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MECHANICAL AND AERONAUTICAL ENGINEERING

Examination of energy damping behavior of fiberglass reinforced sandwich structures with extruded polystyrene core material

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Abstract. Composite materials are defined as new materials formed by combining two or more materials that do not mix, leveraging the best properties of each constituent. Composite materials are used in important industrial sectors such as aerospace and automotive due to their superior properties. In this study, XPS (extruded polystyrene) polymer foam was utilized as the core material. Glass fibers were combined with resin in a total of eight and twelve layers and applied to both the top and bottom of the core structure. Production involved both manual laying and vacuum bagging methods. Two types of glass fiber, weighing 200 g/m^2 and 300 g/m^2, were employed. After production, the composites were cut to standardized dimensions, followed by three-point bending and low-speed impact tests. Impact experiments were conducted with a constant energy of 50 J. Results showed that the 200 g/m^2 glass fiber composites experienced perforation in the eight-layer samples and rebound in the twelve-layer samples. Although greater deformation was observed in the impact tests of the 300 g/m^2 glass fiber composites in the eight-layer samples compared to the twelve-layer samples, a rebound occurred in both. In three-point bending tests, the bending strength increased as the number of layers increased, and at the same number of layers, composites with 300 g/m^2 properties showed higher strength than 200 g/m^2 composites.

Keywords: drop impact test; energy damping; fiberglass; sandwich structures; XPS foam.

1. INTRODUCTION

The advancement of technology and material development are two closely related concepts. Technological progress is often grounded in material science, manufacturing processes, and general industrial developments. Materials science is a discipline used to understand, develop, and apply engineering materials. New materials may exhibit characteristics such as enhanced durability, reduced weight, increased flexibility, or improved electrical properties, enabling the development of novel technologies. As material technology evolves, composite materials are becoming increasingly prevalent in the desired materials for various industries. Composite materials refer to a new class of materials created by combining two or more different materials, typically involving a matrix material, and reinforcing material [1, 2].

Polymer-based resins are used as matrices in the production of composite materials. In the manufacturing of composites, reinforcing fibers or reinforcements within a polymer matrix are commonly employed [3, 4]. The polymer matrix usually consists of epoxy, polyester, vinyl ester, or thermoplastic resins, which determine the overall mechanical properties of the composite [5–7]. Fiber reinforcements are the primary elements enhancing the durability of the composite. Commonly used fiber types include glass fiber, carbon fiber, and aramid fiber, each with distinct properties suitable for various applications [8–11]. The composite structure can be customized and manufactured with different combinations of materials to meet diverse engineering needs. Composite materials can be manufactured with various properties, including lightweight design, high strength and durability, corrosion resistance, and thermal insulation. Additionally, they can exhibit features such as high-temperature resistance, chemical resistance, and effective vibration absorption [12–14]. Fiber-reinforced composite materials embody many of these properties, and ongoing research continues to explore and enhance these material characteristics.

Fiber-reinforced composite materials aim to achieve superior mechanical properties by combining complementary features [15, 16]. Due to these attributes, they are preferred in various applications, including the aerospace industry [17, 18] automotive industries [19–23] sports equipment [24–26], and the construction industry [27–29]. Especially in the automotive industry, all vehicle manufacturers are working toward the reduction of fuel consumption and emission values [30,31]. Composite materials have the potential to significantly reduce fuel consumption and emissions by reducing vehicle weight thanks to their lightweight structure. For this reason, composite structures have a special place in the automotive industry. Another important aspect is the superior corrosion resistance of composite materials. This feature provides a great advantage for marine,

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outdoor, etc. applications that are exposed to different environmental conditions [32–35]. One class of fiber-reinforced composite materials is sandwich composite materials [36]. Sandwich composites have a unique structural composition, typically involving a lightweight core material sandwiched between two robust outer layers [37–39]. This construction combines lightweight properties with exceptional strength and durability. The outer layers are commonly made of fiber-reinforced composite materials, while the core material is often a lightweight foam or a specialized material [40].

