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Investigation of mechanical behavior of glass fiber reinforced extruded polystyrene core material composites

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Layered composites are composite materials created by combining different layers of materials. Each layer can possess unique properties, often tailored to meet specific application or design requirements. These composites have found applications in various sectors due to their features, which include lightness, excellent impact properties, and customization according to specific application areas. In this study, glass fiber reinforced polymer foam core layered composite materials were produced. EPS polymer foam was used as the core material. During production, polymer foams and fibers were bonded to the upper and lower sides of the foams using resin. Samples were produced with 4 and 6 layers on both sides, totaling 8 and 12 layers, respectively. The vacuum bagging method was employed in production, utilizing the manual laying technique. Upon completion of production, the materials were cut into sizes conforming to standards and converted into samples. Subsequently, three-point bending and low-speed impact tests were conducted on the produced samples. As a result of the impact tests, perforation occurred in the 8-layer samples of 200 g m^{-2} glass fiber composites, while rebound was observed in the 12-layer samples. Although more deformation occurred in the 8-layer glass fiber composites of 300 g m^{-2} than in the 12-layer samples, both sets of experiments resulted in rebound. Similar results to the impact tests were obtained in three-point bending tests, with higher strengths observed in the 12-layer samples compared to the 8-layer samples. Composite samples with fiber layers of 300 g m^{-2} exhibited better performance than samples with 200 g m^{-2} fibers.

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1. Introduction

Composite materials have attracted increasing interest over the last century. This heightened attention has led these materials to find a wide range of applications, earning them a significant place in various industries. Given the limitations of traditional materials and the emergence of new requirements, there has been a growing need for materials that are lighter,[1–3] more durable,[4–6] corrosion resistant,[7,8] and possess high thermal resistance.[9,10]

Composite materials are created by combining different components, typically comprising a matrix (matrix material) and reinforcement elements.[11,12] While various classifications exist, they can generally be broadly divided into classes such as fiber reinforced polymer composites (FRP), sandwich composites, metal matrix composites (MMC), ceramic matrix composites, polymer matrix composites, and bio-composites.[13–16]

Sandwich composites consist of a lightweight core material sandwiched between two robust surface layers.[17,18] The reinforcing surface layers are typically made from fiber-reinforced polymer composites, while the core material is chosen from lightweight materials.[19,20] The surface layers contain a polymer matrix with reinforcements such as glass fiber, carbon fiber, or aramid fiber.[21–25] The purpose of these layers is to enhance the overall durability and mechanical properties of the composite.[26–29] The core material generally comprises a lightweight and low-density material, often polymer foam, wood panels, aluminum honeycombs, or other lightweight materials. The core material contributes to increased structural strength, simultaneously reducing the overall density of the composite. This design offers the advantages of high strength and low weight.

Due to these advantages, sandwich composites have a wide range of applications. They are especially used in areas such as aerospace,[30] aviation,[31–33] automotive,[34–36] marine,[37] construction[38] and sports equipment. In the automotive industry, they can be used to improve fuel efficiency due to their light weight.[39,40] They can also be used in structural elements to increase the durability of vehicles[41] as well as in the train and aircraft industries. Their durability and light weight make it possible to use them in the construction of boat hulls and yachts in the marine sector.[42,43]

As composite materials find new areas of use every day, studies on sandwich composites are increasing day by day. In

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some of these studies, metal foam was used as the core material in layered composites. They carried out tests at high speeds, especially for the defense industry such as armor *etc.* At the end of the studies, they reached the conclusion that the core material contributed significantly to energy absorption.[44–48] It is seen that EPS foam is used mostly in the construction industry as a building core material. It is stated that its purpose here is to benefit from features such as low thermal conductivity and medium compressive strength.[49,50] It is seen that EPS foam is used as a core material in sports equipment such as surfboards, which is a different field. At the end of the study, they concluded that high foam density increased the mechanical properties of composites such as flexibility and fracture.[51]

In the study, expanded polystyrene (EPS) foams were utilized as the core material. In the production of composite sheets, foam was employed as the core, and layers of glass fiber fabrics were applied to both the top and bottom surfaces. The sheets were produced using epoxy resin and the vacuum bagging method. Samples were created with 4 and 6 layers on both sides, resulting in a total of 8 and 12 layers. Two different glass fibers, weighing 200 g m^{-2} and 300 g m^{-2}, were used as reinforcing fibers. Impact tests were conducted to assess the strength of the samples.

2. Material method

2.1 Production method

Vacuum bagging, one of the methods of composite material production, is a manufacturing technology utilized in various industries, particularly in sectors such as aerospace, automotive, and marine. This method enables the production of lightweight and durable composite parts with high strength-to-reinforcement ratios. By utilizing vacuum pressure, this method allows the material to conform to the desired shape within the mold. Hence, the vacuum bagging method was employed in this study.

