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Compressive Performance of the PVC Foam Materials used as Sandwich Panel Core

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Abstract

PVC foam materials are preferred in many engineering applications because of their lightweight nature and strength/weight ratio. They are mainly used as the core material in the middle of sandwich panels with improved flexural rigidity. The mechanical performances of sandwich panels, such as flexural load-deflection, core shear load, core shear failure load, and indentation failure load, directly depend on the mechanical properties of the core material. In this study, compression tests of AIREX C70 PVC foams with three different densities were performed. The elastic modulus and strength results obtained from the compression tests were compared with the mechanical properties provided in the dataset supplied by the material manufacturer. The core yield loads of a concept sandwich panel were then obtained using the compression mechanical properties of the core, which were obtained from datasets and experimental results. When the core yield loads obtained using both data were compared, it was revealed that the load obtained using the dataset data was 23% inaccurate. Thus, the study explained why compression tests are necessary even though the mechanical properties of PVC foam materials are known in the datasheet.

Keywords: AIREX C70 PVC foam, Sandwich panels, Core yield loads, Compression tests

Sandviç Panellerde Çekirdek Malzeme Olarak Kullanılan PVC Köpük Malzemelerin Basınç Yüklerine Karşı Performansı

Öz

PVC köpük malzemeler, hafiflikleri ve mukavemet/ağırlık oranları nedeniyle birçok mühendislik uygulamasında tercih edilmektedir. Özellikle eğilme rijitliği artırılmış sandviç panellerin ortasında çekirdek malzeme olarak kullanılırlar. Sandviç panellerin eğilme yükü-sapması, çekirdek kesme yükü, çekirdek kesme kırılma yükü ve çentik kırılma yükü gibi mekanik performansları doğrudan çekirdek malzemenin mekanik özelliklerine bağlıdır. Bu çalışmada, üç farklı yoğunluğa sahip AIREX C70 PVC köpüklerin

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sıkıştırma testleri gerçekleştirilmiştir. Basma testi sonuçlarından elde edilen elastik modül ve mukavemet sonuçları, malzeme tedarikçisi tarafından sağlanan mekanik özellikler veri sayfası verileri ile karşılaştırılmıştır. Daha sonra, konsept bir sandviç panelin çekirdek akma yükleri veri föyündeki ve deneysel sonuçlardaki çekirdeğin basma mekanik özellikleri kullanılarak, elde edilmiştir. Her iki veri ile elde edilen çekirdek akma yükleri karşılaştırıldığında, veri föyündeki verileri ile elde edilen yükün %23 hatalı olduğu ortaya çıkmıştır. Böylece çalışma, PVC köpük malzemelerin mekanik özelliklerinin veri föyünde bilinmesine rağmen basma testlerinin neden gerekli olduğunu açıklamaktadır.

Anahtar Kelimeler: AIREX C70 PVC köpük, Sandviç paneller, Çekirdek akma yükleri, Sıkıştırma testleri

1. INTRODUCTION

The rapid emergence and growth of the use of polymeric foams have been attributed to their numerous advantages. These include their lightweight properties, high strength/weight ratio, and ability to provide excellent insulation [1,2]. Demand for these materials is expected to increase because of the increasing use of lightweight materials such as closed-cell foams, especially in automotive structures. The lightweight nature of these materials can help improve fuel economy and reduce transportation pollution. In addition, the high compressive energy of closed-cell foams can be used to improve the damage tolerance of some automotive structures. Therefore, due to their exceptional lightweight properties, closed-cell PVC foams are widely used in the production of automobile, aerospace, and marine structures [3]. Owing to their high compressive and dimensional stability characteristics, closed-cell foams are also ideal for structural applications [4]. Foam cores from polymers such as PVC have good flammability and chemical resistance [5]. PVC foam is also a core material that produces wind turbine blades [6]. Various engineering products, such as sandwich panel cores, use PVC foams [7,8]. Because of their properties, such as their ability to resist transverse loads, sandwich panels are commonly used in engineering applications [9]. For a sandwich structure, the role of the core in transmitting the shear load between the facesheets is significant. If the core is brittle or has low shear strength, it can cause catastrophic failure. On the other hand, high shear strength can cause delamination because of the failure of the facesheets' adhesion. Although it has a high shear strength, PVC foam tends to behave non-linearly [10].

