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Numerical and Experimental Analysis of the Effect of Material, Diameter and Number of wires as the Reinforcements of the Foam Core in the Bending behavior of Sandwich Panels

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Abstract

In this research, the influence of the parameters of metallic wires in the foam cores of sandwich panels as a reinforcement to improve the bending properties of sandwich panels has been investigated. In this regard, the three parameters including the number of wires (on a scale of 1, 2, and 3 wires), wire material (aluminum, iron, and steel) and their diameter (0.75, 1, and 1.5 mm) as the effective input parameters and specific bending strength and modulus of the structure have been selected as the output parameters of the design of experiment. In order to evaluate the parameters after validating the numerical model using the built prototype, an experiment has been designed using the Mini Tab software (Taguchi method) and simulation of the proposed tests has been carried out using the Abaqus software. The results showed that the optimal sample with priority of strength to weight includes three steel wires on each side, with the diameter of one millimeter. Also, with the increase in the number and diameter of the wires, the strength has increased, but this relationship is not always correct when assessing the strength to the weight of the sample. Increasing the mechanical properties of the wire increases the overall strength of the structure, so that the bending strength of the sandwich panel reinforced with three steel wires rises by about 43%, the bending modulus by about 80%, the specific strength by weight by 21%, and the special bending modulus by about 54%.

Keywords: Composites, sandwich panel, Foam core, metallic reinforcement.

1. Introduction

Sandwich panels are made up of two skins (backing plates) and a core. The skins are in charge for carrying the bending and the core takes care of transverse shear load, and providing impact resistance etc. [1, 2].Gefu Ji et al. [3] where they introduced a new hybrid core for sandwich panel structures using aluminum milli tube in the syntactic foam with two different alignments of tubes in the core (horizontally and vertically). Sun et al. investigated the effect of different SMAs in Glass/epoxy laminated sandwich panels subjected to low-speed impact analysis to improve impact performance of sandwich panels [4] and Wan et al. [5] used steel wire mesh for low-speed application.
Mohammadkhani et al [6] used five different layouts of steel wires imbedded between the layers of Epoxy/Glass face sheets with PU foam core sandwich panel and studied the low-velocity impact both experimentally and numerically and declare using wire between the layers as a delamination problem to the structure.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

The face sheets of the specimens used in this investigation are GFRP laminates. In these laminates, the fabric used was 220 g/m^2 woven glass fabric and the resin was Araldite LY5052 epoxy resin with Aradur hardener From Resitan Co, Ltd., Iran.
polyurethane foam contains two parts (Polyol and Isocyanate) from Arian polyurethane Co, Ltd., Iran with 38 kg/m^3 density was used for making of the sandwich panel cores. Also, to reinforce the core, 1.5 mm diameter Steel wires were used.

3. Design experiment, manufacturing procedure and testing method

In order to enhance the foam, three types of wires with different properties (high-modulus steel, low-modulus steel, and aluminum) have been used in the simulation. In this study, the construction of a sandwich panel with multi-layer composite surfaces and the embedding of metal wires in its core have been investigated to examine the effect of various parameters on flexural properties through both experimental and numerical methods. The parameters considered in this study include:

- Number of reinforcements or wires in the core (one wire, two wires, and three wires on each side of the sandwich panel).
- Material of the reinforcements (aluminum, iron, and stainless steel).
- Dimensions of the reinforcement wire diameter (three different wire diameters of 0.75 mm, 1 mm, and 1.5 mm).

These parameters were chosen due to their significant impact on the selection of reinforcement wires. The Taguchi method was employed in this research, which facilitates flexible and engineered designs simultaneously and is a powerful approach for reducing product costs, improving quality, and concurrently reducing development lead time. Based on the mentioned parameters, the experimental design was carried out using the MiniTab software, and a total of 9 experiments were recommended using the L-9 method by the software.

In the present study, finite element modeling was performed using Abaqus software. A piece with dimensions of 75x210 mm was modeled, with a core thickness of 40 mm and surface thicknesses of 0.698 mm. An 8-node three-dimensional element with approximately 10,000 elements was used. To validate the simulation results, a sandwich panel reinforced with two wires on each side of the foam, made of iron wire with a diameter of 1.5 mm, was constructed and subjected to a three-point bending test. After validating the performance of the initial model, in the next step, the designed experiments by the MiniTab software were simulated in the Abaqus environment, and the displacement force outputs were extracted and converted into stress using MiniTab to investigate the effect of parameters on each other and select the optimal sample. Finally, the suggested optimal condition was constructed. In this research, all samples were fabricated using manual lay-up and a vacuum bagging technique. The application of pressure and vacuum is one of the common methods in the field of composite material component fabrication using manual lay-up. A plastic enclosure was used to encapsulate the mold and layers placed on it, creating a vacuum pressure.
The flexural properties of the specimen serve as an appropriate criterion for assessing and controlling its quality. Additionally, three-point bending tests were used to evaluate the manufactured samples. The samples, with dimensions of 210 mm in length and 75 mm in width, were subjected to three-point bending tests in accordance with ASTM-C393 [7] standards.