In this method, the composite fabric material is placed into a mold by hand and the resin is distributed into the mold by hand. The vacuum bagging production method eliminates the disadvantages of the hand placement method of composite structure production and enables the production of durable and lightweight composite structures. The application of negative pressure in vacuum bagging allows the air between the resin and the composite fabric to be drawn out. During the production of sheet materials, MGS L285 epoxy material and MGS H285 hardener were mixed and applied.

Two different specifications of glass fiber fabrics, 200 g m^{-2} and 300 g m^{-2}, were used as reinforcement elements (Fig. 1). Glass fiber is a material formed by combining glass yarns together. In the literature research, it is seen that glass fibers have an elasticity modulus of 25–35 GPa and a tensile strength of around 800–900 MPa.[52] Glass fiber is used in a wide range of industrial applications due to its durable, lightweight and high strength properties.

Layered composite structures usually contain a core material. This core material should generally be lightweight, stiff and durable. Although rigid core material is generally used for high strength, porous structures are preferred for energy absorption. In this study, expanded polystyrene rigid foam (EPS) was used as the core material since it is an investigation of the energy absorption capabilities of layered composites (Fig. 2).

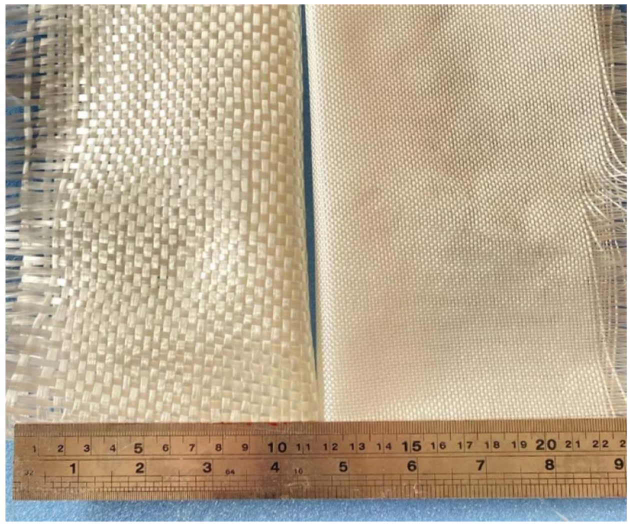

Fig. 1 300 g m^{-2} and 200 g m^{-2} glass fibers used in the study.

EPS foam is a polymer foam material obtained by expanding polystyrene polymer. EPS foam has lightweight, rigid and insulating properties. These materials are lightweight, provide energy absorption and are generally suitable for insulation purposes. According to the literature review, it has been determined that the density of the EPS foam used in the tests varies between 13.5 kg m^{-3} and 28 kg m^{-3}, and its properties range from 0.089 MPa to 0.165 MPa.[53] They are also used in the packaging industry to protect products during transportation. The production and use of EPS foams also contributes to sustainability efforts, as these materials can be recycled.

Fig. 3 shows a schematic view of the composite material production stages. Firstly, epoxy resin hardener was prepared with the help of a mixer. The prepared fiber and core material were combined with the resin using the hand lay-up method. It was cured in a vacuum environment for about 3 hours at room temperature. The prepared specimens were cut with a precision band saw in accordance with the three-point bending and impact test specimen standards. The production parameters of the specimens are given in Table 1.

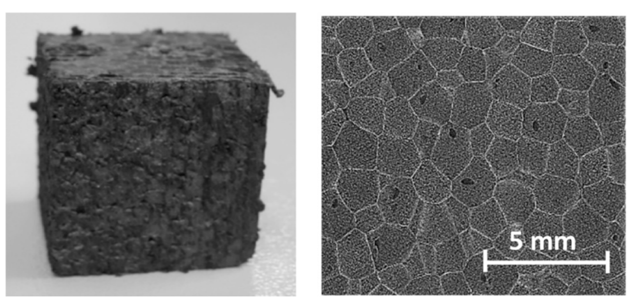

Fig. 2 EPS foam.[54]

