Düzce University
Journal of Science & Technology

Research Article

Effects of Core and Surface Materials on the Flexural Behavior of Lightweight Composites Sandwich Beams

Zeki ÖZCAN [a,*]

[a] *Department of Civil Engineering, Faculty of Engineering, Sakarya University, Sakarya, TURKEY*
** Corresponding author's e-mail address:ozcan@sakarya.edu.tr*
DOI: 10.29130/dubited.1551010

ABSTRACT

Sandwich composite elements are used in many sectors thanks to their low weight/strength ratios, high bending strength, good thermal insulation properties, and low costs. It is widely used in the machinery and construction industry, especially in land, sea, and air vehicles. The main objective of this research is to design and produce lightweight, durable, insulated, and low-cost, sustainable building elements that will meet emergency shelter needs after disasters. For housing purposes, 24 sandwich beams were prepared, eight designs with different surface coatings and core materials, and three in each design group. The effects of surface coating and core material on behavior were investigated with four-point bending experiments. Load-displacement relationships were determined from the experiments, and the beams' load-carrying capacities and failure patterns under the effects of bending and shearing were determined. In addition, theoretical methods determined maximum load values and compared them with the results of the experiments. As a result of the experiments, it was concluded that the best-performing design under bending effects was sandwich beams with plywood surface and XPS core.

Keywords: *Sandwich composite, Four-point flexural test, Beam flexural strength, Flexural stiffness, EPS, XPS foam*

Çekirdek ve Yüzey Malzeme Özelliklerin Hafif Kompozit Sandviç Kirişlerin Eğilme Davranışı Üzerindeki Etkileri

ÖZ

Sandviç kompozit elemanlar düşük ağırlık/dayanım oranları, yüksek eğilme dayanımı, iyi ısı yalıtım özellikleri ve düşük maliyetleri sayesinde birçok sektörde kullanılmaktadır. Makine ve inşaat sektöründe, özellikle kara, deniz ve hava taşıtlarında yaygın olarak kullanılmaktadır. Bu araştırmanın temel amacı, afetlerden sonra acil barınma ihtiyaçlarını karşılamaya yönelik hafif, dayanıklı, yalıtımlı ve düşük maliyetli, sürdürülebilir yapı elemanları tasarlamaktır. Çalışmada, farklı yüzey kaplamaları ve çekirdek malzemelerine sahip sekiz tasarım ve her tasarım grubunda üç olmak üzere 24 sandviç kiriş hazırlanmıştır. Yüzey kaplaması ve çekirdek malzemesinin davranış üzerindeki etkileri dört noktalı eğilme deneyleriyle araştırılmıştır. Deneylerden yük-yer değiştirme ilişkileri belirlenmiş ve kirişlerin eğilme ve kesme etkileri altındaki yük taşıma kapasiteleri ve hasar desenleri belirlenmiştir. Ayrıca, teorik yöntemlerle maksimum yük değerleri belirlenmiş ve deneylerin sonuçlarıyla karşılaştırılmıştır. Deneyler sonucunda, eğilme etkileri altında en iyi performansı gösteren tasarımın kontrplak yüzeyli, XPS çekirdekli sandviç kirişler olduğu sonucuna varılmıştır.

Anahtar kelimeler: *Sandviç kompozit, Dört nokta eğilme testi, Kiriş eğilme dayanımı, Eğilme rijitliği, EPS, XPS köpük*

Received: 16/09/2024, Revised: 01/10/2024, Accepted: 01/10/2024

I. INTRODUCTION

The rapidly growing world population and the global housing crisis is an urgent problem affecting millions worldwide. The need for healthy, safe, affordable housing is increasing Daily. The number of people affected by the global housing shortage is expected to reach 1.6 billion by 2025. In addition, climate change, natural disasters, and rising sea levels are also straining housing markets. Multifaceted approaches are being developed to solve the housing crisis, such as developing environmentally friendly materials and sustainable construction practices, increasing labor force participation through training programs and technological developments, rent regulation, housing initiatives, and fast and affordable housing typologies [1]. In this research, experimental and numerical studies of the building elements that can be used to solve this problem have been tried to contribute.

Finally, the earthquake in Kahramanmaraş on February 6, 2023, caused significant structural damage in different systems. Earthquakes caused damage and destruction in reinforced concrete, masonry, and historical structures [1-4]. The causes of the damages include structural system irregularities such as heavy overhangs and large openings, inadequate concrete and reinforcement workmanship, and low concrete strength. Low-strength, heavy partition walls also caused many people to be injured or lose their lives. Most of the damaged structures were old and heavy structures. As it is known, heavy structures also increase structural risks against earthquakes. For this reason, lightweight composite sandwich structural elements and structures should be highlighted in regions with high earthquake risk due to their life safety, construction speed, and comfort advantages.

Using environmentally friendly and sustainable materials has become an innovative trend in construction and engineering applications. Correct use of resources is inevitable for sustainable construction. The construction industry faces the daunting task of meeting this demand and simultaneously complying with design and structural requirements to limit its environmental footprint. Traditional construction materials, such as concrete and steel, are known for their significant environmental impact, such as their consumption of resources and high energy use. On the other hand, Wood is seen as a sustainable alternative due to its low carbon footprint and lower initial energy requirement. However, it should not be forgotten that the intensive use of wood can lead to environmental problems such as deforestation and loss of biodiversity. Using recycled materials for environmentally friendly alternatives to reduce dependence on natural resources and protect the environment is emerging as a promising option [5].