Figure1. Manufacturing procedure of sandwich panels

4. Results and Discussion

As mentioned earlier, to validate the simulations conducted, sandwich panel samples were initially manufactured. The constructed sample included wire reinforcements, consisting of 1.5 mm diameter iron wires, with two reinforcements on each side of the panel.
In Figure 2, the influence of input parameters on the strength and modulus of the sandwich panels can be observed, respectively. The influence of the number of reinforcements on the flexural strength of the sandwich panel is evident. As the number of wires used in the foam increases, the flexural properties improve, which is an expected result. However, this effect becomes less pronounced for wire numbers greater than 2, which may be due to the arrangement of the wires within the foam. Additionally, as the properties of the wire used for reinforcement increase, the strength of the sample should increase, with a significant difference between aluminum and iron wires compared to iron and steel wires. With an increase in wire diameter, the strength of the samples generally increases, with the difference between a 1 mm diameter and a 0.75 mm diameter being greater than the difference between a 1 mm diameter and a 1.5 mm diameter.
Figure 2 shows the results of the optimization of design parameters and their impact on the specific strength of the samples. According to the graph in Figure 10, as the number of wires increases, the specific strength of the sample increases. Therefore, the specific strength to weight ratio initially increases and then decreases with a rise in wire

diameter. The parameters of the number of reinforcement wires, material, and wire diameter have the most to least impact on both strength and specific strength.