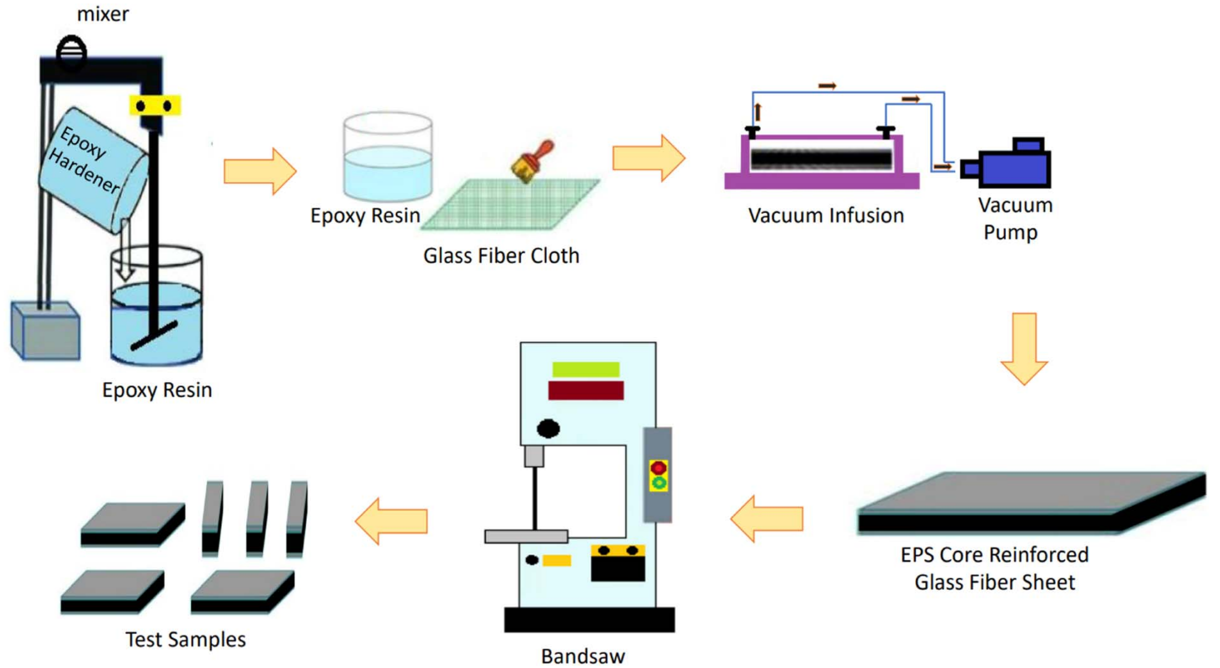

Fig. 3 Stages of layered composite production.

Table 1 Production parameters of the specimens used in the tests

Abbreviations	Core material	Fiber properties (g m^{-2})	Number of layers	Core material thickness (mm)	Total thickness (mm)
EPS-8-200	Expanded polystyrene rigid foam	200	8	20	21
EPS-12-200			12		21.5
EPS-8-300		300	8		21.5
EPS-12-300			12		22

2.2 Impact test methods

Various tests are utilized to assess the impact resistance of layered composite materials. These tests are conducted to comprehend the material's behavior under different conditions and to ascertain its performance in the design process. The low-speed impact test is a method employed to evaluate materials' resistance to impact. It helps in understanding the material's behavior under varied conditions, determining its performance in the design process, and meeting specific application requirements. In this test, a weight dropped from a certain height impacts the material, and its behavior is assessed. Fig. 4 depicts the Instron Ceast 9350 instrument used in this test method.

The Instron/Ceast 9350 Rapid Impact Tester is used to test a wide range of specimens from composite materials to finished products in various impact tests such as tensile impact, puncture, Izod and Charpy.

In impact tests, three damage modes usually occur: rebound, stab and puncture. As seen in Fig. 5, for low energy impacts, the curve is a parabolic curve. As the applied impact energy increases, the resulting force also increases, and the maximum force value is almost constant, as can be seen in the stub and puncture curves. When the specimen is punctured, the force should be zero, but due to the friction between the striker and the specimen, the end of the curve runs parallel to the horizontal axis. Fig. 5 shows the force–displacement curves as a result of the impact test.[55]

3. Findings

3.1 Impact test results

Since there are many different production parameters in impact tests, tests were performed according to ASTM D7136 standard at a constant energy of 50 joules.[56] Production parameters were compared by considering the force deformation curves as test results. The specimen dimensions are 100 mm × 100 mm square. Three specimens from each experiment were tested and averaged and graphs were drawn.

3.1.1 Effect of layer thickness on impact strength. Fig. 6 shows the force–deformation graph of EPS-8-200 and EPS-12-200 specimens. The puncture and rebound of the specimens can be seen in the graph.

Perforation occurred in both the top and bottom layers of the EPS-8-200 specimen due to impact energy (Fig. 7a). Perforation

Fig. 4 Instron Ceast 9350 instrument.

