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# Investigating on the energy absorption of PA/GF6 thermoplastic composite produced by hot pressing method under low-velocity impact test

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## Abstract

Thermoplastic composite sheets have attracted increasing attention in various industries due to their high Specific strength and energy absorption capacity. In this research, the behavior of composite sheets with polyamide6 thermoplastic matrix and continuous glass fibers (PA6/GF) has been investigated under quasi-static penetration and drop weight test. Since the polyamide matrix is significantly sensitive to the effects of strain rate, the Hopkinson test was used to extract the required mechanical properties at different strain rates. Based on this test, the strength of the studied composite increased by 47% at the same strain rate as the drop weight compared to the quasi-static penetration test. As a result of the impact, failure modes such as fiber breakage, separation of fibers from the matrix, vertical and horizontal cracks oriented in the direction of the fibers have been observed. Also, numerical simulation was performed with LS-DYNA software and the effects of strain rate extracted from Hopkinson's test were applied in numerical simulation, resulting in an accuracy of 9.6% in calculating the maximum force. Based on the results of numerical simulation, in thicknesses less than 2.5mm, the SAE of the composite sheet is constant; Also, the maximum energy absorption in 4-layer composites were related to the laminate [$90_2/0_2$] with 18J of energy absorption.

**Keywords:** Thermoplastic composite, PA6/GF, Quasi-static indentation test, Drop weight, LS-Dyna.

## 1. Introduction

The mechanical properties of composite sheets have led to an increase in their use in many engineering fields such as aerospace, railway, automotive, and marine. In these industries, composite materials have mainly replaced metal materials. Polymer/glass or carbon composites are more fragile compared to metal alloys, and the failure or destruction of these materials is related to fiber breakage, matrix cracking, delamination, and fiber separation from the matrix [1, 2]. Common composite materials are divided into two categories, thermoset and thermoplastic, based on the material of the matrix. Thermoplastic composites have higher fracture toughness and better damage tolerance than thermoset composites, which results in less damage upon impact area under the same impact energy [3]. One of the special properties of thermoplastic polymer materials is the possibility of their recycling however, this is not possible in thermosetting materials, and its waste has become a global issue [4].

The LS-DYNA finite element software is one of the most widely used software in the automotive as well as in aerospace and medical industries [5]. In finite element software, the accuracy of material behavior prediction depends on the correct application of loading, boundary conditions, and correct material properties. Multi-layer composite models are defined in LS-DYNA software; therefore, instead of defining a new material, the default composite material models can be used in LS-DYNA software [6].

One of the common ways to produce thermoplastic composites is to use the hot pressing method. In general, the type of laminate layers is effective in determining the behavior of the material at high strain rates. For example, with the increase of the strain rate, the modulus of elasticity of the unidirectional composite plate decreases, but in the composite with a symmetrical layer arrangement, the modulus of elasticity has increased. This effect on the strength of the material is not as significant as the modulus of elasticity.

The review of the research conducted in the field of energy absorption and numerical modeling of composite materials has indicated that the main focus in composite structures is on materials with thermoset fields. Composite materials with a thermoplastic background have complex and new production technology and are recently used in various industries. Because thermoplastic composites do not have a baking process, they have a much higher production speed than thermosetting composites. Unlike thermosetting materials, these materials are recyclable and can be modified after the manufacturing process is completed. All of these factors, along with the better energy absorption of these materials and the softness of their mechanical behavior, have made a research on thermoplastic composites attractive to researchers. This research tries to investigate the mechanical behavior of thermoplastic PA6/GF composite under low-speed impact loading and quasi-static indentation. Along with the experimental test, a numerical model is developed to predict the mechanical properties of this material; also, the effect of strain rate on the properties and behavior of this composite will be investigated.

## 2. Experimental tests

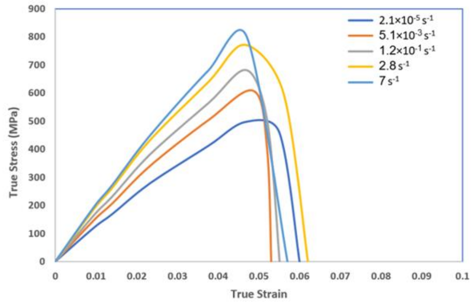
In this research, the energy absorption values of PA6/GF thermoplastic composite with [0,90] degree layer arrangement are investigated under quasi-static indentation and drop weight test. Before performing the two mentioned tests, tensile and shear tests were performed according to ASTM D3039 and ASTM D7078 standards respectively. According to these tests, the mechanical properties were reported in Table 1.