Sandwich composites, typically comprising a core coated with two face layers, offer the potential to reduce the total part weight while enhancing specific mechanical properties under non-uniformly distributed loads. Thus, the sandwich core facilitates load transfer, while the surface layers absorb tensile and compressive loads occurring in bending stress [41, 42]. The objective is to optimize the efficiency of these sandwiches while minimizing weight per unit area, achieved, for instance, by employing (fiber) reinforced surface layers and foamed core materials.

For this reason, a sandwich composite was produced in this study using the manual laying method. XPS (extruded polystyrene) foam was chosen as the core material for its excellent compressive strength. Glass fiber layers were applied to both surfaces of the foam, with four and six layers on each side, resulting in a total of eight and twelve layers. Two different types of glass fibers, weighing 200 g/m^2 and 300 g/m^2, were used. To assess the strength of the samples, impact and three-point bending tests were conducted, and the fiber density and number of layers were compared.

2. MATERIAL METHOD

2.1. Production method

Hand lay-up is a method used in the production of composite materials, wherein layers of fiber-reinforced material, impregnated with resin, are manually placed into a mold. The material is then left in the mold and allowed to harden in a suitable environment. This method is typically employed in small-scale production or prototype manufacturing. Figure 1 illustrates a schematic view of the production stages of the composite material studied.

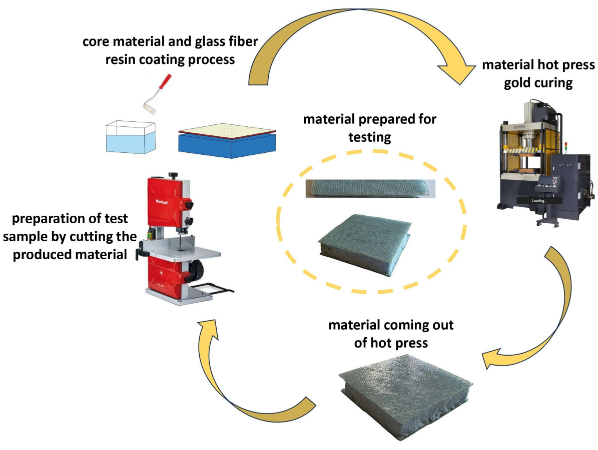

Fig. 1. Layered composite production stages

Before commencing production, the glass fiber materials and XPS foams to be used were cut to size for test samples. Subsequently, MGS LR 285 resin and MGS LH 285 hardener were prepared by mixing them with a mechanical mixer for a specific duration. Prepared glass fiber fabrics were then applied to the upper and lower surfaces of the core material in eight and twelve layers (see Fig. 2).

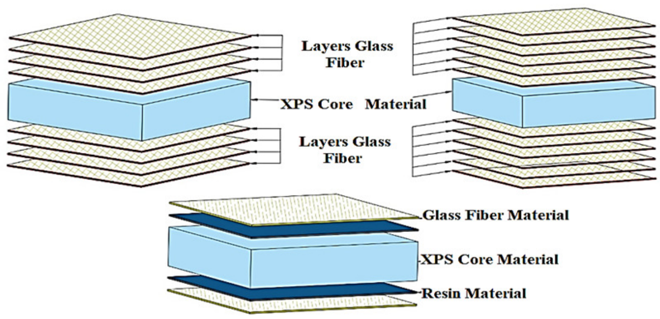

Fig. 2. Sample production schematic view

Resin is applied between each layer using a brush to ensure proper adhesion of the layers. The fabrics combined with the core material were placed under the press to eliminate air bubbles and ensure rapid curing. The curing time was approximately two hours, under a two-bar pressure with the upper and lower tables heated to 45°C. During this period, the resin hardens and cures, resulting in the formation of an XPS core structured sandwich composite material. After removal from the press, the composite materials are precisely cut into standard test sample sizes. The production parameters of the samples are provided in Table 1.