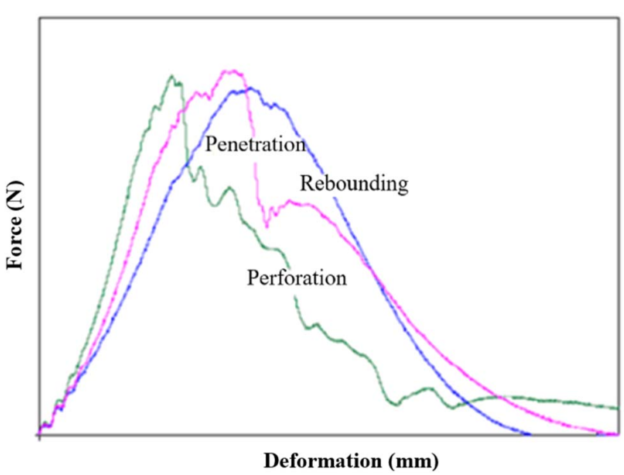

Fig. 5 Force–displacement curves after impact test.[55]

was observed in the top layer of EPS-12-200 specimen. Due to the energy absorption of the core material, no perforation was observed in the bottom layer, only trace and rebound occurred (Fig. 7b). The maximum force at the EPS-8-200 maximum force point was observed to be approximately 3650 N. In EPS-12-200, the maximum force was observed as 5100 N with a deformation of approximately 19 mm.

Fig. 8 shows the force–deformation graph of EPS-8-300 and EPS-12-300 specimens. At the end of the impact test, perforation occurred in the upper layers of both specimens and the deformation of the 8 and 12 layer specimens was approximately 16.5–13.5 mm, respectively. In addition, no deformation was observed in the bottom layer of both specimens (Fig. 9a and b) and rebound occurred in both. At the end of the impact test for EPS 300 8 and 12 layer specimens, the maximum force value was close to each other and measured approximately 6800 N.

3.1.2 Effect of fiber density on impact strength. When the force–deformation graph in Fig. 10 is analyzed, it is observed that the EPS-8-200 specimen was perforated, while the EPS-8-300 specimen rebounded. A deformation of 16.5 mm occurred in the EPS-8-300 specimen. In line with the data obtained from the graph, it was determined that EPS-8-300 specimens showed better strength than EPS-8-200 specimens.

In the graph in Fig. 11, rebound occurred in both EPS-12-200 and EPS-12-300 specimens. The approximate deformations of EPS-12-200 and EPS-12-300 specimens were 19 mm and 13.5 mm, respectively. According to the data obtained from the graph, it was determined that EPS-12-300 specimens showed better strength than EPS-12-200 specimens.

3.2 Three point bending test results

Three-point bending tests were examined under 2 headings: layer thickness and fiber densities. The specimen dimensions were 180 × 30 mm in length x width. The feed rate of the device was selected as 1 mm min^{-1} according to D 7264/D 7264M-07 standard. In the experiments, an average deformation of around 30 mm was applied to determine the fracture of the substrate. Three specimens from each experiment were tested and averaged and graphs were drawn.[57]

The reason why the force curves do not decrease to zero at the end of the experiments is due to the porous structure of the core layer in between. The decrease at the end of the graph is due to the tearing of the core structure (EPS) structure (Fig. 12). At the end of the experiments, no fracture occurred in the lower layers due to the structure of the core material. For this reason, the experiments were terminated as soon as deformations started in the core structure.

3.2.1 Effect of layer thickness on three-point flexural strength. Fig. 13 shows the force–deformation graph of EPS-8-200 and EPS-12-200 specimens obtained during the three-point bending test.

When Fig. 14 is examined, the fracture of the EPS-8-200 sample occurred in the upper layer deformation around 12 mm and the maximum force here is around 160 N. In the EPS-12-200 specimen, fracture occurred around 13 mm and withstood a force of around 200 N. As a result of the test, EPS-12-200 specimen gave better results than EPS-8-200.

Fig. 14 shows the force–deformation graph of EPS-8-300 and EPS-12-300 specimens obtained during the three-point bending test. In the EPS-8-300 specimen, the first layer fracture occurred

