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Araştırma Makalesi / Research Article

Investigation of Mechanical Behavior of Carbon Fiber Reinforced Sandwich Composites with Different Weights

Ercan ŞİMŞİR[1*]

[1*] Afyon Kocatepe Üniversitesi, Teknoloji Fakültesi, Otomotiv Mühendisliği Bölümü, Afyonkarahisar, Türkiye,
ORCID ID: https://orcid.org/0000-0001-6655-2324, esimsir@aku.edu.tr

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ABSTRACT: In this study, the impact and three-point bending performances of sandwich structures produced using carbon fiber-reinforced composite materials and XPS foam core with different fiber weights were investigated. Carbon fiber weighing 200 g/m² and 400 g/m² were used in sandwich structures. The reinforced layers were formed by placing four layers above and four layers below the XPS foam core. For the impact resistance test, low-speed impact tests and three-point bending tests were performed at 30 J, 50 J, and 70 J energy levels. As a result of the tests, it was determined that the increase in fiber weight has a significant effect on the impact resistance and bending strength of the materials. While the samples with a fiber weight of 200 g/m² reached a maximum force value of 1200 N under 30 J energy, the samples with a weight of 400 g/m² reached a force value of 6400 N. Similarly, at energy levels of 50 J and 70 J, heavier fiber samples provided higher maximum force and energy absorption. In three-point bending tests, samples with a fiber weight of 200 g/m² reached a maximum force value of 200 N, while samples with a weight of 400 g/m² reached up to 450 N. As a result, increasing the fiber weight significantly increased the mechanical strength and energy absorption capacity of sandwich structures, indicating that materials are a critical parameter for engineering applications.

Keywords: Carbon fiber, Laminated composite, Low speed impact test, XPS foam

*Sorumlu yazar / Corresponding author: esimsir@aku.edu.tr
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1. INTRODUCTION

Sandwich structures consist of core material and fiber-reinforced layers placed on this core. According to the literature research, it has been observed that these structures have been examined in a wide range of mechanical properties, especially impact strength (Abid et al., 2020; He et al., 2021) and bending strength (Djafar et al., 2021; Adin and Adin, 2022). These studies show that the mechanical performance of structures is directly related to important engineering parameters. Composite materials are used in many sectors, such as the automotive sector (Bhong et al., 2023; Gebrehiwet et al., 2023), defense, aviation (Ozturk et al., 2023) and construction (Fan, 2024), especially due to their properties such as low weight and high strength (Khan et al., 2024). In addition to these features, the processability of sandwich composites is also important in industrial applications. The easy-to-process structure accelerates the production processes of these materials and increases their adaptability to different designs (Ceritbinmez et al., 2021; Ceritbinmez et al., 2022; Doğan et al., 2024) The most preferred of these composite materials are carbon fiber reinforced composite materials (Wu et al., 2023). (Wu et al., 2023). In engineering application areas, carbon fiber-reinforced materials exhibit good performance in terms of strength as well as lightness. The mechanical behavior of these materials has been studied in the literature using different weights and parameters (Muthukumarana et al., 2023). These materials offer both high strength and durability and are advantageous in terms of energy efficiency with their low weight (Mohanty et al., 2023). The factors affecting the mechanical properties of carbon fiber include fiber weight and number of layers. Increasing the fiber density can increase impact resistance and flexural strength but reduce deformation resistance (Burley and Aitharaju, 2023).

Within the realm of sandwich composites design framework, the core material is just as critical, as the fiber layers (Habib et al., 2024). Core materials that possess properties, like energy absorption and being lightweight and flexible are usually favored choices. In scenarios where impact and bending resilience're vital factors extruded polystyrene foam (XPS) is a preferred option because of its low water absorption rate, exceptional insulation capabilities and lightweight nature (Ižvolt et al., 2023; Karpenko et al., 2023; Yavuz et al., 2024). Many studies in the literature have shown the impact of XPS on structures; XPS contributes to the lightweight nature of sandwich composite structures due, to its low-density feature and simultaneously enhances their mechanical strength. XPS is highly favored as a material, in industries like automotive and aviation due to its unique qualities (Tawil et al., 2022). The cellular makeup of XPS enhances its impact absorption capabilities significantly. Studies indicate that the use of XPS core sandwich composites can improve impact resistance effectively (Zhang et al., 2023). XPS protects the structural integrity of the composite structure with its capacity to absorb impact energy. Using XPS as a material helps minimize distortions that may develop in the material post impact (Özcan, 2024).

Impact resistance is an important criterion when comparing the overall performance of composite materials. Low-velocity impact tests are often used to determine the post-impact behavior of materials. (Acanfora et al., 2023; Mohammadi et al., 2023). For safety purposes, especially in the automotive and aerospace industries, impact tests are used to evaluate how long materials can maintain their structural integrity during impact. The relationship between fiber weight and type of core material and impact toughness has been discussed in detail in many studies.