The core material directly affects the flexural behavior of sandwich beams, such as core shear deflection, core yield load, and core shear failure mode [11-14]. The core yield load depends on the compressive strength capability of the core material, especially when sandwich beams lose their stiffness properties under bending load. When analytical methods estimate the core yield load values of sandwich beams, the compressive yield strength of the core material is required [11]. Therefore, the compressive strengths of the PVC foam material must also be known to estimate the core yield-bearing load of a sandwich beam made of the PVC foam core material.

This study investigated the compressive strengths of AIREXC70 PVC foam, the preferred core material of sandwich materials. There is a wide range between the average and minimum values in the supplier's strength specifications for PVC foams (Table 1). Therefore, using these values in analytical calculations may increase the error rate in providing reliable estimates. For these reasons, we subjected three different AIREXC70PVC foam materials used as cores in sandwich plates to compression tests. Thus, the authors revealed where the compression properties of the PVC foams they tested fell within the property range in the data sheet provided by the supporting company.

2. MATERIAL AND METHOD

The AIREX C70 foam is made from high-quality closed-cell materials and exhibits exceptional stiffness and strength. This material is water resistant and has excellent anti-chemical capabilities. Its delicate cell design also helps in bonding. AIREXC70 is suitable for various resins and manufacturing processes. Owing to its exceptional properties, AIREXC70 can be used as a core material for various sandwich structures [15]. Figure 1 shows the three densities and thicknesses of AIREX C70. They are widely chosen as the core material for sandwich beams. The samples exhibited 75, 48, and 130 kg/m^3 densities. The manufacturer of AIREXC70 provides the mechanical properties of PVC foams. The mechanical characteristics of the AIREX C70 PVC foams are shown in Table 1.

Compression testing was performed on the three densities of AIREX C70 PVC foams to check their mechanical properties, as shown in Table 1. ASTM C365 is the standard used for determining the compressive modulus and strength of PVC foam used for sandwich structures [16]. According to standard procedures, five AIREX C70 PVC foam samples were prepared with 30 mm thickness and 60X60 mm surface cross-section sizes. The test samples are shown in Figure 2.

Compression tests were performed on PVC foam using ASTM C 365 [16]. The rigid plates, which were 20 mm thick, were fixed to the lower and upper jaws of the machine, as shown in Figure 3. The specimen was then placed between them. The cross-head motion was set at 0.50 mm/min. It was ensured that the load was evenly distributed across the specimen surface. The tests were resumed until the foam was densified.

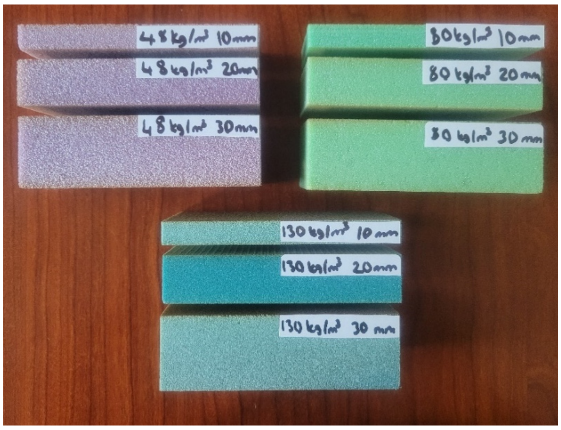

Figure 1. AIREX C70 foams are used as the core material

Table 1. Mechanical properties of the AIREX C70 foam materials [17]