**Table 1.** Mechanical properties of glass/polyamide facesheet

| $E_1$,$E_2$ (GPa) | $V_{12}$ | $G_{12}$ (GPa) | $X_{1T}$ (GPa) | $Y_{1T}$ (GPa) | $S_{12}$ (GPa) |
|---|---|---|---|---|---|
| 12 | 0.18 | 3.9 | 0.32 | 0.32 | 0.09 |

In Table 1, the values of $E_1$, $E_2$, $V_{12}$, $G_{12}$, $X_{1T}$, $Y_{1T,}$ and $S_{12}$ are respectively the modulus of elasticity in the direction of the fibers and perpendicular to it, Poisson's ratio, shear modulus, tensile strength in the direction of the fibers, tensile strength in the direction perpendicular to the fibers and shear strength.

The behavior of the PA6/GF composite at higher strain rates up to a strain rate of 10/s is calculated by the compressive Hopkinson test. Figure 1-a shows the true stress-strain diagram of the composite sample. According to this diagram, with the increase of the strain rate, the strength of the material has increased and the failure strain has decreased. Figure 1-b explains the effect of strain rate on the strength of PA6/GF composite logarithmically. From this graph, it can be concluded that the increase in strength of the PA6/GF composite has a linear relationship with the strain rate.

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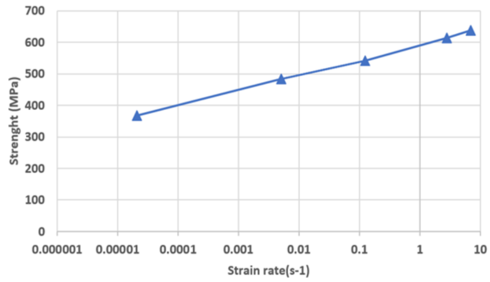


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**Figure 1.** a) True stress-strain diagram of PA6/GF composite at different strain rates. b) Diagram of the effect of strain rate on the strength of PA6/GF composite

## 3. Numerical model

The numerical modeling of the sheet and the boundary conditions in the simulation are quite similar to the experimental test conditions. The dynamic modeling of this simulation is done in LS-DYNA software and it is a combination of two shell and solid elements, which are used for the composite sheet and indenter, respectively. Indentation simulation is defined based on the Chang-Chang failure criterion.

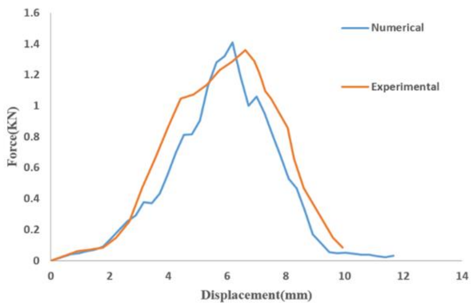
In this research, the penetrator is simulated as a rod with a hemispherical end with a diameter of 20 mm. The density of the material is determined in such a way that the indenter weight is equal to the actual weight of the projectile in the experimental test. Penetrator modeling is modeled with MAT_20 material model, which is specific for solid materials. MAT_54 material model is used for modeling composite materials that predict the behavior of orthotropic composites until reaching the failure mode of the fibers and reducing the compressive strength of the composite when the matrix is destroyed.

The mesh dimensions of the shell are 2 and 1.5 mm, which are uniformly meshed. In order to ensure the correctness of the modeling, the test of independence of the mesh has been carried out. In each step of the mesh independence test, the dimensions of the elements become smaller so that the result of energy absorption converges to a certain number. After achieving convergence in the results, the number of suitable elements for modeling is determined. This number should not be so high that it imposes an additional computational load on the system, nor should it be so low that its error affects the accuracy of the results. Therefore, 3450 elements were selected for the shell.