Sandwich building materials used in structural engineering applications are composite structures consisting of at least two materials: foam, honeycomb, polymer, or wood. The structure of a sandwich element consists of two surface plates, adhesive layers, and a core. Surfaces are generally thin, dense, high-strength solid materials, while the core is lower-strength, lower-density. A highly efficient building material is obtained as a product when these materials are combined in a sandwich structure. In sandwich structures, the core material plays a vital role in determining the overall performance of the beam. It provides the thickness required for rigidity and strength while keeping the structure lightweight. Sandwich building materials are widely used in automotive, aerospace, marine, construction, and other industries due to their high strength-to-weight ratios, high stability, low weight, thermal insulation, and easy assembly.

Sandwich structural elements are widely used in the construction industry in load-bearing walls and floors, roof and façade cladding elements, and heat-insulated partition walls [6]. Thin metal sheets, fiber-reinforced polymer (FRP) composites, and reinforced concrete [7-10] are preferred as surface materials. Core materials include balsa wood, polymer-based foams, fiber-reinforced polymer (FRP) cores, metallic foams, and honeycomb cells [11-20]. Polymeric composites reinforced with natural fibers such as jute and hemp are being investigated as alternative building materials. Fajrin et al. [21] proposed natural fiber composites for the interlayer of the hybrid sandwich panel. They showed that hybrid sandwich panels with aluminum sheets and expanded polystyrene (EPS) cores outperformed traditional panels. It was stated that the damage modes of hybrid sandwich panels are core shift and delamination.

Borsellino et al. performed static pressure, shear, and flexural tests for both individual components and mechanical characterization of the entire structure for accurate design, noting the anisotropy of sandwich structures [22, 23]

Several studies have been conducted on the usability of sandwich panels for shelter after natural disasters. Researchers have shown that sandwich panels offer an effective solution in emergency shelters due to their performance and durability, fast assembly, user satisfaction, and isolation properties. Eco-friendly materials and the potential for recycling make sandwich panels stand out as a sustainable disaster shelter solution. It also plays a vital role in meeting post-disaster shelter needs by providing cost-effective solutions [24–28]. In construction and engineering applications, wood-surfaced EPS core sandwich panels have a wide range of applications due to their lightweight and high-strength properties.

The types of damage in sandwich beams are classified into six groups in the literature in their most general form. Delamination is the separation of surface coatings from the core material due to insufficient adhesion or high shear stresses; Buckling, wrinkles, or folds seen by buckling surface coatings under compressive forces; Core crushing is the local crushing of the core material under high compressive stresses; Core shear failure, ruptures in the core under high shear stresses; Interlaminar cracking is the separation or cracks between layers due to high bending or impact loads; Localized impact damage is the dents or fractures seen in surface coatings or core material due to impact loads [29-34].

This study investigates lightweight sandwich structural elements designed for earthquake-resistant construction and rapid housing solutions. It represents a step toward creating safe, environmentally friendly, energy-efficient, and accessible structures. Today, the production of sandwich panels is highly advanced, with ultra-thin, lightweight aluminum-walled, and foam-core composite elements widely utilized in land, sea, and air transportation [8, 14, 15]. The construction sector has a growing demand for economical and environmentally friendly structural components.

This study focuses on the bending and shear behavior of sandwich panels. Future research will investigate connection details and the overall safety of these structural elements. The findings are expected to provide valuable insights for researchers in this field.

II. MATERIALS and METHODS

A. PREPARATION of the TEST SPECIMENS

Eight designs were made with two other core materials and four different surface elements to design post-disaster shelter structures. To determine the mechanical properties of the designed sandwich elements, 24 samples, three from each experimental set, were produced. Expanded polystyrene (EPS) boards with a density of 16 kg/m^3 and extruded polystyrene (XPS) boards with a density of 32 kg/m^3, which also serve as thermal insulation, were used as core materials. Four different top surface elements were used as surface elements: wooden plywood (poplar) on the lower face of each experimental group, PVC board, wooden plywood (poplar), galvanized flat metal, and triangular corrugated galvanized metal sheet on the upper faces. Polyvinyl acetate resin was used to bond the layers. The vocabulary, composition, and dimensions of the test specimens produced are given in Table 1, and their visuals in Figure 1. The mechanical properties of the materials used are also shown in Table 2.

B. TEST SETUP and TEST PROCEDURE

Sandwich building materials are structures with orthotropic properties. Therefore, determining and analyzing its mechanical properties is crucial in deciding its use. When preparing test specimens, improper bonding or misalignment of core and surface elements, gaps or core and surface discontinuities, out-of-plane curvature, surface thickness variation, and surface roughness are all factors that directly affect data distribution. The four-point bending test can obtain the sandwich structural element's bending stiffness, core shear strength, shear modulus, compressive, and tensile strength. The ASTM C393/C393M-16 [35] test standard is widely used to determine beams' bending and shear behavior, especially sandwich beams [36]. The four-point flexure test produces uniform tensile and compressive stresses and zero shear force in the area between the loading points, not just below the loading point, as in the three-point flexure test. Thus, the same stresses force the cross-section between the loading points, and the damage starts from the weakest point. The previous standard version included three- and four-point loading with short-beam and long-beam sandwich specimens. 2006, when ASTM D7249 / D7249M-20 [37] was standardized for long-beam flexure testing, ASTM C393 was rewritten to focus solely on short-beam flexure testing. However, the four-point loading configuration was maintained in the standard for "historical continuity" with previous versions of this test method. In addition, ASTM D7250 / D7250M-16 [38] was standardized in 2006 to determine the stiffness properties of sandwich composites using results from bending tests of long and short beams. This standard sandwich provides correlations for calculating bending and shear stiffness and core shear modulus. A universal SHIMADZU tester with a capacity of 50kN was used to perform the four-point flexure test. The specimen was placed on two support pins with a 210 mm support span and loaded with two loading pins symmetrically placed 70 mm apart. Loading was continued with a constant loading speed of 3 mm/min until the specimen lost strength. The four-point bending test layout and sandwich beam cross-section properties are given in Figure 2. where t is the surface thickness, c is core thickness, b is beam width, h is the total thickness of the beam, and d indicates the distance between the centers of the surfaces.

