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Impact Loading Performance of Polymer Foam Core Aluminium Sandwich Panels

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In this study, two different foam core aluminum face sheets sandwich panels were developed. The core materials were selected as expanded polypropylene (EPP) and extruded polystyrene (XPS) foams. Two aluminum face sheets and foam cores were combined with flexible epoxy-based adhesives, under 20 N static compression load. The average density of the produced sandwich panels was 0.39 g/cm^3 for EPP foam core sandwich and 0.33 g/cm^3 for XPS foam core sandwich panel. Produced specimens were subjected 3-point bending experiments under impact loading. Damage behavior of the sandwiches was observed using post-mortem pictures. The results show that the produced sandwiches damaged perfectly plastic deformations with face sheets and core. There was not any adhesive and cohesive failure in the core and face sheets interfaces.

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PACS/topics: aluminum sandwich panel, EPP foam, XPS foam, impact loading, adhesive bonding

1. Introduction

Global warming is seen as one of the most significant problem of recent times. One of the main reasons for this is the CO_2 emissions caused by vehicles in traffic [1, 2]. For these reasons, researchers and automotive industry companies have carried out various studies to reduce emissions. The basis of these studies is to reduce the vehicle engine volume and thus reduce the total weight of the vehicle [3]. Furthermore, it is critical to reduce the total weight of the vehicles for fully electric vehicles, which are the future of automotive, since it is not possible to develop the battery technology which can provide sufficient maximum range yet [4–6]. Sandwich structures are formed by combining a light core material between two plates. In these structures, a bending load is carried by sheet plates on both surfaces, and the transverse shear load is carried by the core material which has sufficient shear strength and shear stiffness. Due to the difference between the skins and the core material, these types of structures are joined together with an adhesive. Bonding surfaces are the weakest points of these structures, and the stiffness of the structures is usually determined by the behaviour of the adhesive [7]. Sandwich structures are attracting much interest in the automotive industry due to their features as they provide a significant increase in specific strength, impact resistance, sound and vibration insulation, and damping properties compared to conventional sheet metal [8].

In this paper, sandwich structures with a core of EPP foam and XPS foam and aluminium face sheets are proposed. Impact loading performance of the sandwich structures, foam core, and adhesive bonding are obtained using a dynamic 3 point bending experiments.

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2. Materials and method

Impact response of two different foam core sandwich structures was examined experimentally. Firstly, the foam materials EPP, and XPS of the sandwich cores were tested under quasi-static compression loading. Secondly, impact experiments were conducted for foam core sandwiches. Dynamic three-point bending results were evaluated according to the impact reaction force of structure.

Three different densities of EPP foams were selected for compression, and their density values were $D1 = 65.7$, $D2 = 36.5$, and $D3 = 27$ kg/m^3. Test specimens' volume of $25 \times 25 \times 25$ mm^3 was used, which was extracted from EPP foam block. The same volume was used for XPS foam, and its density was 27 kg/m^3. Quasi-static compression tests were conducted using Zwick Proline Z010 TH machine. To determine the mechanical performance of foams, several compression tests were carried out at 0.01 strain rate. Figure 1a shows the universal tension-compression test device with compression test grips, Fig. 1b and c shows EPP foam and XPS foam quasi-static compression specimens, respectively.

Compression test results are given in Fig. 2. Three phases have been seen as linear elastic, plateau stress, and densification. Test results show that elastic and plateau regions increase in direct proportion to foam density. D2 and D3 EPP foam have exhibited almost the same behaviour. Thus, D3 and D1 EPP foam were selected for the sandwich experiments.