## 4. Results

In this section, the results extracted from numerical simulation and experimental tests for both quasi-static indentation and drop weight tests are reviewed. Figure 2 compares the force-displacement diagram of the PA6/GF composite sheet in both quasi-static indentation and drop weight tests in both experimental and numerical modes. According to Figure 2-a, the maximum force applied to the composite shell in numerical and experimental simulation is 1.41 and 1.35 kN, respectively, which are about 4% different from each other. The amount of energy absorption of the numerical simulation and the experimental test was 7.9 and 9.5 joules, respectively, as a result, the numerical simulation has an error of 16.8% compared to the experimental test. After moving 6.2 mm, the penetrant reaches the maximum force that can be tolerated by the composite shell, and when it moves 10 mm, it completely passes through the sheet.

The acceleration recorded by the sensor due to the fall of a 7 kg weight from a height of 80 cm is compared with the numerical data in Figure 2-b after being converted into force. The impact speed of the projectile with the test sample is 3.95 m/s, and in these results, the effect of the strain rate compared to the quasi-static test is evident. The maximum force recorded in the numerical simulation and the experimental test is 1.82 and 1.66 KN, respectively, and the error value of numerical results compared to experimental results is 9.6%. By calculating the area under the force-displacement diagram in Figure 2-b, the amount of energy absorption of the sample under experimental testing and numerical simulation is obtained as 11.4 and 9.6 joules, respectively.

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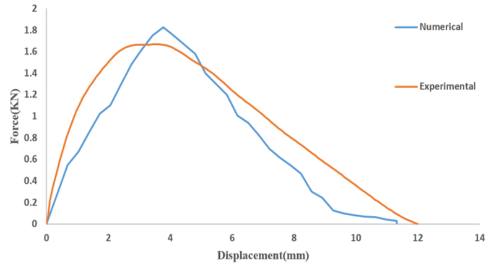


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**Figure 2.** Experimental and numerical diagram of a)quasi-static indentation test b)Drop weight test

## 5. Conclusion

As a result of the impact loading on the composite sheet, in addition to fiber breakage, the separation of fibers from the background, cracks in the direction, and perpendicular to the direction of the fibers were observed. Since the separation of fibers from the background is related to the adhesion of fibers and the background, it is possible to increase the energy absorption properties of this type of composite by improving the adhesion of fibers and the background. By adding the effects of the strain rate in the numerical simulation, the error of the force required for penetration in the quasi-static indentation test and drop weight was 4% and 9.6%, respectively. Numerical simulation has acceptable accuracy for sheets with a thickness of less than 2.4 mm, but the accuracy of the simulation drops in larger thicknesses due to the significant effects of shear stress. The highest absorption of energy and the maximum force required for penetration occurred in the layer of [$90_2/0_2$]. By presenting the numerical simulation proposed in this article, the prediction of the behavior of composite sheets (PA/GF) has become much easier, which increases the efficiency of production and design of industrial parts.

## 6. References

[1] A. K. Sambale, M. Schöneich, and M. Stommel, *"Influence of the processing parameters on the fiber-matrix-interphase in short glass fiber-reinforced thermoplastics"*, Polym, vol. 9, no. 6, p. 221, 2017

[2] M. Karamooz, H. Rahmani, and H. Khosravi, "An experimental and numerical study on the low-velocity impact behavior of polymer matrix Kevlar-Basalt hybrid composites," *Iranian Journal of Manufacturing Engineering*, vol. 7, no. 6, pp. 44-55, 2020

[3] X. Xu, Z. Zhou, Y. Hei, B. Zhang, J. Bao, and X. Chen, "Improving compression-after-impact performance of carbon–fiber composites by CNTs/thermoplastic hybrid film interlayer," *Composite Science Technology*, vol. 95, pp. 75-81, 2014.

[4] T. Bárány, A. Izer, and J. Karger-Kocsis, "Impact resistance of all-polypropylene composites composed of alpha and beta modifications," Poly Test, vol. 28, no. 2, pp. 176-182, 2009

[5] W. J. Cantwell and J. Morton, "The impact resistance of composite materials—a review," compos, vol. 22 ,no. 5, pp. 347-362, 1991.

[6] A. Massaq, A. Rusinek, M. Klosak, S. Bahi, and A. Arias, "Strain rate effect on the mechanical behavior of polyamide composites under compression loading," *Composite Structure*, vol. 214, pp. 114-122, 2019.

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