Table 1. *Geometric properties of test specimens.*

Code	Top skin materials	Core mat.	Bottom skin mat.	L/W/H (mm)	Weight (gr)
EPS-1	PVC sheet 1 mm			250/80/35	65
EPS-2	Plywood 4 mm	EPS	Plywood	250/80/38	90
EPS-3	0.3 mm galvanized metal sheet	30 mm	4 mm	250/80/34	130
EPS-4	0.3 mm corrugated galv. metal sheet			250/80/34	135
XPS-1	1 mm PVC sheet			250/80/35	75
XPS-2	4 mm plywood	XPS	Plywood	250/80/38	100
XPS-3	0.3 mm galvanized metal sheet	30 mm	4 mm	250/80/34	140
XPS-4	0.3 mm corrugated gal. metal sheet			250/80/34	145

L; length, W; width H; height

(a)

(b)

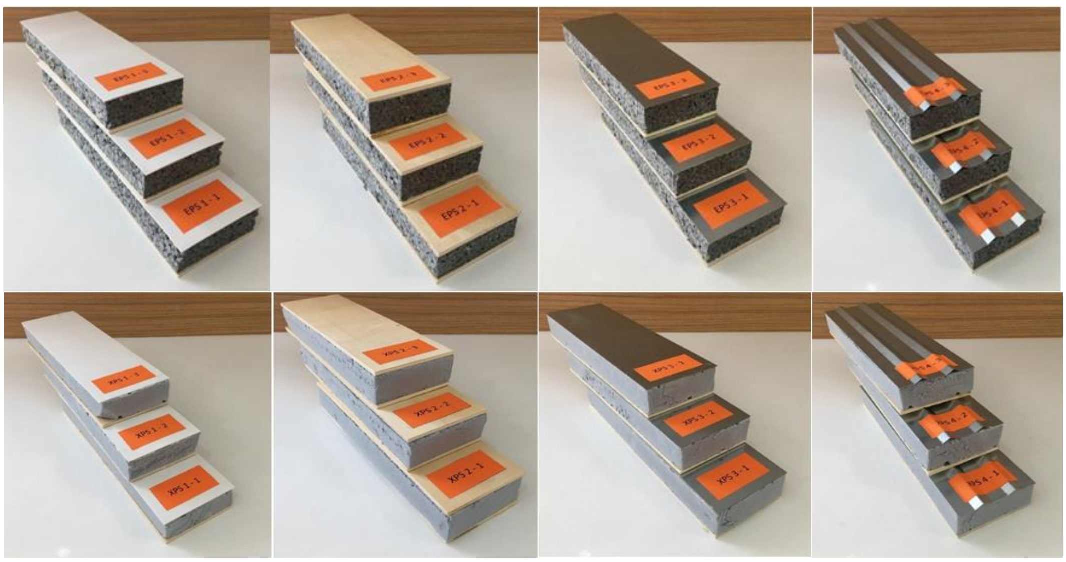


Figure 1. (a) *EPS samples,* ***(b)*** *XPS samples*

__Table 2.__ Static mechanical properties of the test materials.

	Plywood skin mat.	Metal sheet skin mat.	PVC sheet skin mat.	EPS foam core mat.	XPS foam core mat.	Resin polyvinyl acetate
Mod. of Elasticity (MPa)	$10x10^3$	$200x10^3$	300	1.2	5	$2x10^3$
Density (kg/m^3)	500	7850	1375	16	32	1200
Comp. Strength (MPa)	30	280	60	0.10	0.25	20
Tensile Strength (MPa)	25	280	50	0.15	0.45	15
Flexural Strength (MPa)	30	250	70	0.15	0.25	20
Shear Strength (MPa)	7	~80	20	0.10	0.20	10

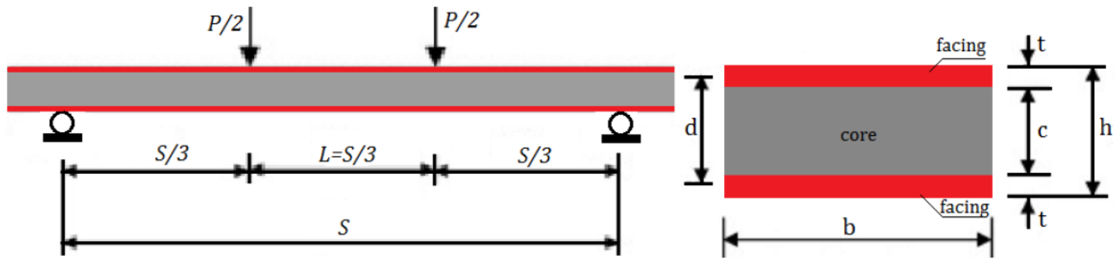


__Figure 2__. Four-point bending test layout and sandwich beam cross-sectional property.

C. FOUR-POINT BENDING TESTS

The prepared EPS and XPS group of 24 specimens underwent a four-point bending test (Figures. 3 and 4). Vertical displacements against the applied load are recorded and graphed in Figure 4. The samples' behavior patterns and failures were evaluated and given in Tables 3 and 4.

