Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(11) (2022) 1037-1040
DOI: 10.22060/ceej.2020.18510.6884

Experimental and Numerical Study of Bending Behavior of Sandwich Beams with Steel Surfaces and Elastomeric Core

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ABSTRACT: Sandwich plate manufacturing technology is evolving day by day and it has led to the higher strength and load-bearing capacity of new fabricated models in comparison to previous models. Due to their high ratio of strength to weight and great energy absorption characteristic, they are widely used in various industries including aerospace, marine, and bridge construction. However, the problem with most of these types of plates is that the core crushes due to loading and thus leads to beam failure. In the present study, the load-bearing capacity and ultimate strength of a novel type of sandwich beam with steel faces and elastomeric foam core are numerically and experimentally investigated. The use of this type of core in sandwich beams has not been reported in previous research. Although elastomeric foams have a lower modulus of elasticity, they show reversible behavior in large deformations, and therefore they can be used in structures such as bridges, where high absorption of energy is expected. In this paper, by fabricating sandwich panels, in addition to determining the mechanical properties of materials, the effect of adding elastomeric core on the deformation of the sandwich beam and its energy absorption was studied; Furthermore, the simulation of sandwich structure and steel plates under three-point bending load was done with the help of Abacus software. Experimental and parametric studies showed that there is good compliance between experimental investigations and numerical results. Thus, it can be considered as a bridge deck in larger dimensions in future studies.

Review History:

Received: May, 31, 2020
Revised: Aug. 01, 2020
Accepted: Aug. 18, 2020
Available Online: Oct. 04, 2020-

Keywords:

Sandwich structure
Three-point bending load
Elastomeric core
Steel surface
Bridge building.

1- Introduction

Conventional sandwich beams consist of two thin face sheets and a thick core. The face sheets are made of hard, high-strength, and high-density materials such as steel or composites which are joined by low-density materials called cores. Sandwich beams with different designs are used in different industries. Depending on the application of these members, different materials for cores and faces are used to fabricate them [1].

With the advent of new manufacturing technologies, sandwich panels have gained a wider position as structural and non-structural members in various industries. The wide variety of sandwich beams with different design variables as well as modern design methods has made it possible to produce members with valuable capabilities and high efficiency in various industrial applications. Today, the unique performance of sandwich beams has made their use common in various industries, including maritime transport, aerospace, and automotive industries [2, 3]. According to studies by Murton [4], the weight of sandwich panel bridge decks is about one-fifth of reinforced concrete decks.

If it is decided to fill the entire space between the top and bottom faces with a material, it will be selected from materials with high volume and low weight, which also have adequate strength and stiffness. The best materials for this purpose are foams. Foam cores are inexpensive and have a high rigidity to weight ratio, however, low strength and low tensile modulus are considered as their disadvantages. These foams include polyvinyl chloride (PVC), polyurethane, and polypropylene foams [5].

Since the core used for the sandwich beams studied in this article is made of foam, more attention has been paid to the research done on foam cores. Tagarielli et al. [6] used a type of PVC foam, which had high strength and modulus of elasticity, as the core in sandwich panels. They indicated that the initial modulus of elasticity observed under tension was 10 GPa, the tensile strength was 220 MPa, and the compressive strength when micro buckling occurred in the foam was 150 MPa. They also mentioned that the shear strength for this foam was 1 MPa. Triantfillou and Gibson [7] used a type of polyurethane foam with a modulus of 1.6 GPa and a strength of 127 MPa to investigate the failure mechanisms of sandwich panels. Corigliano et al. [8] used a type of syntactic foam that had high mechanical properties and mainly demonstrated a linear behavior in the stress-strain curves under tension and compression. The foam used

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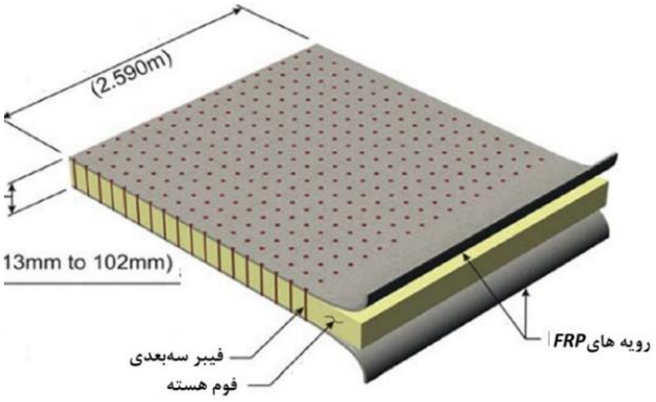

Fig. 1. Schematic of 3D FRP sandwich panel [11].

Fig. 2. Three-point bending test on sandwich panels.

by Mines and Alias [9] consisted of two types of PVC foam. Moreover, Flores and Li [10] used Rohacell foam, which had relatively high mechanical properties compared to the foams used in industry.

Tarek Hassan and Reis [11] reinforced the sandwich panels made up of fiber-reinforced polymer (FRP), as shown in Fig. 1, by inserting three-dimensional fibers in the core which leads to connecting the top layer to the bottom layer to investigate the increase in the strength of the sandwich panel.

They plotted the load-displacement curve of 1.5" and 2.5" thick panels as shown in Fig. 2. Based on the obtained results, they concluded that the behavior of the panel was linear before the initiation of the first crack in the core foam and then became nonlinear. Finally, it was found that the reason for the failure of all specimens was the rupture of the face sheets.