At the same time, bending resistance is likewise the most extensively used approach to deciding the electricity of composite substances. Three-factor bending assessments are used to degree how composite systems react below bending forces (Acanfora et al., 2023; Mohammadi et al., 2023). Studies show that bending strength varies depending on the weight of the fiber. The range of fiber layers and the weaving form make a contribution to the cloth turning into extra immune to bending forces. The number of layers of fibers and the texture properties (such as weight, density, and expansion) increase the strength, resistance to bending forces; However, this increase causes a decrease in the flexibility capacity. In this study, XPS foam and carbon fiber composites with different weights were used as core materials. Different carbon fiber weights and mechanical properties of XPS core material were investigated. The combination of core material and fiber weights used contributes to the literature and presents a new technique.

2. MATERIALS AND METHODS

Sandwich composites are a special class of composite materials produced by bonding two rigid shells to a core. In this study, extruded polystyrene (XPS) foam was used as the core material (Figure 1). Different carbon fiber woven fabrics with weight ratios of 200 g/m² and 400 g/m² have been favored because of the layer fabric (Figure 2). The thickness of the carbon fiber fabrics used in this study was measured as 0.25 mm for those with a density of 200 g/m² and 0.50 mm for those with a density of 400 g/m². The 200 g/m² fabric was used in 1 cm thickness in the upper and lower layers, and the 400 g/m² fabric was used in 2 cm thickness. In the layout of those systems, a total of 8 layers of carbon fiber woven cloth have been used, positioned 4 layers above and 4 layers underneath the XPS middle fabric. Carbon fiber woven fabric stands out as a crucial fabric in lots of commercial packages with their excessive power and lightness properties. This fabric, which might be broadly favored in terms of electricity performance due to their low weight, additionally permits the manufacturing of long-lasting and dependable merchandise via means of displaying excessive resistance to corrosion and chemical effects.

Figure 1. XPS foam core material

Porous structures are widely used in many sectors due to their lightness and superior energy absorption ability (Yavuz and Yildirim, 2023). The energy absorption capacity of these structures is directly determined by many factors, such as the shape, length and distribution of the air voids they contain. Extruded polystyrene (XPS) foam is a polymer foam cloth produced through extrusion beneath excessive temperature and pressure. During the production process, polystyrene granules are melted and passed through various molds in the extrusion line. These molds allow the material to take the desired form, and the formation of the cell structure is achieved by adding foaming agents. In addition, XPS is resistant to chemical and biological effects, which allows the material to maintain its structural integrity even in various difficult environmental conditions. As a result, a dense, lightweight, waterproof, and highly insulating material is obtained.

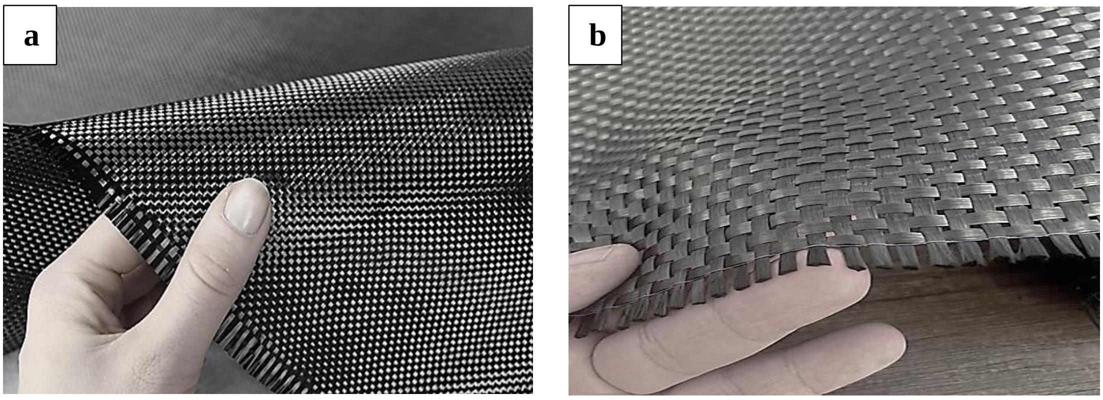

Figure 2. Carbon fiber woven fabrics used a) 200 g/m², b) 400 g/m²

Figure 3 shows the production process of the composite sample with XPS core material and carbon fiber coating. The production process starts with the homogeneous mixing of MGS LR 285 epoxy resin and LH 285 hardener with a mixer. This mixture is applied to the XPS core material and the surface of the carbon fiber layers. The composite structure is created with the carbon fiber layer placed four layers above and four layers below the XPS core material. Then, these prepared layers are processed in a hot-pressing machine for about two hours at a temperature of 40 °C and turned into composite panels. After the process is finished, the produced panels are cut with a bandsaw according to the test dimensions, and the samples are prepared. Finally, these samples are prepared for testing by subjecting them to low-speed impact and three-point bending tests.