Three different sandwich structures were produced for dynamic tests. These structures' cores consist of D1 EPP foam, D3 EPP foam, and XPS foam of which the densities respectively were 65, 27, and 26 kg/m^3. The sandwich

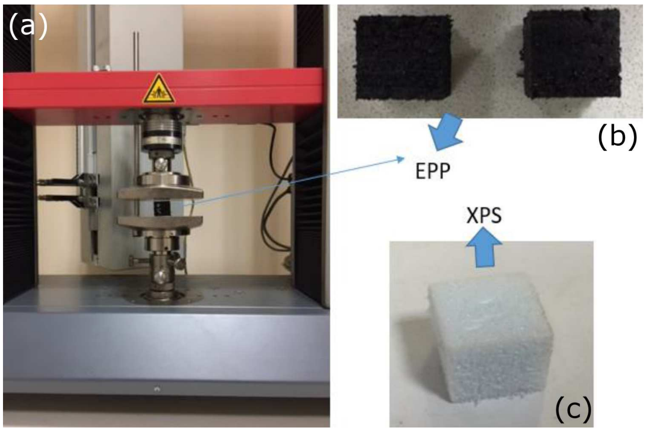

Fig. 1. Quasi-static compression test of EPP and XPS foams: (a) universal tension-compression test machine with compression grips, (b) EPP foam specimen, (c) XPS foam specimen.

structures had $200\times50\times30$ mm^3 sizes. The adhesion process was applied using West System Gflex 655 adhesive. As first, one side of the core was glued with epoxy based adhesive and pressed under 20 N static load until the adhesive had been cured. In the second stage, the same process was repeated for the other side of the foam core. The same adhesive was used for all sandwich structures. The masses of the sandwiches after bonding aluminium skins and foam cores were measured for D1-EPP foam core specimens as 118 g, for D3-EPP foam core as 103 g, and XPS foam core as 101 g.

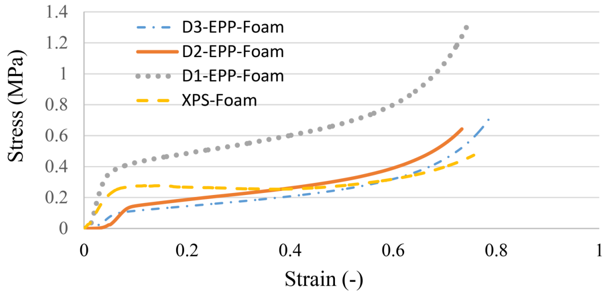

Fig. 2. Quasi-static compressive stress–strain curves of EPP and XPS foams at 0.01 strain rate.

Figure 3a shows the photo of the dynamic impact test setup and Fig. 3b also illustrates the dynamic test setup assembly. Compressed argon gas loads into the gas tank. Valve regulated gas pressure triggered by a solenoid valve launches the impactor mechanism. High-velocity impactor hits the test specimen. Dynamic impact load is measured by YMC 512F06 Dynamic Force Sensor located on the impactor mechanism. The signal is collected using the 8-channel data acquisition system. All dynamic tests were executed in the same condition. The gas-gun pressure was adjusted as 15 bar.