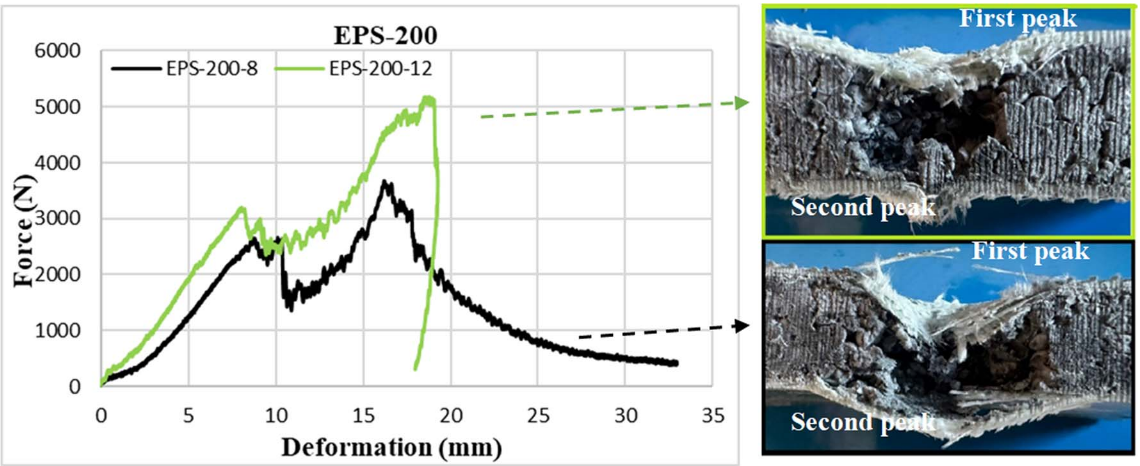

Fig. 6 Effect of layer thickness on impact strength.

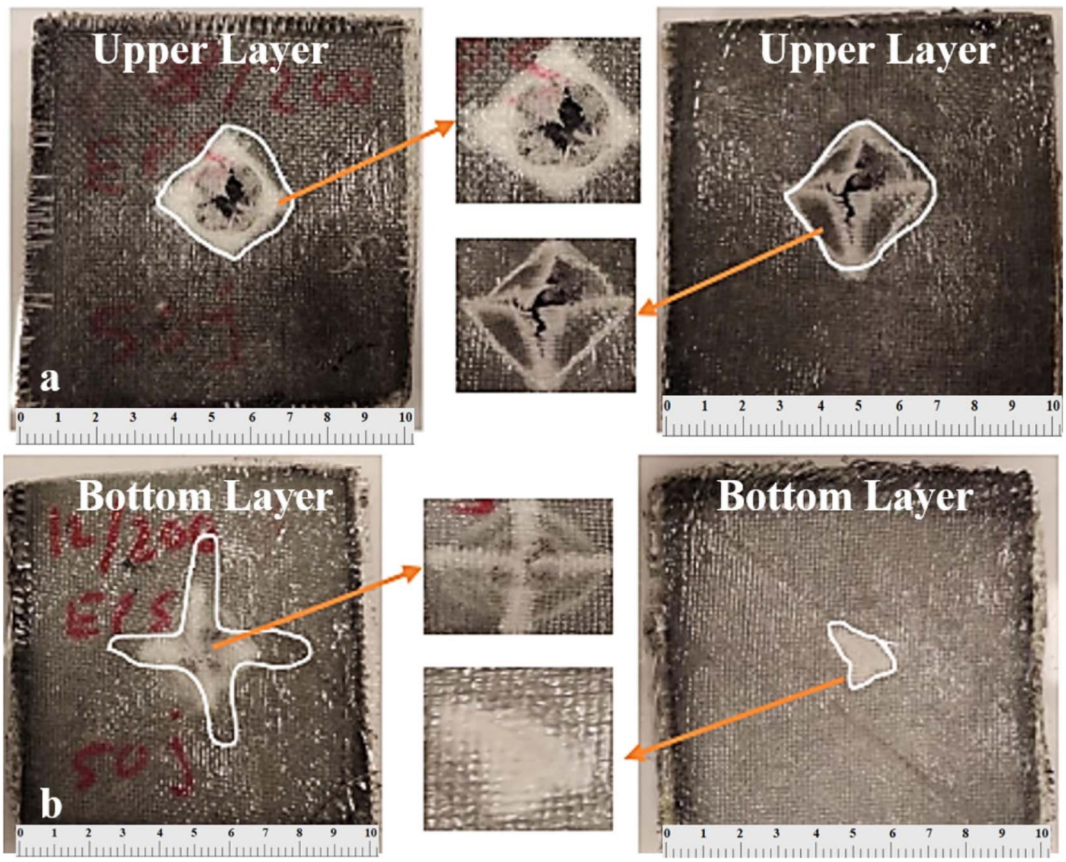

Fig. 7 Impact test results ((a) EPS-8-200, (b) EPS-12-200).

at a deformation of around 14 mm and the maximum force is around 255 N. In the EPS-12-300 specimen, the first layer fracture occurred around 22 mm and withstood a force of around 320 N. As a result of the test, EPS-12-300 specimen gave better results than EPS-8-300.