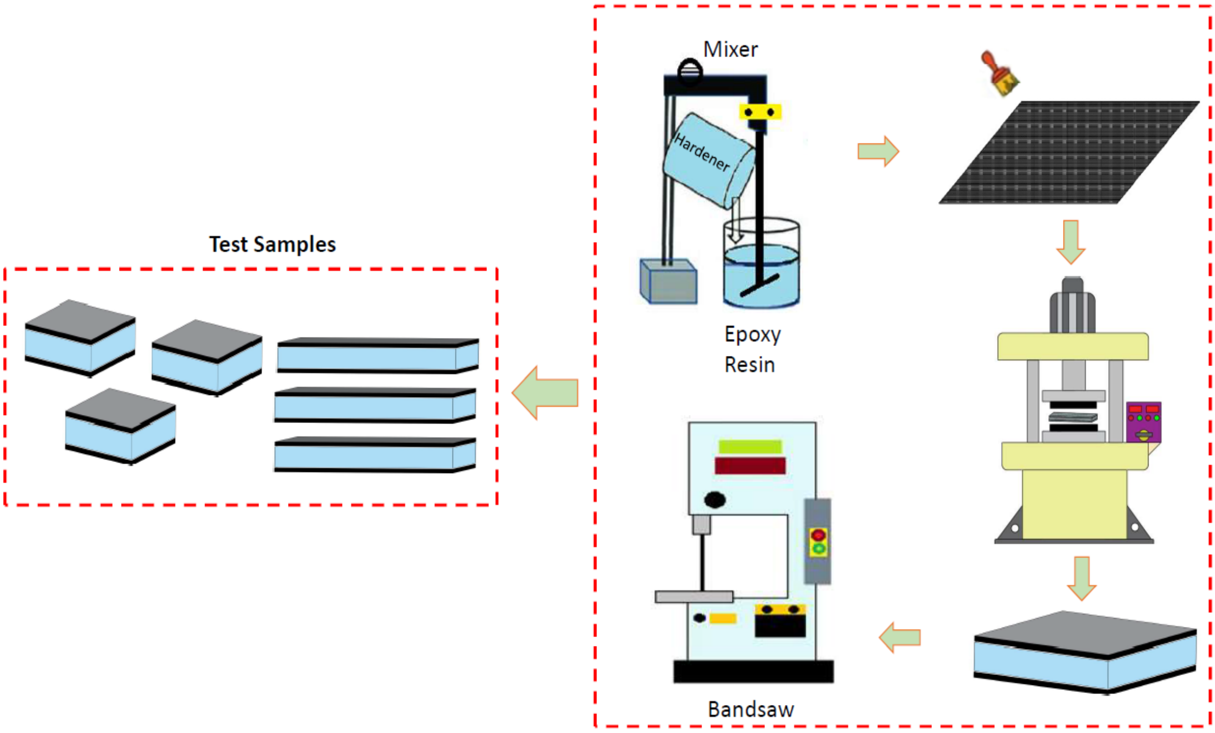

Figure 3. Schematic representation of the manufacturing process

2.1 Low Speed Impact Test

This test method measures the response of materials to impact energy. This technique is used to determine the impact resistance, energy absorption, and damage mechanisms of composite materials. Low-velocity impact events provide important information about the durability and strength of the material. Test results are very important in the safety and performance analysis of materials used in sectors such as construction, automobiles, and aviation. Thus, the structural integrity of materials after impact is evaluated, and the service life of the materials can be predicted. Low-velocity impact testing is a valuable method for improving safety and durability in engineering applications.

In this study, impact tests were carried out at Hitit University Scientific Technical Application and Research Center (HÜBTUAM). A CEAST 9350-Fractovis Plus impact testing machine was used, shown in Figure 4. The testing machine used in this study is presented in Figure 1. The striking tip used in the tests is 20 mm in diameter and made of steel in a hemispherical shape; this tip weighs 4.926 kg. The experiments were carried out at room temperature (20 °C), the released height was set as 1.657 m, and the impact energy was determined as 30, 50, and 70 Joules. All tests were performed in accordance with ASTM D7136 standard (Şimşir et al., 2021; Ferreira et al., 2023).

Figure 4. Low speed impact tester

The impact energy (joule) values applied in the study were calculated using the weight of the striking tip and the free fall height. Impact energy calculation is made with the equation given below:

$$E = m\,.\,g\,.\,h \qquad (1)$$

In the equation, E is the impact energy (joule), m is the mass of the striking tip (kg), g is the acceleration due to gravity (9.81 m/s²) and h is the free fall height. These calculations were made automatically by the data logger system used during the low-speed impact test. Thus, energy levels of 30, 50 and 70 joules were achieved.