Figure 3. Four-point bending tests of EPS specimens

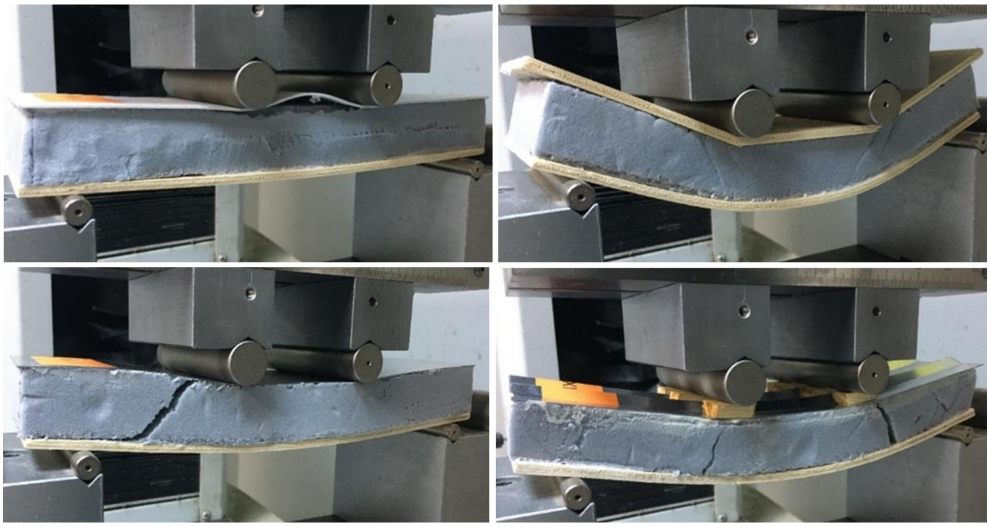


Figure 4. Four-point bending tests of XPS specimens

D. RESULTS of the FOUR-POINT BENDING TEST

The force-displacement changes of 24 specimens subjected to the four-point bending test are given in Figure 5. Experiments were continued until the samples were damaged. Depending on the surface properties, displacement limits of 10 and 20 mm in the EPS group and 4 and 6 mm in the XPS group were determined for the loads carrying the samples without compromising their integrity. The mean load-displacement values from the test results are given in Table 5. These load values include elastic and elastoplastic displacements.

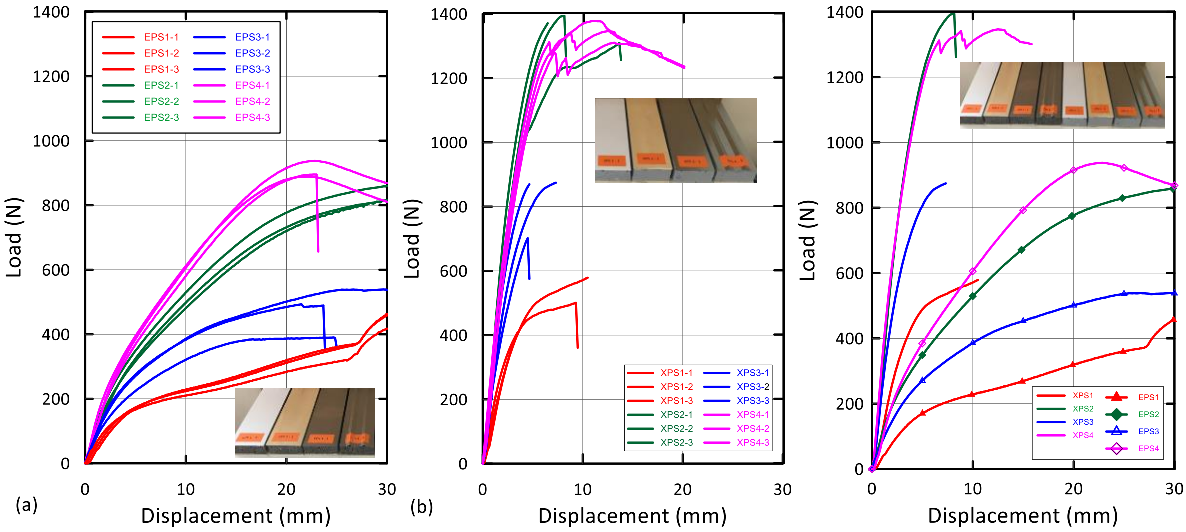


Figure 5. *Force-displacement variations:* ***(a)*** *EPS group,* ***(b)*** *XPS group,* ***(c)*** *EPS-XPS comparison*

Table 3. *The behavior of EPS samples and damage patterns.*

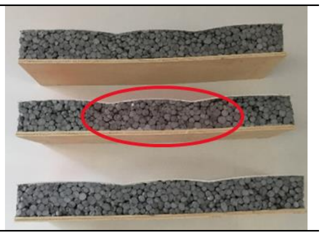
EPS-1: Local collapse and crushing occurred in the PVC sheet on the upper face of the samples under load grips. After half of the loading, the core material was crushed and transferred a load to the substrate, maintaining its integrity up to a displacement of 30 mm. No damage was observed to the plywood sheet on the bottom. All three specimens exhibited similar behavior.	