3.2.2 **Effect of fiber density on three-point flexural strength.** The graph in Fig. 15 shows the force–deformation graph of EPS-8-200 and EPS-8-300 specimens obtained during the three-point bending test. In the EPS-8-200 specimen, the first layer fracture occurred at a deformation of around 12 mm and the maximum force was around 160 N. In the EPS-8-300 specimen, the first layer fracture occurred at a deformation of around 14 mm and the maximum force here is around 255 N. As a result of the test, EPS-12-300 specimen gave better results than EPS-8-300.

When the graph in Fig. 16 is examined, the first layer fracture occurred around 12 mm in the EPS-12-200 sample and

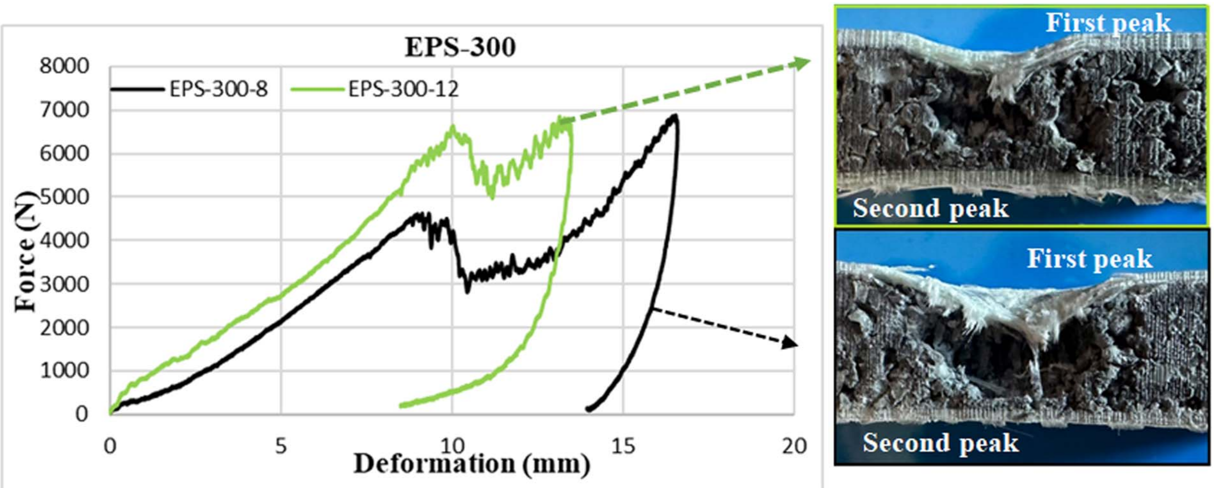

Fig. 8 Effect of layer thickness on impact strength.