2.2 Three Point Bending Test

The three-point bending test was performed using the Shimadzu Autograph tensile device with a capacity of 10 kN located in the Mechanical Engineering Laboratory of Afyon Kocatepe University. The feed rate in the test was determined as 1 mm/min. The tests were carried out in accordance with the ASTM D7264 standard (Mohamad et al., 2023; Burkov et al., 2024), and the feed rate was determined as 1 mm/min. Samples were prepared in accordance with ASTM D7264 standards, with a width of 13 mm and a length of 125 mm. Sample thicknesses were measured as 22 mm for 200 g/m² fabrics and 24 mm for 400 g/m² fabrics. Figure 5 shows images of the samples during the test.

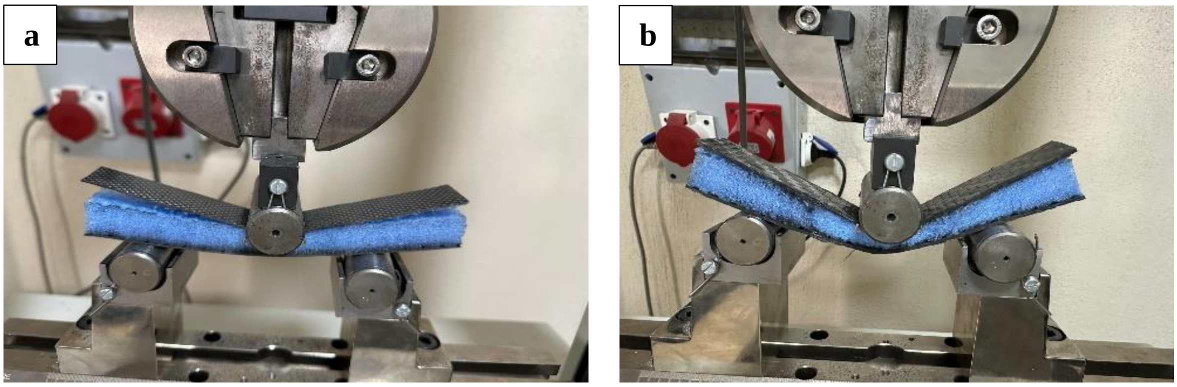

Figure 5. a) 200 g/m², b) 400 g/m² Three point bending test

3. RESULTS AND DISCUSSION

3.1 Low Speed Impact Test Results

In this study, the results of the experiments carried out using carbon fiber fabrics with two different weights of 200 g/m² and 400 g/m² and XPS core material were investigated. Three test samples were prepared for each energy value with dimensions of 100 mm x 100 mm and thickness of 22 mm and 24 mm to be used in the impact test. Force-deformation graphs were obtained at energy levels of 30 Joule, 50 Joule and 70 Joule.

3.1.1 Effect of fiber weight on strength under 30 Joule energy

Figure 6 shows the Force-Deformation graph of carbon fiber-reinforced composites at different weights and 30 joules of energy.