Table 1
Production parameters of the samples used in the tests

Abbreviations	Core material	Fiber feature (g/m^2)	Number of layers	Core material thickness (mm)	Total thickness (mm)
XPS-8-200	Expanded polystyrene Rigid foam	200	8	20	21
XPS-12-200			12		21.5
XPS-8-300		300	8		21.5
XPS-12-300			12		22

2.2. XPS foam

XPS foam is commonly employed as an insulation material in buildings and industrial applications, owing to its properties such as low thermal conductivity, high durability, and water resistance. The extrusion process yields a homogeneous cell structure, contributing to the material high strength. These applications extend to lightweight and structural support. In the automotive industry, XPS foam aids in reducing vehicle weight, thereby lowering fuel consumption and emissions. Moreover, it is utilized in certain automobile bumper designs to enhance energy absorption and mitigate crash effects. XPS was chosen as the foam core material for its strength and porous structure (Figs. 3a and 3b).

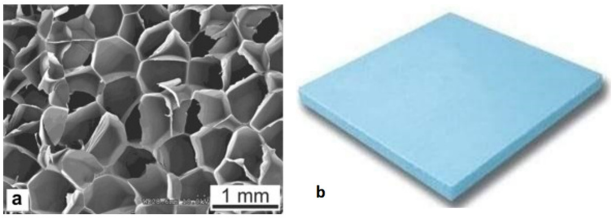

Fig. 3. XPS foam core material (a) SEM micrographs [43], (b) commercial image

2.3. Glass fiber composite

Glass fiber fabric, typically produced from glass fibers, serves as a reinforcement element in various industries. It boasts high-strength properties, enhancing the durability and lifespan of the materials it reinforces. Glass fibers exhibit remarkable resistance to tensile and impact forces, enabling the creation of durable and reliable structures across numerous applications.

Glass fiber is a versatile reinforcement material widely employed across various industries, particularly in the automotive sector. It finds extensive use in components aimed at reducing vehicle weight, enhancing fuel efficiency, and improving performance. These components include body parts, interior trim and panels, chassis and structural elements, wheel covers, and fuel tanks. In this study, glass fibers weighing 200 g/m^2 and 300 g/m^2 were selected for their advantageous properties, as illustrated in Fig. 4.

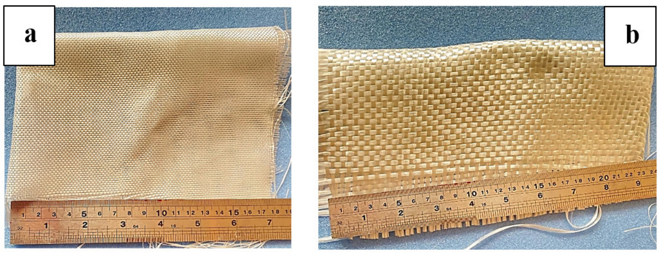

Fig. 4. Glass fiber composite material. (a) 200 g/m^2 glass fibers, (b) 300 g/m^2 glass

3. FINDINGS

3.1. Impact test results

The low-speed impact test is a testing method employed to measure the impact resistance of composite materials. In this test, a weight is dropped from a specific height onto the material, and subsequently, the behavior of the material is evaluated [44]. The study utilized an Instron Ceast 9350 type impact tester for conducting the impact tests. Since there are many different test standards in impact tests, the tests were performed according to ASTM D7136 standard [45]. The tests were performed at a fixed energy of 50 Joules to compare the samples with each other. Production parameters were compared by considering force-deformation curves as test results. Sample dimensions are 100 mm × 100 mm square shape. Three samples from each experiment were tested, their averages were taken, and graphs were drawn.