In 2015, Hashem et al. [12] evaluated a trapezoidal-shaped structure consisting of two glass fiber-reinforced polymer (GFRP) faces and a low-density trapezoidal polyurethane foam core, as shown in Fig. 3 for sandwich beams. The specimen was made on small scale and then subjected to a static bending test to investigate the ultimate load capacity and force-displacement behavior of the panels. The initial failure state for all specimens was the local buckling of the top compressive face sheet; finally, due to the crushing of the brittle core, the sandwich beam was collapsed.

Camata and Shing [13] studied the fatigue of sandwich-panel bridge decks with FRP faces and honeycomb core experimentally and numerically. The purpose of their study was to determine the performance of this type of beam under cyclic loadings. They identified that the delamination of the face sheets and their separation from the honeycomb core is the main mode of failure in this type of beam.

2- Methodology

Sandwich structures have been widely used in various industries such as aerospace, marine, and bridge construction due to their high strength-to-weight ratio and energy absorption. Besides, the finite element method has provided a valuable tool for simulating these beams [14-15]. As it has been mentioned, in most cases, the rupture and failure of brittle cores is the main cause of beam failures, which is why in this paper the failure modes related to the core are eliminated due to the elastomeric properties of the core material and instead, the hyperelastic performance that can model the nonlinear behavior of the foam is used in finite element models. Due to the lack of similar research history on sandwich beams with steel faces and elastomeric foam cores, the results of this study can provide useful outcomes for the use of this type of sandwich beams.

3- Results and Discussion

Although extensive studies have been carried out on load-bearing behavior and different types of failure in sandwich beams with various faces and cores, sandwich beams with elastomeric foam cores have not been studied so far. The results presented in this study showed that the behavior of the core in these beams is different from the behavior assumed for sandwich beams with brittle cores. It might be assumed that the use of this type of foam does not sufficiently increase the load-bearing capacity of the beam and to increase the load-bearing capacity the use of common brittle foams is more appropriate, however, a look at the results of this study shows that the use of elastomeric foams has specific advantages, including the elimination of core failure modes in comparison to brittle foams which lack such advantage.

Experimental studies performed on elastomeric foam showed entirely different and highly nonlinear stress-strain relationships under different loads, including tension, compression, and shear. Therefore, foam behavior was simulated based on hyperelastic theory. To reproduce the stress-strain curve, the proposed energy functions in different references were used; among these functions, the most convergent results with experimental results were obtained by the first-order Mooney-Rivlin function.

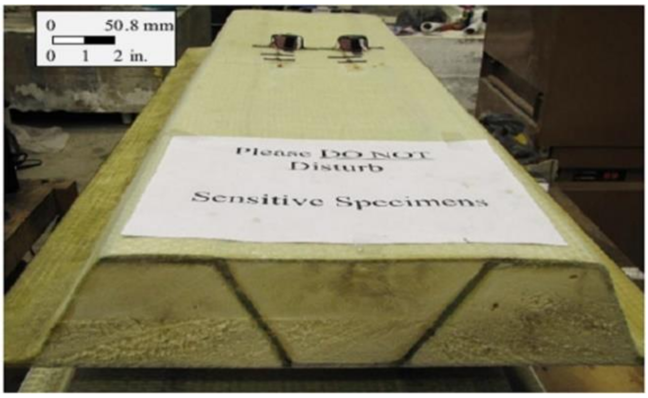

Fig. 3. Trapezoidal sandwich beam [12].

The results showed that using elastomeric core in sandwich beams improves the mechanical properties of the specimens such as energy absorption and maximum load-bearing capacity compared to those where only steel plates are used. However, this increase is different for sandwich panels with different face sheets. Despite the fact that using elastomeric plates demonstrated weak performance in transferring stress between the top and bottom face sheets, advantages such as regaining the load-bearing capacity after the face sheets' failure were a valuable advantage of using these sandwich beams.

One of the disadvantages of using these foams as the core was low stiffness and large deformation of the beam due to elastomeric properties; it can be eliminated by increasing the elasticity modulus of elastomeric foams.

Due to the low stiffness of the elastomeric foam and therefore the reduction of the forces between the face and the core layers, no damage of the delamination of the face sheets from the foam core was observed in these beams. Based on the experimental observations and finite element models simulation in this study, it was observed that the ratio of energy absorption increment was more significant compared to the ratio of load-bearing capacity increasing in these beams.

4- Conclusion

Sandwich beams with elastomeric cores show reversible behavior in large deformations. Therefore, they are very suitable for applications such as bridge decks where high absorption of energy is required. These types of foams have some residual strength in case of face sheets damage, unlike crushing foams which completely lose their load-bearing capacity when the face sheets lose their strength. Thus, by strengthening the shear capacity of the core, this type of structure can be studied and evaluated as a bridges deck that needs to absorb a high amount of energy.

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HOW TO CITE THIS ARTICLE
A.R. Rahai, A.R. Golshan, M.R. Golshan , Experimental and Numerical Study of Bending Behavior of Sandwich Beams with Steel Surfaces and Elastomeric Core, Amirkabir J. Civil Eng., 53(11) (2022) 1037-1040.

DOI: 10.22060/ceej.2020.18510.6884