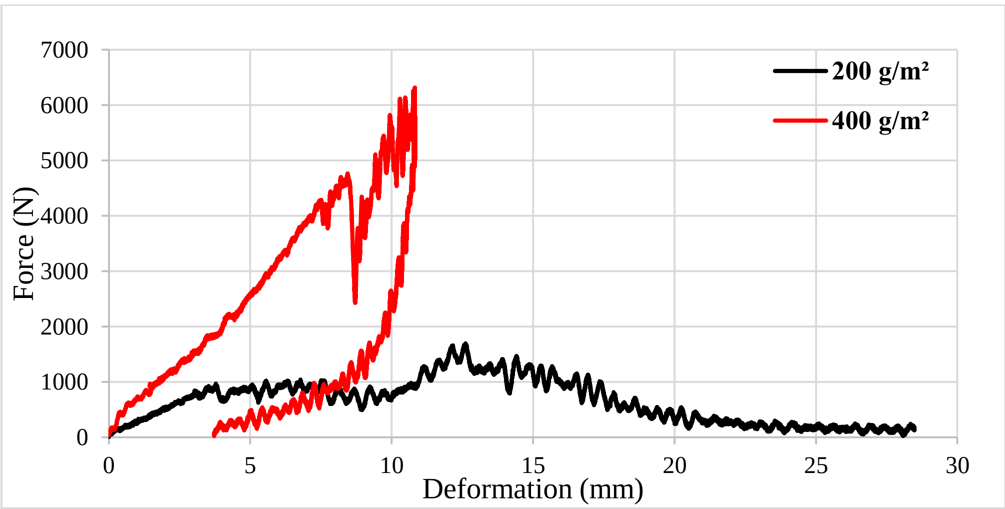

Figure 6. Effect of fiber weight on 30 Joule impact energy

30 Joule impact energy was applied to samples with fiber weights of 200 g/m² and 400 g/m². The sample weighing 200 g/m² reached a maximum force value of approximately 1200 N, and a puncture occurred on both surfaces, creating an open curve. The sample weighing 400 g/m², on the other hand, created a closed curve by bouncing back to the upper surface of the striking tip. This sample reached a maximum force value of approximately 6400 N and showed a deformation of approximately 10 mm at this level. The damage types in the upper-lower surfaces and core material of the samples as a result of the 30 Joule impact are given in Figure 7.

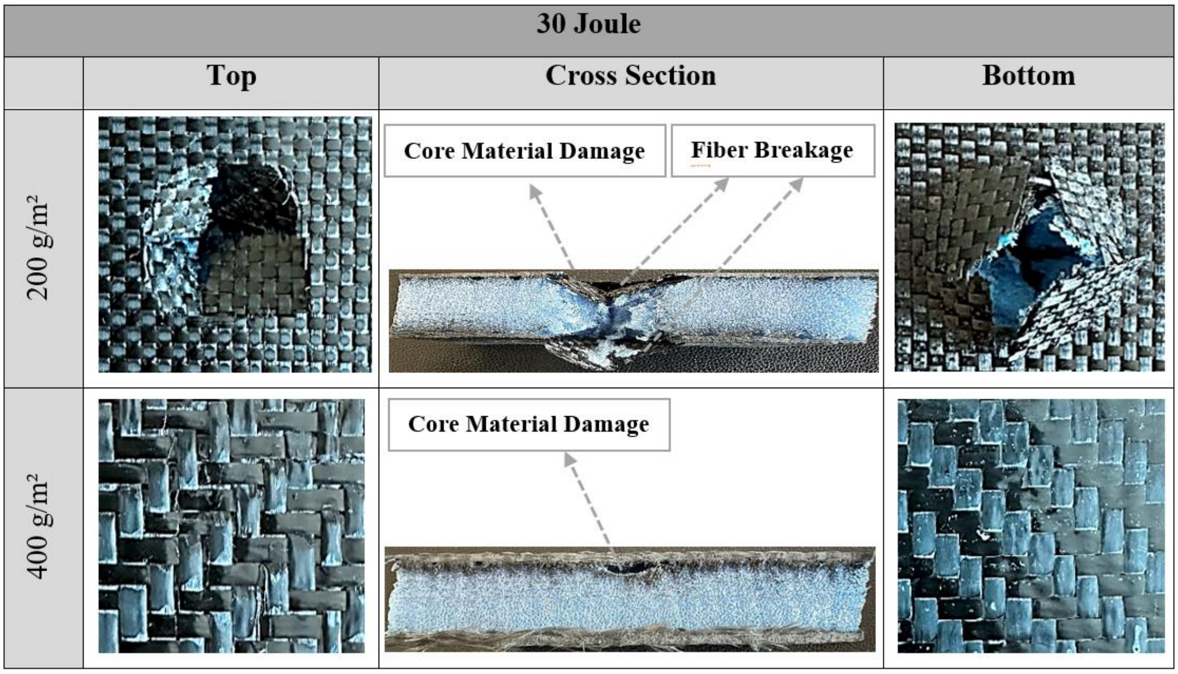

Figure 7. Damage image of the sample after a 30 Joule impact

3.1.3 Effect of fiber weight on strength under 50 Joule energy

Figure 8 shows the Force-Deformation graph of carbon fiber-reinforced composites at different weights and 50 Joules of energy.