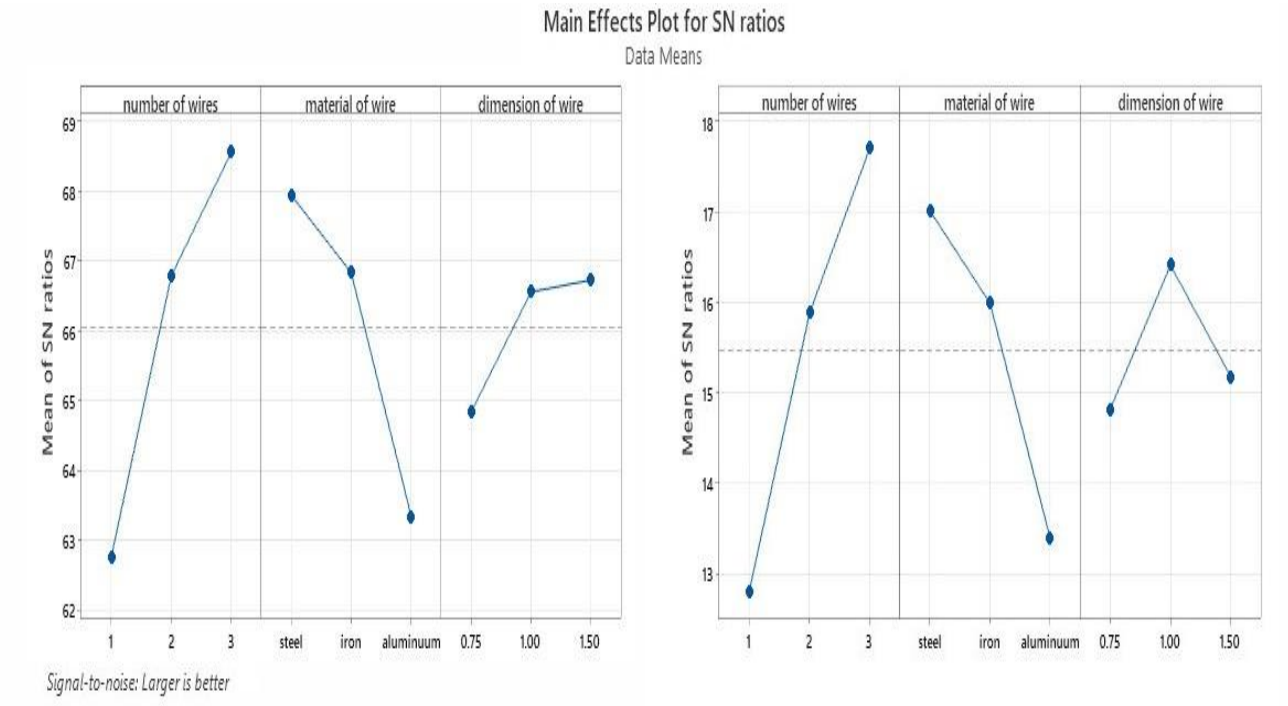

Figure2. Optimization Results of minitab software

Considering the results of the experimental design, an optimized sample with the following specifications was chosen: three wires on each side of the sample, each with a diameter of 1 mm and made of steel.
To examine and compare the significant impact of steel wires in the manufactured sandwich panels, the results of the three-point bending test are shown in Figure 3 and Table 1 as a force-displacement graph. It is evident that the positive impact of the reinforcements in the foam core of the sandwich panel is clearly visible.

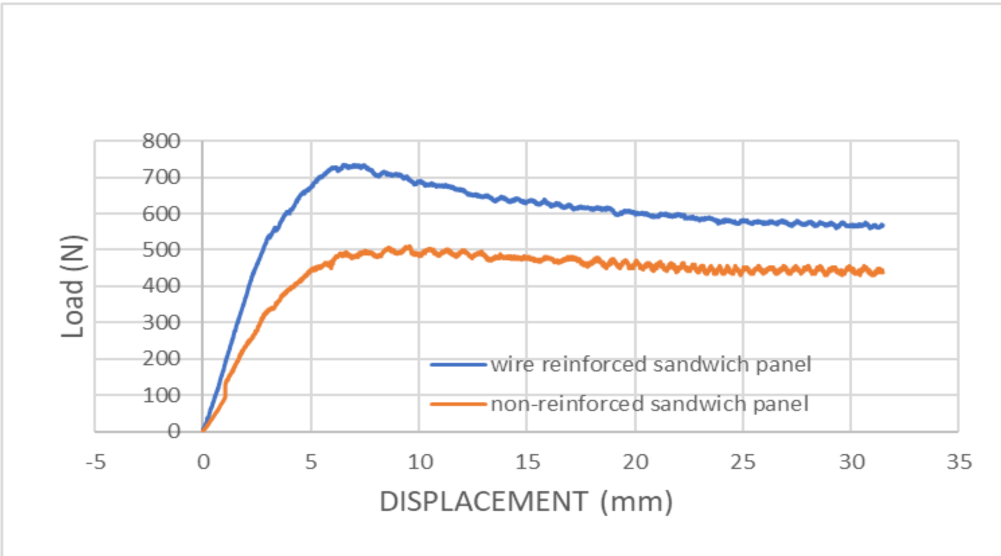

Figure3. Comparative Results of Reinforced and Unreinforced Samples

The reinforced samples exhibit significantly higher strength and stiffness compared to the unreinforced samples. This underscores the effectiveness of using steel wires as reinforcements in the foam core of sandwich panels, as shown in the experimental data.

Table1. Results of Reinforced and Unreinforced Samples

Sample	Maximum Applied Load (N)	Flexural Modulus (N/mm)	Sample Weight (gr)	Strength-to-Weight Ratio (N/gr)	Specific Flexural Modulus (N/mm·gr)
Unreinforced	511	6.100	2.51	98.9	96.1
Reinforced	729	182	2.60	09.12	02.3

5. Conclusion

The presence of metal wires within the polyurethane foam core enhances the properties and flexural strength of the sandwich panel. However, using a higher number of reinforcement wires leads to an increase in the weight of the component, and in such cases, the strength-to-weight ratio may not necessarily improve. Determining the exact number of wires used requires consideration of a broader range of parameters. Although increasing the mechanical properties of the used wire can result in higher strength, increasing the diameter of the consumption wires for core reinforcement does not always increase the strength, and as mentioned earlier, an increase in diameter negatively affects the strength-to-weight ratio of the sample. Among the parameters studied in this research, the number of wires has the most significant impact, while the diameter of the reinforcements has the least impact on the strength and specific strength of the samples. It was also evident that the parameters examined in this study have a similar effect on the flexural modulus, which behaves similarly to their effect on the specific flexural strength. However, the positive impact of these reinforcements on the flexural modulus is more significant than their effect on flexural strength, and the flexural modulus is more influenced by the presence of wires as reinforcements.

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