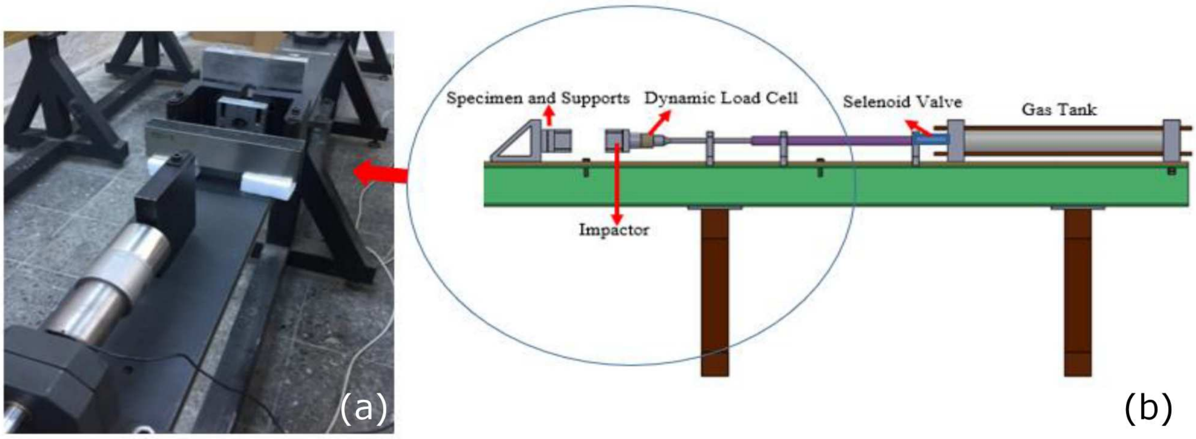

Fig. 3. Dynamic test setup for impact loading: (a) a photo of test setup, (b) an illustration of the test system for assembly detail.

3. Results and discussion

According to impact loading experiments, peak impact load was measured as approximately 28 kN from the D1-expanded propylene foam sandwich panel. Concurrently least permanent deflection was determined as 7.2 mm from D1-EPP foam sandwich panel. Additionally, any adhesion failure was not seen in the test panels. Gflex 655 adhesive showed compatibility with D1-EPP foam surface and aluminum surface. Similarly, in D2-EPP foam core sandwich panel and XPS-foam core sandwich panel, GFlex 655 showed good adhesion behaviour. The most permanent deflection was determined in XPS foam core sandwich panel as 30 mm. All impact test results are shown in Fig. 4. Figure 4a shows measured permanent maximum deflections of the sandwich specimens after the dynamic impact of three-point bending experiments. Figure 4b shows the maximum bending loads during the impact test. Figure 4c also gives a mass comparison of all three types of sandwiches.

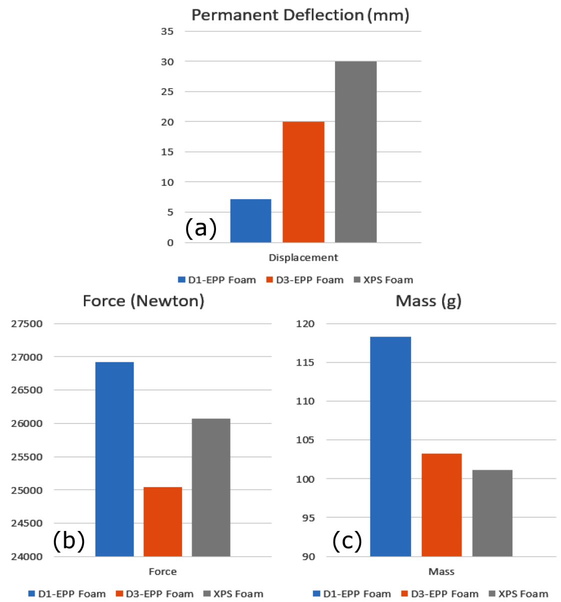

Fig. 4. Compression of dynamic tests results: (a) permanent deflection of the sandwich beams, (b) maximum bending load, (c) average sandwich beam masses.

Fig. 5. Permanent deflection results of sandwich panels: (a) D1-EPP foam core sandwich, (b) EPP foam core sandwich, (c) XPS foam core sandwich.

Figure 5a–c show the post-mortem pictures of the dynamic load subjected sandwich specimens. As seen in these figures, any face sheet debonding and core failure was not obtained.

4. Conclusion

In this study, three different foam core aluminium sandwich panels were investigated with the static and the dynamic conditions. According to tests results, all sandwich panels showed plastic deformation and core compression. It was observed that they have high impact energy absorption ability. All sandwich panels were not shown to present any shear crack in core and face sheet debonding. In all sandwich panels, adhesive layer showed the same deformation with aluminium face sheets. In all sandwich panels, any surface wrinkling due to relatively thick face sheets was not observed. EPP foam core aluminium sandwich panels for D1 density core can be preferred due to their better mechanical performance as well as recyclability.

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