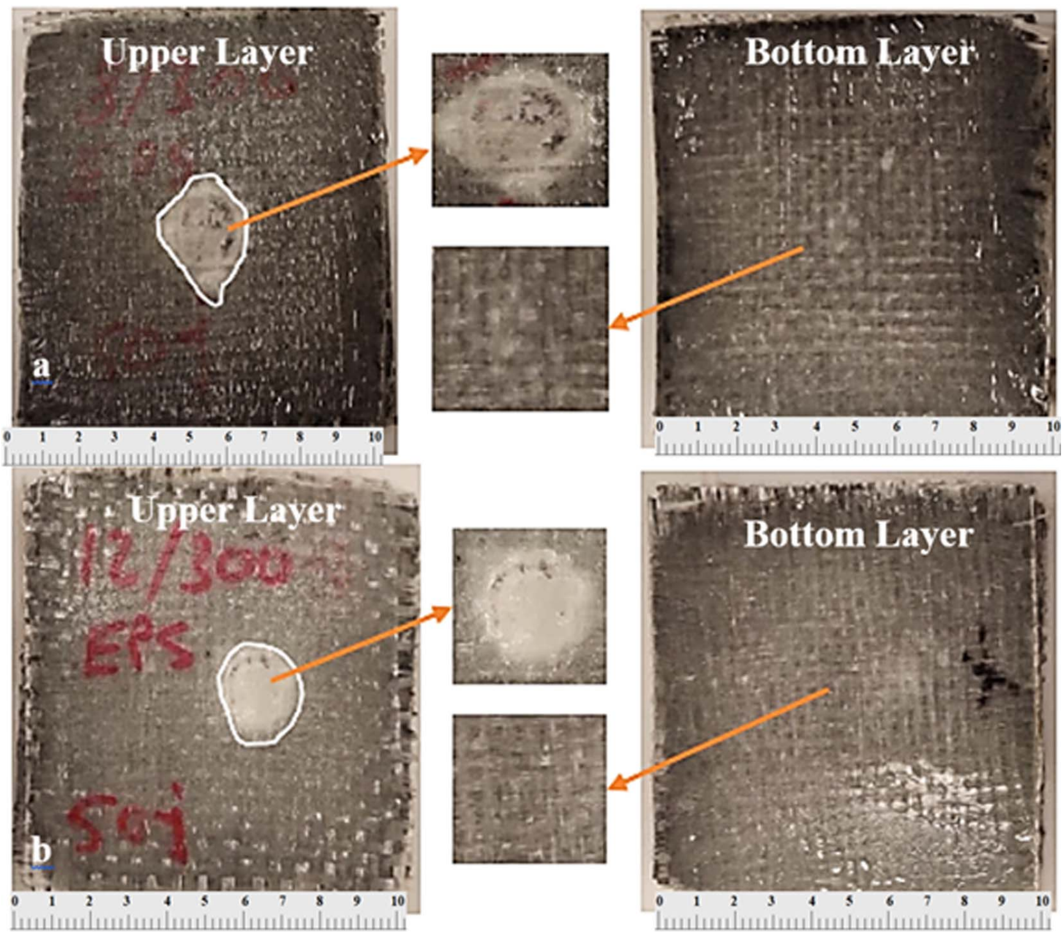

Fig. 9 Impact test results ((a) EPS-8-300, (b) EPS-12-300).

withstood a force of around 200 N. In the EPS-12-300 specimen, the first layer fracture occurred around 22 mm and withstood a force of around 320 N. Based on these data, EPS-12-300 specimens gave better results than EPS-12-200 specimens.

4. Discussion and conclusion

In this study, the mechanical properties of glass fiber reinforced polymer foams were compared. Glass fiber 200 g m^{-2} and 300 g

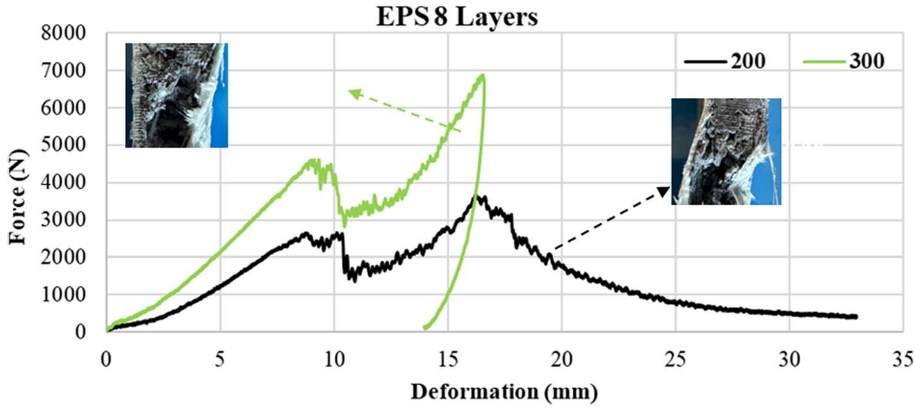

Fig. 10 Effect of fiber density on impact strength.

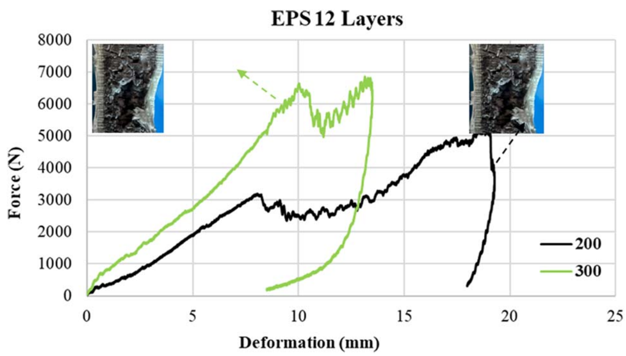

Fig. 11 Effect of fiber density on impact strength.

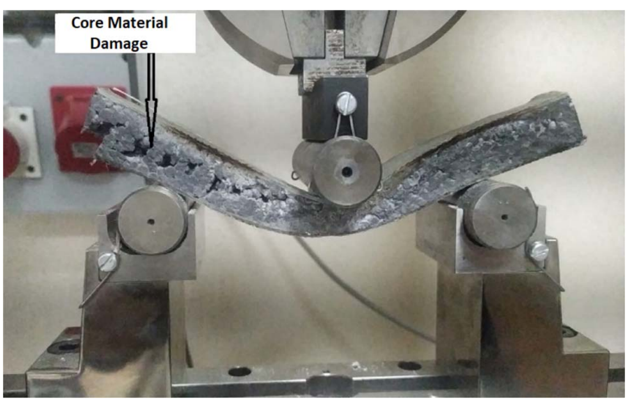

Fig. 12 Compression test view of EPS 8-300 foam core specimen.

m^{-2} were preferred as reinforcement material. EPS foam was used in the core of the composite materials.