3.1.1. Influence of layer thickness on impact strength

Figure 5 shows the force-deformation curves of XPS-200, eight-layer, and twelve-layer samples and the deformation pictures of the samples as a result of the experiment.

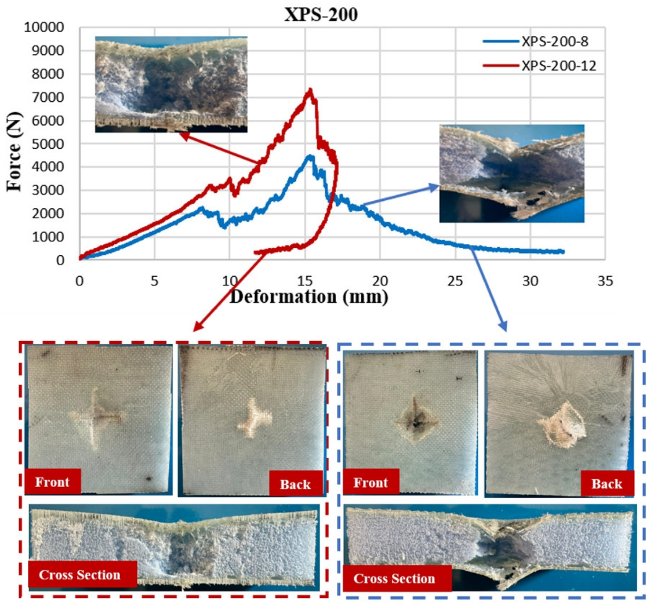

Fig. 5. Effect of layer thickness on impact resistance (XPS, 200 gr)

The graph in Fig. 5 illustrates that the core structures of the samples and the fiber densities used are the same, albeit with varying numbers of layers. In the XPS-12-200 sample, the maximum energy value and maximum deformation were measured at approximately 7300 N and 17 mm, respectively. Conversely, the maximum energy value for the XPS-8-200 sample was determined to be approximately 4500 N. While puncture occurred in the XPS-8-200 sample, a rebound was observed in the XPS-12-200 sample.

The twelve-layer sample absorbed more energy during the impact and damage was observed only on the front surface and core. In addition, due to the strong bond between the layers, delamination occurred only on the front surface. The eight-layer sample also showed lower energy resistance. The test resulted in visible damage and irregular fiber breaks (delamination) on both the front and back surfaces. Although damage to the core material was observed in both samples, the damage in the twelve-layer sample was less. This difference is evident from the deformations on the front and back surfaces of both samples, as depicted in Fig. 5.

Figure 6 displays the force-deformation graph of XPS-300 samples with eight and twelve layers, along with images depicting the deformations resulting from the experiment. Following the impact test, both samples exhibited damage to their front surfaces, accompanied by rebound. Deformations of approximately 15.5 mm and 14.5 mm were observed in the eight-layer and twelve-layer samples, respectively. The maximum energy forces were measured at approximately 8000 N for the eight-layer sample and 9000 N for the twelve-layer sample.

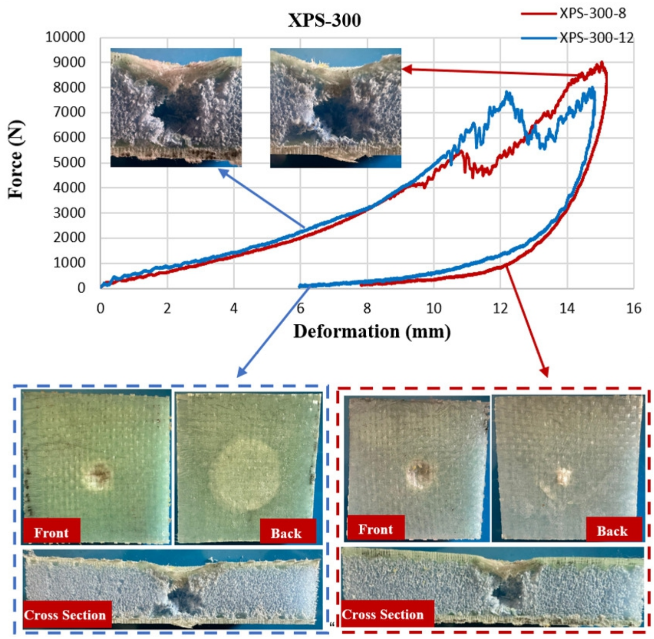

Fig. 6. Effect of layer thickness on impact resistance (XPS, 300 gr)