Table 3 (cont). *The behavior of EPS samples and damage patterns.*

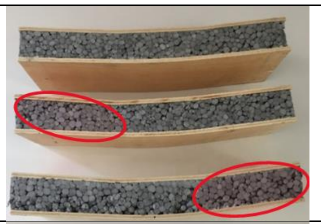
EPS-2: There was no damage to the upper and lower faces of the plywood sheets. At the end of loading, shear cracks appeared at the ends of the beams in the core layer. The beam made a displacement of 30 mm, maintaining its integrity. All three specimens exhibited similar bending behavior.	
EPS-3: Local crushing occurred in the core under the load grips on the flat metal plate on the upper face of the samples. There was no damage to the plywood sheet on the bottom due to bending. All three specimens showed similar behavior.	
EPS-4: At the beginning of the experiment, due to the relatively high strength of the triangular corrugated metal sheet on the upper surface, it did not bend, causing crushing at the ends of the beams. After bending the metal sheet, the displacements increased, and the middle of the beam was crushed. The plywood on the bottom surface of a specimen was broken, and the experiment ended with a displacement of 24 mm.	

Table 4. *The behavior of XPS samples and damage patterns.*

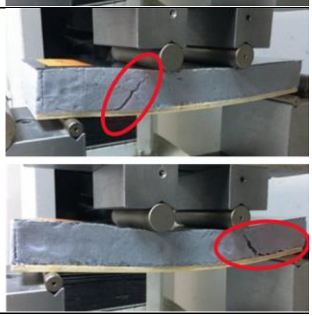
XPS-1: On the upper face of the sample, local collapses occurred in the PVC sheet under load grips in the middle of the experiment. At the end of the experiment, the top layer was separated from the core between the force grips or in the support area. The experiment was discontinued. No damage was observed to the plywood sheet on the bottom. Delamination occurred in all three samples. The adhesive that bonded the PVC sheet to the XPS core was ineffective.	
XPS-2: The samples showed a near-linear behavior until the end of the experiment. At the end of the experiment, shear cracks occurred in the core close to the support, and separations occurred between the upper layer and the core. While deformations were observed under the force grips on the upper face, no damage was observed on the bottom. Delamination occurred in all three samples.	
XPS-3: The samples showed a near-linear behavior until the end of the experiment. At the end of the experiment, shear cracks occurred in the margins of the core, and separations occurred between the bottom face and the core. There was no damage to the bottom face. Delamination happened on the lower face in all three samples. A shear failure occurred in the core.	

Table 4 (cont). *The behavior of XPS samples and damage patterns.*

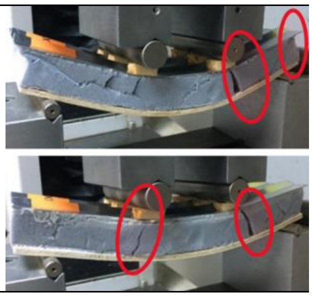
XPS-4: The specimens showed a near-linear behavior up to the maximum force. After the metal upper face wrinkled, there was a sudden decrease in strength; it regained strength. Shear cracks occurred in the core, and separations occurred between the upper face and the core. While there was no damage on the bottom surface, delamination occurred in the bottom layer due to the relative reduction of the adhesion surface in all three samples.	

Table 5. *Safely load-displacement values for test specimens.*

Code	Load (N)	Average Load (N)	Displ. (mm)	Code	Load (N)	Average Load (N)	Displ. (mm)
EPS-1-1	212			*XPS-1-1*	428		
EPS-1-2	228	221	10	*XPS-1-2*	438	433	4
EPS-1-3	223			*XPS-1-3*	433		
EPS-2-1	721			*XPS-2-1*	1345		
EPS-2-2	777	744	20	*XPS-2-2*	1304	1261	6
EPS-2-3	734			*XPS-2-3*	1134		
EPS-3-1	386			*XPS-3-1*	872		
EPS-3-2	389	366	10	*XPS-3-2*	816	725	4
EPS-3-3	323			*XPS-3-3*	602		
EPS-4-1	879			*XPS-4-1*	1205		
EPS-4-2	915	892	20	*XPS-4-2*	1275	1239	6
EPS-4-3	882			*XPS-4-3*	1237		

III. EVALUATION of SANDWICH BEAM BEHAVIOR

Theoretical predictions were made for the damage load and load-displacement behavior under bending loads obtained from four-point bending tests. This study used the static mechanical properties of the test materials in Table 2 for 2-Series test specimens with only cross-sectional symmetry plywood outsides.

A. ESTIMATION OF FAILURE LOADS AND MECHANISMS

The damage modes of sandwich beams arise depending on the cross-sectional geometry, material properties, and loading pattern. Figure 2 shows the four-point bending test layout and the components of the composite section. Steeves et al. stated that the most common modes of damage in composite sandwich beams under bending stresses are compression/tensile damage at the surface, core shear failure, and core damage at tensile/pressure [39]. In this study, the correlations given by Manalo et al. [40] were used to estimate the damage loads and shapes of the beams tested.