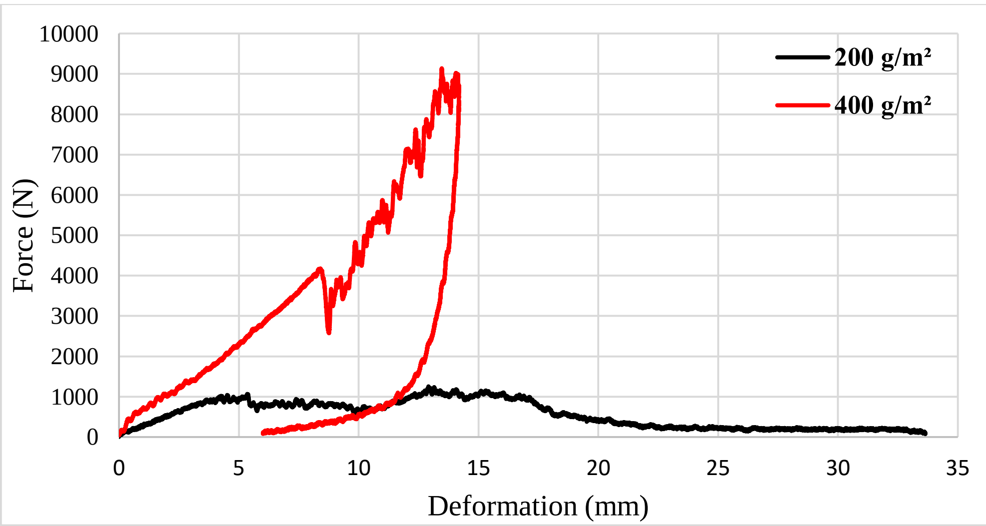

Figure 8. Effect of fiber weight on 50 Joule impact energy

50 Joule impact energy was applied to samples with fiber weights of 200 g/m² and 400 g/m². The sample weighing 200 g/m² reached a maximum force value of approximately 1000 N, and an open curve was formed by perforation on both surfaces. The test sample weighing 400 g/m² had a closed curve formed by bouncing back from the striking tip of the sample. The sample showed a deformation of about 12 mm and reached a max. value of about 9000 Newtons. The damage types in the upper-lower surfaces and core material of the samples as a result of the 50 Joule impact are given in Figure 9.

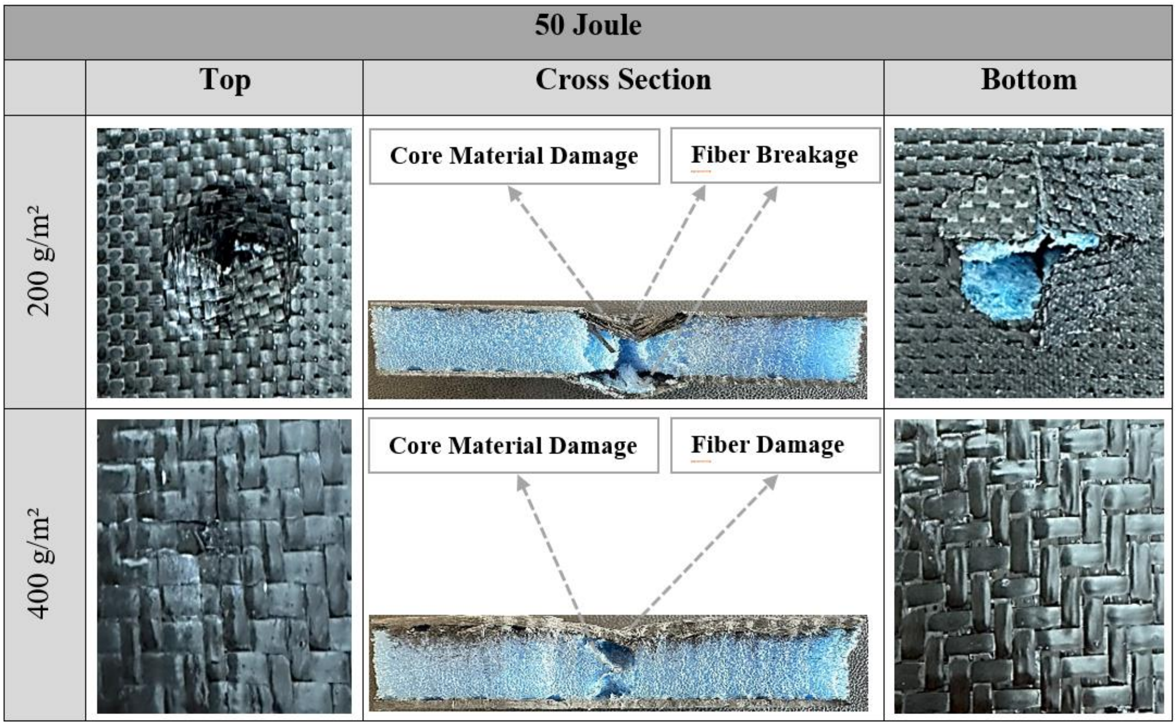

Figure 9. Damage image of the sample after a 50 Joule impact

3.1.4 Effect of fiber weight on strength under 70 joule energy

Figure 10 shows the Force-Deformation graph of carbon fiber-reinforced composites at different weights and 70 Joules of energy.