3.1.2. Effect of fiber density on impact strength

Figure 7 shows the force-deformation curves of XPS 8-300 and XPS 8-200 samples.

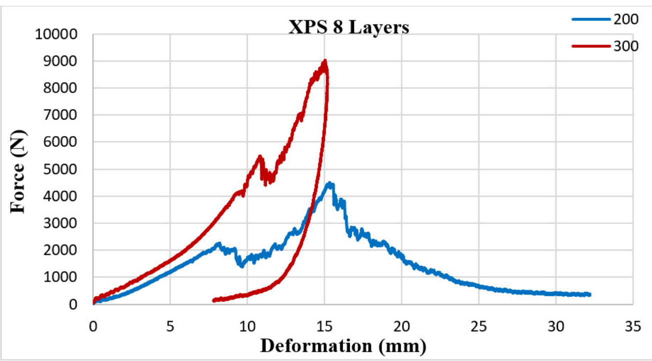

Fig. 7. Effect of fiber density on impact strength (XPS, eight layers)

In the force-deformation curves in Fig. 7, samples with the same core structure and number of layers (eight layers) but different fiber densities are compared. While perforation occurred in the sample using 200 g/m^2 fiber, rebound occurred in the sample using 300 g/m^2 fiber. It was determined that XPS-8-300 samples performed better than XPS-8-200 samples.

In the force-deformation curves in Fig. 8, samples with the same core structure and number of layers (twelve layers) but different fiber densities are compared. The fact that the graphs appear as a closed curve is an indication that a rebound has occurred in both samples. At the end of the experiments, less deformation occurred in the samples using 300 g/m^2 fiber compared to the samples using 200 g/m^2 fiber.

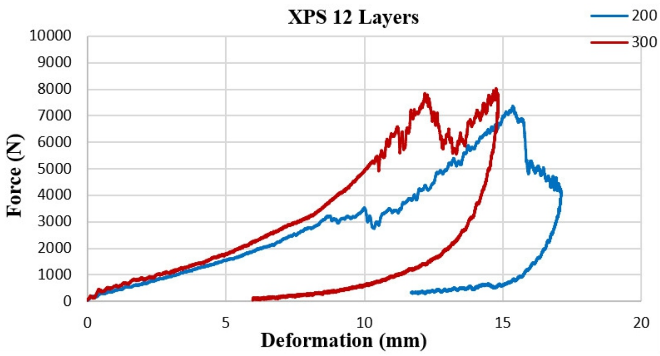

Fig. 8. Effect of fiber density on impact strength (XPS, 12 layers)

3.2. Three-point bending test results

In three-point bending tests, layer thicknesses and fiber densities were compared. The samples produced were prepared in dimensions of 180×30 mm. The feed rate in bending tests was set to 1 mm/min in accordance with the D 7264/D 7264M-07 standard. Approximately 30 mm of deformation was applied in the experiments. Three samples from each experiment were tested, and the average was calculated and graphed [46].

During the experiments, no deformation or breakage of the layers occurred in the samples. For this reason, the experiments were limited to 30 mm of deformation (Fig. 9).