In the analysis of sandwich beams, it is generally assumed that the core carries only the shear stress, while the surfaces have the tension and compression stress that occur during bending. This study considered the contribution of the surface and the core to both bending and shear rigidity. The bending stiffness for the composite section, *D* or *EI*, and the shear stiffness *AG* can be calculated using Eqs. (1) and (2).

$$D = EI = \frac{bt^3E_f}{6} + \frac{btd^2E_f}{2} + \frac{bc^3E_c}{12} \approx \frac{E_f btd^2}{2} \quad (1)$$

$$AG = \frac{bd^2G_c}{c} \approx bdG_c \quad (2)$$

A.1. Skin Failure (Compression or Tension)

Compressive or tensile damage occurs when the axial stresses on the beam surface reach the maximum value. For a symmetrical composite sandwich beam, the peak strength for this failure mode under four-point bending can be estimated by P_{sf} Eq. (3). D is the bending stiffness, σs, E_s is the surface material's maximum stress and modulus of elasticity, S is the support span, and h is the beam height.

$$P_{sf} = \frac{12D\sigma_s}{ShE_s} \qquad (3)$$

A.2. Core Shear Failure

It occurs when the shear strength of the core is exceeded. The highest core shear strength for the cross-section, P_{cs}, can be estimated by Eq. (4). Here, τ_c and τ_s are the shear strength of the core and faces, and E_c is the modulus of elasticity of the core.

$$P_{cs} = \frac{2\tau_c D}{(E_s td/2 + E_c c^2/8)} \qquad (4)$$

A.3. Core Failure in Tension and Compression

It occurs when the core region's tensile or compressive stress values are exceeded. The force of P_{cf} can be estimated by Eq. (5). Here, σ_c is the maximum bending strength of the core.

$$P_{cf} = \frac{12D\sigma_c}{ScE_c} \qquad (5)$$

A.4. Load–Deflection Behavior of Composite Sandwich Beams

According to the Timoshenko beam theory, it is the sum of displacements due to bending and shear effects. The displacement in the middle of the span in a simple supported composite sandwich beam under 4-point bending can be calculated by Eq. (6). Here, Δ_{4FSW} is the displacement in the middle of the span, and AG is the shear stiffness.

$$\Delta_{4FSW} = \frac{23PS^3}{1296D} + \frac{PS}{6AG} \qquad (6)$$

The load-deflection curves representing the XPS-2 and EPS-2 specimens are shown in Figure 6. The load capacity of the XPS-2 specimen increased to a near-linear load of 1200 N and deviated by 5 mm. The deviation from linearity started with crushing the core at about 50% of the maximum load. Then, due to the onset in the core, the decreases in rigidity continued. The experimental specimen was defeated by core fracture at a load level of 1400 N, and a sudden drop in load was observed. The EPS-2 specimen has linear behavior up to 25% of the maximum load (Figure 6). It has reached a load of about 220 N with an almost linear aperture deviation of up to 2.5 mm. After that, the stiffness decreased slightly with the core crushing, detached from the linear behavior, reached up to 20 mm deflection undamaged, shear cracks began in the core, and the experiment was terminated at 30 mm.

The tested panel's material failure occurs after exceeding the bending limit, which is 1/100 of the span length. This can be assumed in the design as the primary boundary state being the serviceability boundary state due to the deviation constraint. The stiffness of the tested XPS and EPS core plywood sandwich beams in the elastic region was calculated. Failure loads were estimated by Eqs (3-6) and are given in Table 6. As a result of the research, it was determined that plywood beams with XPS cores have 70% more load-bearing capacity than EPS-core samples.

The first part of the force-displacement curve is linear elastic. The appearance of a second change in the slope of the displacement curve, in which the cells of the EPS foam begin to be crushed, is associated with the initial collapse of its core. It should be noted that the crushing of the plastic region's core significantly affects the sandwich structure's mechanical stability. Since the aim of the study was limited to characterizing the composite element with experimental and theoretical calculations in the elastic region, the elastoplastic behavior was neglected.

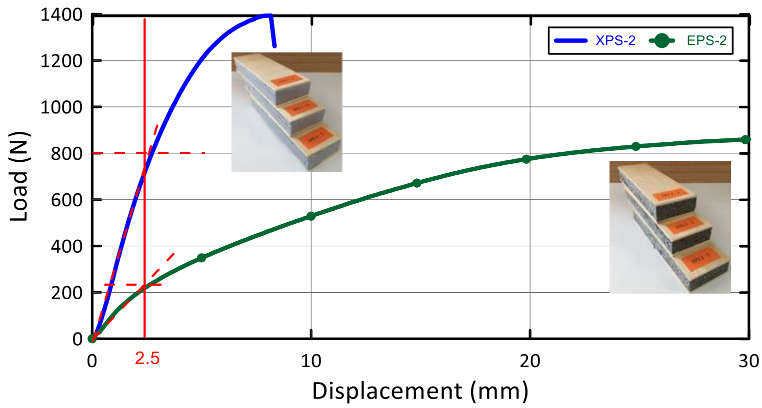


Figure 6. *Load displacement curves of XPS-2 and EPS-2 samples*

Table 6. *Experimental and predicted failure load of composite sandwiches.*

Code	Failure load (N) (experiment)		Predicted failure Load (N)		
	Total	Elastic region	[a]Shear failure of core	[b]Compressive failure of the face	[c]Tensile failure of the core
EPS-2	744	225	335	6980	295
XPS-2	1261	785	928	6980	177

[a]Calculated using Eq. (3); [b]calculated using Eq. (4); [c]calculated using Eq. (5).

IV. CONCLUSION

The study investigated the bending and shear behaviors of sandwich beams designed with two different cores and four different surface materials by a four-point bending experiment. The following findings were obtained from the experiments, observations, and theoretical studies.

- XPS-core specimens showed higher performance than EPS-core specimens. 70% more load-carrying capacity was achieved in XPS core beams than in EPS core beams. In samples with plywood and triangular corrugated metal surfaces (series 2 and 4), higher load values were obtained for both core materials than the other series.

- Significant behavioral differences were observed between samples with flat metal and triangular corrugated metal surfaces. Although they have the same material properties, the surface geometry has been improved with triangular corrugated, resulting in higher strength and a 100% increase in load bearing. An adequate adhesion was achieved between the plate and the core, but failure appeared in the core area.