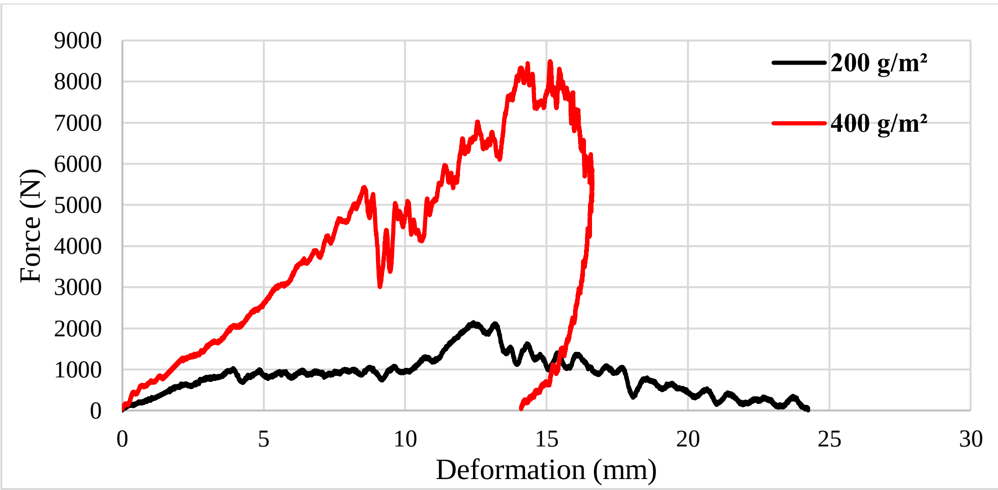

Figure 10. Effect of fiber weight on 70 Joule impact energy

70 Joule impact energy was applied to samples with fiber weights of 200 g/m² and 400 g/m². The sample weighing 200 g/m² reached a maximum force value of approximately 2000 N, and an open curve was formed by perforation on both surfaces. The sample weighing 400 g/m², on the other hand, created a closed curve by bouncing back to the upper surface of the striking tip. This sample reached a maximum force value of approximately 8000 N and showed a deformation of approximately 15 mm at this level. The damage types in the upper-lower surfaces and core material of the samples as a result of the 70 Joule impact are given in Figure 11.

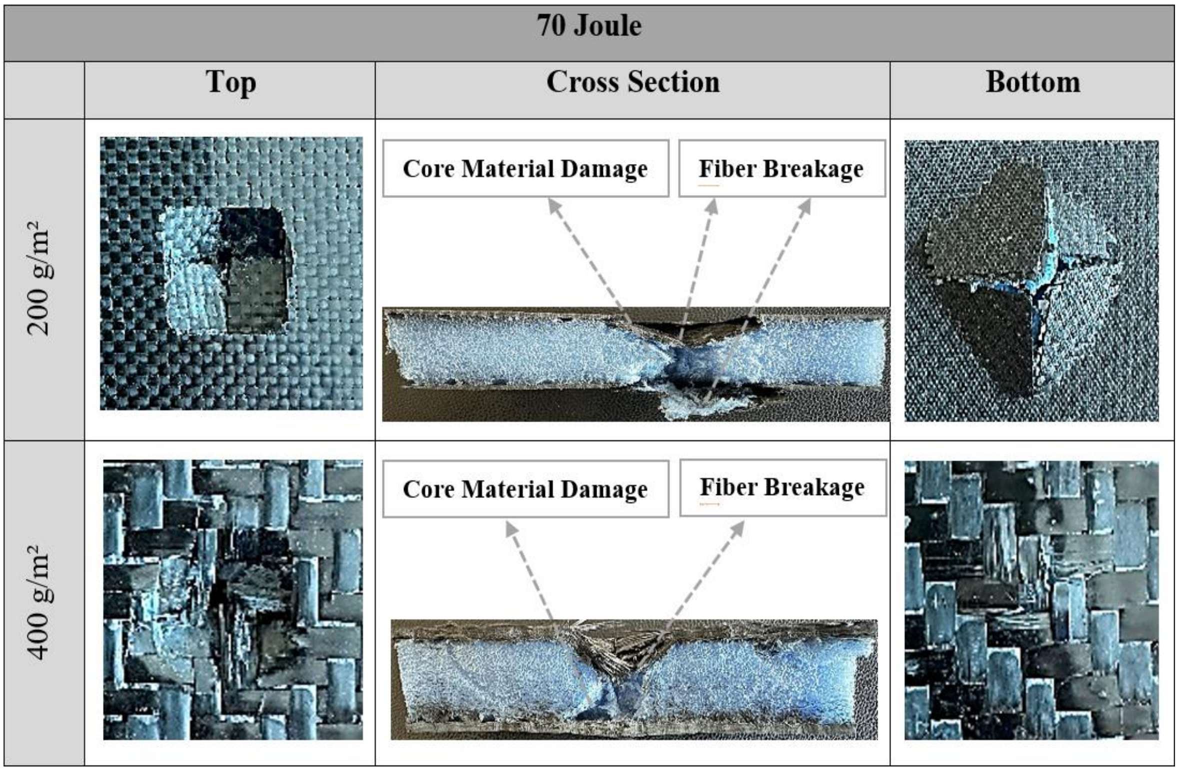

Figure 11. Damage image of the sample after a 70 Joule impact

3.2 Three Point Bending Test Results

The graph in Figure 12 shows the Force-Displacement curves of carbon fiber-reinforced composite samples with different fiber weights subjected to three-point bending tests.