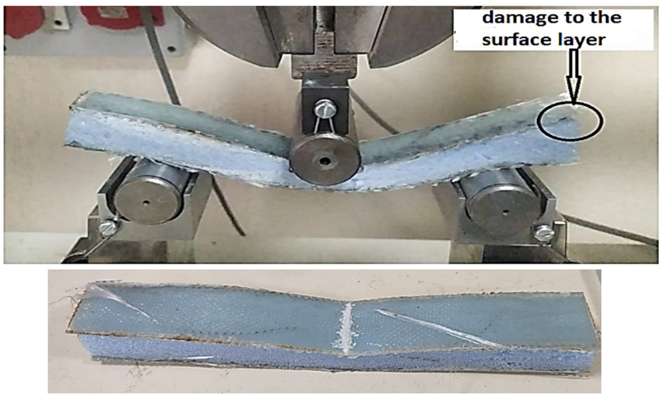

Fig. 9. View of the XPS foam core sample at the end of the compression test

3.2.1. Effect of layer thickness on three-point bending strength

Figure 10a shows the force-deformation curves obtained during the three-point bending test of XPS-8-200 and XPS-12-200 samples, and Fig. 10b shows the XPS-8-300 and XPS-12-300 samples.

The XPS-8-200 sample withstood a maximum force of approximately 220 N, while the XPS-8-300 samples endured a

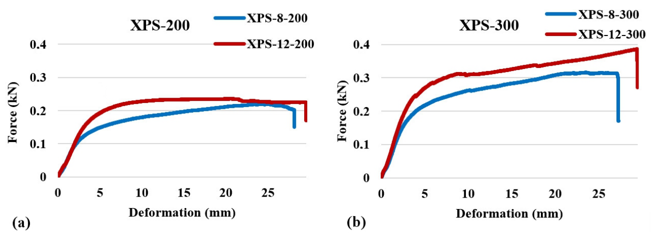

Fig. 10. Effect of layer thickness on three-point bending strength

force of approximately 315 N. Based on these data, the XPS-8-300 samples yielded better results than the XPS-8-200 samples. Similarly, the maximum force of the XPS-12-200 sample was approximately 235 N, whereas the XPS-12-300 sample withstood a maximum force of approximately 385 N. Consequently, the XPS-12-300 sample demonstrated superior performance compared to the XPS-12-200 sample.

4. DISCUSSION AND CONCLUSIONS

In this study, the mechanical properties of glass fiber-reinforced polymer foams were compared. Glass fibers weighing 200 g/m^2 and 300 g/m^2 were selected as reinforcement materials, while XPS foams were utilized in the core part of the composite materials.

In the impact tests, 200 g/m^2 glass fiber composites experienced puncture in the eight-layer samples, while rebound was observed in the twelve-layer samples, indicating their higher resistance.

Although more deformation occurred in the impact tests of 300 g/m^2 glass fiber composites in the eight-layer samples compared to the twelve-layer samples, both sets of tests resulted in rebound for the two-layer samples. Towards the end of the three-point bending test of XPS layered composites, the separation between the fiber layer and foam structure was observed. It is thought that the separation between the fiber layer and the core sample mentioned in the study did not result from insufficient bonding of the resin but from the structural weakness between the inner layers of the foam during the experiment. This situation was supported by the observation of residues of the core material on the fiber layer during the experiment, and it was concluded that the weakness that occurred in the inner layers of the foam layer was the main reason for the separation.

Comparable results to the impact tests were obtained in the three-point bending tests, with higher strengths observed in the twelve-layer samples compared to the eight-layer samples. Similarly, the 300 g/m^2 fiber layer composite samples exhibited better performance than the 200 g/m^2 samples. No breakage occurred in the fiber layers in any of the three-point bending tests. This can be attributed to the energy-absorbing properties of the core layer, thanks to its porous structure. This inference is supported by the horizontal trend observed in the graph.

In the study, a constant 50 J impact energy was preferred to compare the differences between the samples. However, this approach does not provide the opportunity to evaluate the damage conditions of different impact energy levels. Therefore, examining the effects of different impact energy levels can be a reference for other studies in the future.

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