• When comparing the EPS 200 specimens with 8 and 12 layers, perforation was observed in the 8-layer specimens, with a maximum impact force measured at approximately 3650 N. In the 12 layers specimens, a force of approximately 5100 N was measured, resulting in a deformation of approximately 19 mm, with subsequent rebound.

• When comparing EPS 300 samples with 8 and 12 layers, rebound occurred in both. In both cases, the maximum impact force was measured to be approximately 6800 N. The 8-layer sample experienced a deformation of approximately 16.5 mm, while the 12-layer samples showed a deformation of approximately 13.5 mm before rebounding. Based on the data obtained, it has been determined that EPS-12-300 samples are more durable than EPS-8-300 samples.

• In the three-point bending tests, 300 g m^{-2} force curves showed decreases and increases. This is thought to be due to the fact that the fabric is thicker due to its density and therefore the layers are more brittle.

• At the end of the three-point bending test, deformation could not occur in the lower fiber layers. This is due to the energy absorption of the foam layers.

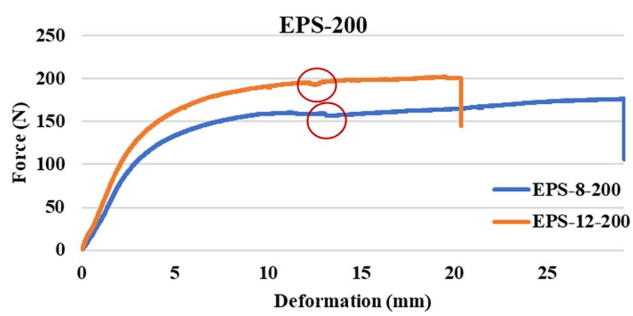

Fig. 13 Effect of layer thickness on three-point bending strength.

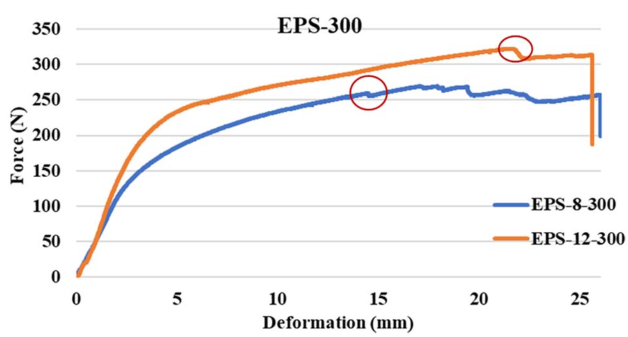

Fig. 14 Effect of layer thickness on three-point bending strength.

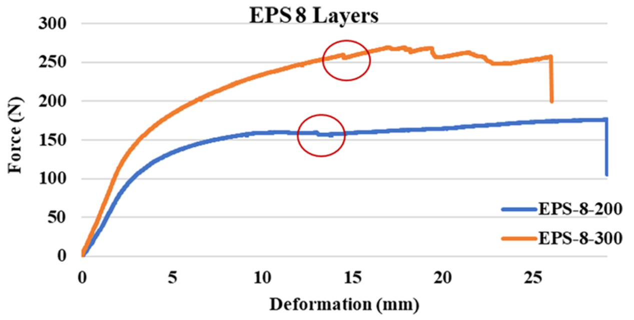

Fig. 15 Effect of fiber density on three-point bending strength.

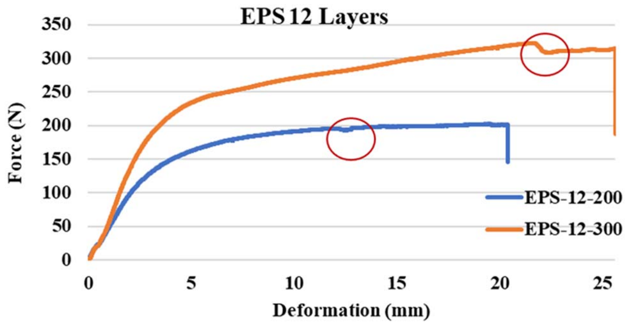

Fig. 16 Effect of fiber density on three-point bending strength.

• Similar results were obtained in three-point bending tests as in impact tests. The 12-layer specimens had higher strengths than the 8-layer specimens.

• In three-point bending tests, composite specimens with 300 g m^{-2} fiber layer performed better than specimens with 200 g m^{-2} fiber layer.

As a result of the study, as evident from the literature review, it has been observed that EPS core material finds extensive usage in automotive sector bumper applications, construction sector, and sports equipment. Similarly, it is believed that it can be employed in various applications across space, air, sea, and land vehicles.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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