- Local core crushing occurred in samples with EPS core and PVC surfaces under the load grips. Polyvinyl acetate resin could not provide the required connection in samples with XPS cores and PVC surfaces. In samples with PVC surfaces, the deterioration of the top surface began with local wrinkling on the compression side of the panel and resulted in delamination.

- The results showed that core density, type, and surface thickness significantly affected the stability and failure modes of the beams. High-density cores fail primarily due to core shift, while lower-density cores suffer from both core shift and creasing. Damage load estimates using theoretical correlations agree with values from static tests. With the study, obtaining the mechanical values required for the engineering design of sandwich composite structures was possible.

- The results show that it is possible to successfully join plywood surfaces with EPS and XPS cores in a fast and one-step manufacturing process. The rigidity and load-bearing capacity of the sandwich element with a foam core and corrugated metal surface are significantly plus. However, it also brings additional weight, thermal expansion, vibration damping, increased cost, and manufacturing complexity. As a result of the experiments, it was concluded that the best-performing design under bending effects was sandwich beams with plywood surface and XPS core.

- Future research should optimize these material combinations and investigate innovative bonding techniques to improve sandwich beams' overall performance and strength in various structural applications. This comprehensive review can guide the selection process for engineering applications by evaluating the effects of different top surface and core materials on the structural performance of sandwich beams. Further studies will investigate other functional qualities of sandwich panels designed for residential purposes, such as thermal insulation, environmental resistance, and sound absorption.

V. REFERENCES

[1] E. Işık, “Structural failures of adobe buildings during the February 2023 Kahramanmaraş (Türkiye) earthquakes,” *Applied Science*, vol. 13, no. 15, pp. 8937, 2023.

[2] A. Demir, E. Celebi, H. Ozturk, Z. Ozcan, A. Ozocak, E. Bol, S. Sert, F.Z. Sahin, E. Arslan, Z.D. Yaman, M. Utkucu and N. Mert, “Destructive impact of successive high magnitude earthquakes occurred in Türkiye’s Kahramanmaraş on February 6, 2023,” *Bulletin of Earthquake Engineering*, pp. 1-27, 2024.

[3] E. Çelebi, M. Aktas, N. Çağlar, A. Özocak, M. Kutanis, N. Mert and Z. Özcan, “October 23, 2011, Turkey/Van–Ercis earthquake: structural damages in the residential buildings,” *Natural Hazards*, vol. 65, pp. 2287–2310, 2013.

[4] E. Arkan, E. Işık, E. Harirchian, M. Topçubaşı and F. Avcil, “Architectural characteristics and determination seismic risk priorities of traditional masonry structures: a case study for Bitlis (Eastern Türkiye),” *Buildings*, vol. 13, no. 4, pp. 1042, 2023.

[5] R. Kassab and P. Sadeghian, “A comparative study on the mechanical properties of sandwich beams made with PET FRP facings and varied recycled PET cores,” *Composite Structures*, vol. 344, pp. 118340, 2024.

[6] A. Manalo, T. Aravinthan, W. Karunasena and A. Ticoalu, “A review of alternative materials for replacing existing timber sleepers,” *Composite Structures*, vol. 92, no. 3, pp. 603–611 2010.

[7] G. Dhaliwal and G. Newaz, “Flexural response of degraded polyurethane foam core sandwich beam with initial crack between face sheet and core," *Materials*, vol. 13, no. 23, pp.1–18, 2020.

[8] J.R. Liew and K. Sohel, “Structural performance of steel-concrete-steel sandwich composite structures,” *Advanced Structural Engineering, vol.* 13, no. 3, pp. 453–470, 2010.

[9] M. Dawood, E. Taylor and S. Rizkalla, “Two-way bending behavior of 3-D GFRP sandwich panels with through-thickness fiber insertions,” *Composite Structures*, vol. 92, no. 4, pp. 950–963, 2010.

[10] K.M. A Sohel and J.Y.R. Liew, “Steel-Concrete-Steel sandwich slabs with lightweight core-Static performance,” *Engineering Structures*, vol. 33, no. 3, pp. 981–992, 2011.

[11] J.L. Grenestedt and B. Bekisli, “Analyses and preliminary tests of a balsa sandwich core with improved shear properties,” *International Journal of Mechanical Sciences*, vol. 45, no. 8, pp.1327–1346, 2003.

[12] A.G. Mamalis, K.N. Spentzas, D.E. Manolakos, M.B. Ioannidis and D.P. Papapostolou, “Experimental investigation of the collapse modes and the main crushing characteristics of composite sandwich panels subjected to flexural loading,” *International Journal of Crashworthiness*, vo. 13, no. 4, pp. 349–362, 2008.

[13] E.M. Reis and S.H. Rizkalla, “Material characteristics of 3-D FRP sandwich panels,” *Construction and Building Materials, vol.* 22, no. 6, pp. 1009–1018, 2008.

[14] T.M. McCormack, R. Miller, O. Kesler and L.J. Gibson, “Failure of sandwich beams with metallic foam cores,” *International Journal Solid and Structures, vol.* 38. No. 28, pp. 4901–4920, 2001.

[15] K. Kabir, T. Vodenitcharova and M. Hoffman, “Response of aluminum foam-cored sandwich panels to bending load,” *Composite Part B: Engineering, vol.* 64, pp. 24–32, 2014.

[16] A.A. Nia and M.Z. Sadeghi, “The effects of foam filling on compressive response of hexagonal cell aluminum honeycombs under axial loading-experimental study,” *Materials and Design*, vol. 31, no. 3, pp. 1216–1230, 2010.