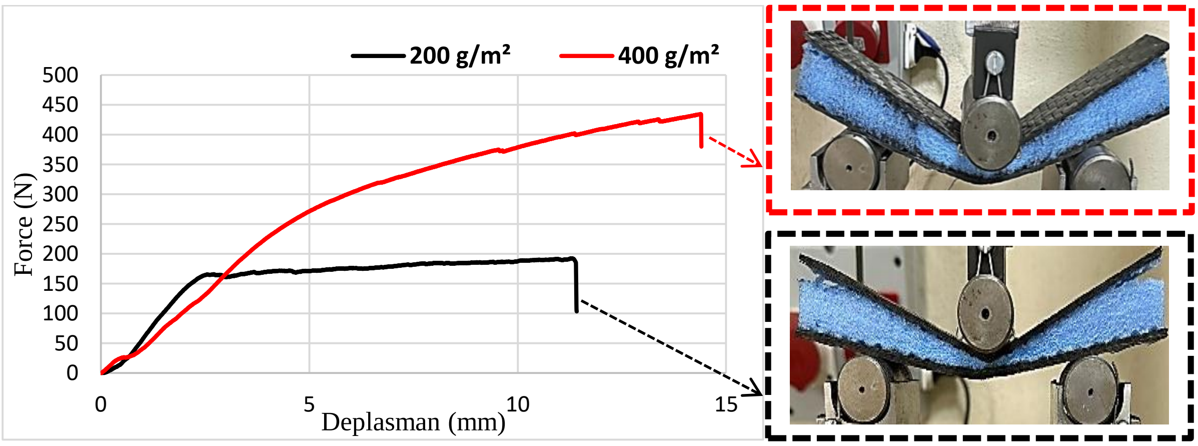

Figure 12. Three point bend test chart

In the three-point bending tests, the sample with a fiber weight of 200 g/m² reached a maximum force value of approximately 200 N and showed the lowest force-carrying capacity. The 200 g/m² sample showed little resistance to bending resistance, and the first fracture occurred. The sample with a density/weight of 400 g/m² showed the highest performance. This sample reached a maximum force value of approximately 450 N and showed the highest force-carrying capacity. The 400 g/m² sample was found to be more resistant to bending resistance than the 200 g/m² sample. Therefore, the increase in fiber density/weight significantly increased the strength of the material.

4. CONCLUSION

In this study, mechanical tests of sandwich structures prepared using carbon fiber-reinforced composite materials and XPS foam cores of different weights were carried out. Impact resistance and bending strength of these structures were investigated at 30 J, 50 J, and 70 J energy levels. According to the results:

Low-speed impact tests applied to carbon fiber-reinforced samples with different fiber weights showed that fiber weight significantly increased impact resistance In the 30 J, 50 J and 70 J impact test results, it is revealed that the sample with a fiber weight of 200 g/m² reached the maximum force elements of approximately 2000 N and punctured on both surfaces. In contrast, the sample with a fiber weight of 400 g/m² reached the maximum force of approximately 9000 N and less damage was observed after the new impact. However, less deformation was observed in heavier fiber materials at the same energy level. The first increase and then the decrease in forces for the 400 g/m² fabric is due to the material being able to absorb energy up to 50 J and being pushed to its structural limits at 70 J. Addition, it was determined that the sample with a fiber weight of 400 g/m² reached a deformation of approximately 10 mm. Three-point bending tests also showed similar results. The sample with a fiber weight of 200 g/m² reached a maximum force of 200 N, while the sample with a fiber weight of 400 g/m² showed the highest performance with 450 N. It was observed that the bending strength improved significantly by increasing the fiber weight in the produced samples. These results show that increasing the fiber weight has a positive effect on both impact strength and bending strength.

As a result, the weight of the fibers must be taken into account as a factor when selecting materials and designing products. It is stressed that this aspect needs to be evaluated to enhance performance, in engineering applications. These results suggest that enhancing the impact resistance and flexural strength of materials can lead to the creation of robust and dependable structures particularly in the automotive and aviation sectors.

5. ACKNOWLEDGEMENTS

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6. CONFLICT OF INTEREST

The author accepts that, to the best of his knowledge, he has no conflict of interest or common interest with any institution/organization or person that could influence the evaluation process of the article.

7. AUTHOR CONTRIBUTION

Ercan ŞİMŞİR has the full responsibility of the paper about determining the concept of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript and critical analysis of the intellectual content with the final approval.

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