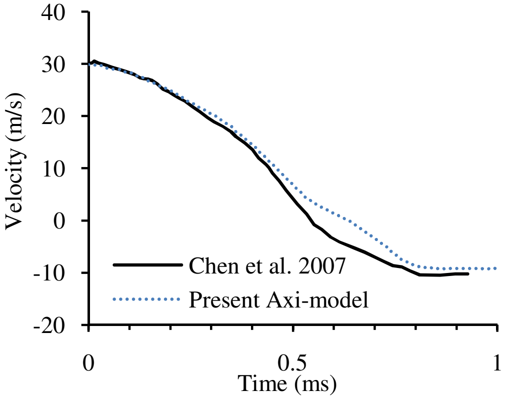


Fig. 10 Validation: impactor velocity time responses ($m_p = 54.4$ g, R_p=6.35mm, $V_0 = 29.9$ m/s)

Table 2 Mechanical properties of impactor and circular plate

Parameters	Material	Young modulus $E(GPa)$	Poisson's ratio ν	Density $\rho\left(Kg/m^3\right)$	Yield stress $\sigma_e\left(MPa\right)$
Circular Plate	Aluminum	69	0.3	2600	290
Impactor	Steel	200	0.3	7800	-

3.4 Impact Behavior of Glass Fiber Reinforced Polyamide

The dynamic behavior of a clamped circular plate, of natural PA66_00, PA66_10, PA66_20 and PA66_30, subjected to impact by a projectile is discussed in the following section. The target circular plate with radius R = 60mm and thickness h = 4mm whose density, Young's modulus, Poisson ratio, yield stress and σ_e are already mentioned in the previous paragraph. The impactor has the same characteristics described above except that the mass and speed become respectively 1.369 Kg and $V_0 = 3.418$ m / s.

The evolution of plate center displacement according to the time is presented in Figure 11 for incidental impact energy of 8J for PA66_00, PA66_10, PA66_20 and PA66_30.

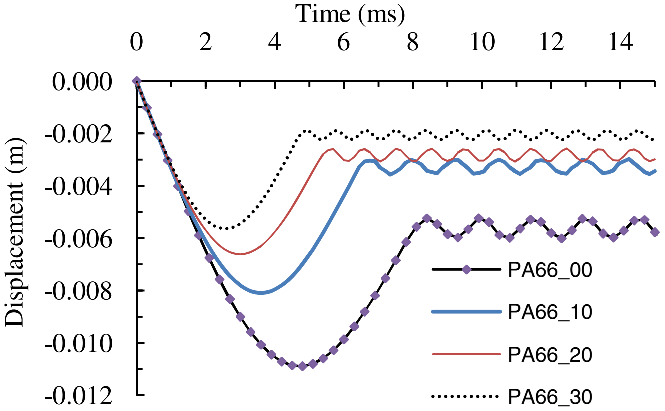


Fig. 11 Center plate displacement time responses for impact energy of 8J

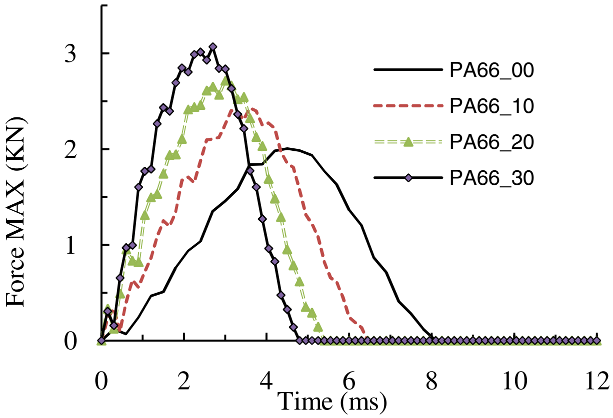


Fig. 12 Impact force versus time curves for an impact energy of 8J

Figure 12 presents examples of force-times curves obtained for impact energy of 8 Joules. One can note that an increase in values of the maximal impact forces when varying the glass fibre volume fractions introduced in polyamide, but the impact time decrease greatly by increasing the glass fibre volume fractions.

According to the displacement response and impact force as shown in Figures 11 and 12, it can be noted that the central deflection keeps decreasing until the peak force appears. Also, it can be noticed that the circular plate will rebound when the projectile is completely separated, then the circular plate will be in a free vibration mode around the permanent deflection position.

4 Conclusion

Impact behaviors at low velocity of glass fibre-reinforced polyamide are investigated for different glass fibre volume fractions. The assessment of the impact behavior has driven the need to perform tensile tests to determine the elasto-plastic model of the polyamides. The X-Ray microtomography machine is used to check the glass fibre distribution. The mechanical elasto-plastic model used can predict the stress-strain behavior of the studied materials. The elastic-plastic model was implemented in ABAQUS/EXPLICIT for studying the behavior of the composites under low velocity impact. The results have shown that the impact force increase with increasing fibre volume fractions.

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