[17] N. Geren, Ç. Uzay, M. H. Boztepe ve M. Bayramoğlu, “Sandviç Malzeme Geliştirmede Polimer Köpük Çekirdek Kalınlığının Eğilme Dayanımına Etkisinin Deneysel olarak Araştırılması”, *Çukurova Üniversitesi Mühendislik Fakültesi Dergisi*, c. 32, s. 2, ss. 13–22, 2017

[18] F. Balıkoğlu and T. K. Demircioğlu, “Experimental and Theoretical Study on Behaviour of Geometrically Asymmetric Composite Marine Sandwich Beams under Bending Load,” *DUBİTED*, 10(4), pp. 1776–1792, 2022.

[19] E. Camcı, “Metal Esaslı Sandviç Kompozitlerin Balistik Performansının İncelenmesi,” *DÜBİTED*, c. 8, s. 2, ss. 1454–1469, 2020.

[20] S. Subaşı, V. Çetin ve A. Şamandar, “Kompozit Panellerde CTP Levha ve Çekirdek Kalınlığının Mekanik Özelliklere Etkisi,” *El-Cezeri Journal of Science and Engineering*, c. 4, s. 2, ss. 135–145, 2017.

[21] J. Fajrin, Y. Zhuge, F. Bullen and H. Wang, “Flexural behaviour of hybrid sandwich panel with natural fiber composites as the intermediate layer,” *Journal of Mechanical Engineering and Sciences*, vol. 10, no. 2, pp. 1968-1983, 2016.

[22] C. Borsellino, L. Calabrese and. A. Valenza, “Experimental and numerical evaluation of sandwich composite structures,” *Composites Science and Technology*, vol. 64, pp. 1709–1715, 2004.

[23] C. Atas and U. Potoğlu, “The effect of face-sheet thickness on low-velocity impact response of sandwich composites with foam cores,” *Journal of Sandwich Structures and Materials*, pp. 1–14, 2015.

[24] E. Avlar, S. Limoncu and, D. Tızman, “Post-earthquake temporary housing unit: CLT E-BOX,” *Journal of the Faculty of Eng. and Arch. of Gazi University*, vol. 38, no. 1, pp. 471-482, 2023.

[25] R. Sarmento, M. Posani, P. Fernandes, A.M. Rodrigues and M.G. Gomes, "Energy efficiency in modular emergency shelters: Impact of envelope finishings and shadowing," *Journal of Building Engineering*, vol. 94, pp. 110029, 2024.

[26] J. Li, G.W. Foden, S.K.W. Chow and L.S. To, "Integrating sustainable and energy-resilient strategies into emergency shelter design," *Renewable and Sustainable Energy Reviews*, vol. 191, pp. 113968, 2024.

[27] R. Potangaroa, "Sustainability by Design: The Challenge of Shelter in Post Disaster Reconstruction," *Procedia - Social and Behavioral Sciences*, vol. 179, pp. 212-221, 2015.

[28] S.M. Şener and M.C. Altun, "Design of a post disaster temporary shelter unit," *ITU A|Z*, vol. 6, no. 2, pp. 58-74, 2009.

[29] A. Petras and M.P.F. Sutcliffe, "Indentation resistance of sandwich beams," *Composite Structures*, vol. 46, no. 4, pp. 413-424, 1999.

[30] A. Petras and M.P.F Sutcliffe, "Indentation failure analysis of sandwich beams," *Composite Structures*, vol. 50, no. 3, pp. 311-318, 2000.

[31] F. Aviles and L. Carlsson, "Experimental Study of Debonded Sandwich Panels Under Compressive Loading," *Journal of Sandwich Structures and Materials*, vol. 8, no. 1, pp. 7-31, 2006.

[32] F. Yuan, A.H. Sheikh and G. Li, "Analysis of Intact/Delaminated Composite and Sandwich Beams Using a Higher-Order Modeling Technique," *Journal of Composites Science*, vol. 8, no. 5, pp. 175, 2024.

[33] W. Su and S. Liu, "A couple-stress model to predict the wrinkling stress of sandwich panels with foam cores," *Composite Structures*, vol. 268, pp. 113978, 2021.

[34] V. Kahya, "Buckling analysis of laminated composite and sandwich beams by the finite element method," *Composites Part B: Engineering*, vol. 91, pp. 126-134, 2016.

[35] *Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure*, ASTM C393 / C393M-16, 2016.

[36] R.K. Pekgökgöz, G. İzol, F. Avcil, M.A. Gürel, "Experimental and Numerical Investigation of the Tendon Layout Effect on Flexural Capacity in Post-Tensioning Beams", *Tehnički vjesnik*, vol. 31, no. 5, pp. 1553-1560, 2024.

[37] *Standard Test Method for Facesheet Properties of Sandwich Constructions by Long Beam Flexure*, ASTM D7249 / D7249M-20, 2020.

[38] *Standard Practice for Determining Sandwich Beam Flexural and Shear Stiffness*, ASTM D7250 / D7250M-16, 2016.

[39] C.A. Steeves and N.A. Fleck, "Collapse mechanisms of sandwich beams with composite faces and a foam core, loaded in three-point bending. Part I: Analytical models and minimum weight design," *International Journal of Mechanical Sciences*, vol. 46, no. 4, pp. 561-583, 2004.

[40] A.C. Manalo, T. Aravinthan, W. Karunasena and M.M. Islam, "Flexural behaviour of structural fibre composite sandwich beams in flatwise and edgewise positions", *Composite Structures*, vol. 92, no. 4, pp. 984-995, 2010.