Properties of the AIREX C70	Unit	C70.48	C70.75	C70.130
Density	kg/m^3	48 (min 43)	80 (min 72)	130 (min120)
Compressive strength	MPa	0.60 (min 0.50)	1.45 (min 1.10)	3.0 (min 2.6)
Compressive modulus	MPa	48 (min 35)	104 (min 80)	170 (min 145)
Tensile strength in the plane	MPa	0.95 (min 0.80)	2.0 (min 1.6)	4.0 (min 3.0)
Tensile modulus in the plane	MPa	35 (min 28)	66 (min 50)	115 (min 95)
Shear strength	MPa	0.55 (min 0.50)	1.2 (min 1.0)	2.4 (min 2.1)
Shear modulus	MPa	16 (min 14)	30 (min 24)	54 (min 45)

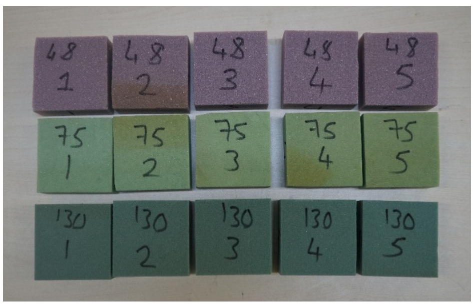

Figure 2. PVC foam specimens prepared for compression testing

Figure 3. Compression test setup of the PVC foam core material

3. RESULTS AND DISCUSSIONS

Table 1 shows the mechanical properties of the three PVC foams. Although the data collected by the supplier company are shown in Table 1, the average and minimum values of the foam materials are not always the same. For instance, a high-density PVC foam with an average density of 48 kg/m^3 can have a maximum density of 55 kg/m^3 and a minimum density of 43 kg/m^3. The variance between the densities at the extremes and the average values is approximately 14.5%. The mechanical properties of the foam are considered to be the basis of its average value at 48 N/mm^2. However, the minimum value for this material is 35 N/mm^2. The difference is noteworthy, as it amounts to 27%. Compression tests were performed on the foams to determine their mechanical range. These were compared with the materials used in the study. The force-extension data obtained during the compression tests are shown in the curves in Figure 4. The stress-strain curves presented in Figure 5 were then obtained.

The compressive modulus and strength of the PVC foams were obtained from Figure 5. The mechanical compression properties of the PVC foams obtained from the tests are given in Table 2, with the mechanical compression properties provided by the supporting company. The data presented in the table show that the compression properties of all tested PVC foams are between the minimum and maximum values presented in the data sheet. The experimental compression modulus and strength values of AIREX C70.48 PVC foam with a density of 48 kg/m^3 are in the middle of the minimum and average values presented in the data sheet. The experimental compression mechanical properties of 80 kg/m3 density AIREX C70.75 and 130 kg/m^3 density AIREX C70.130 PVC foams are close to the minimum values presented in the data sheet.

It can be said that there is agreement between the experimental results and the values presented in the data sheet. However, this wide range in the data sheet may lead to erroneous predictions in application areas. For example, consider a sandwich beam design made of AIREX C70.75 foam among the foams tested in compression and plain woven fabric composite material. The mechanical properties of the plain woven fabric composite material used as the facesheet material of the designed sandwich material were taken from the literature. Facesheet material has a thickness of 0.82 mm, an elastic modulus of 50.2 (E_f), and tensile strength of 674 MPa, respectively [18]. Let the thickness (c) of the PVC foam material be 30 mm. Also, assume the sandwich beam (b) width is 50 mm. The designer wants to estimate the core yield load of this sandwich beam under bending loads. The designer can predict the core yield loads (P_1) of the sandwich beam with the equations presented below [11].

$$P_1 = \frac{2\sigma_c b}{\lambda} \quad (1)$$

where,

$$\lambda = \left(\frac{k}{4E_f I_f}\right)^{\frac{1}{4}} \quad (2)$$

With the foundation modulus k defined as;

$$k = \frac{E_c b}{c} \quad (3)$$

Using the PVC foam material and facesheet material properties given in the case study and the set of equations, the core yield loads of the sandwich were determined. Two different methods were applied to the solutions. In the first case, P_1 is obtained using the average elastic modulus of PVC foam from Table 2. The second case calculation was made using the experimental compressive elastic modulus. Thus, the error probability for P_1 was determined. The P_1 value obtained from the average value of the data sheet was 1041 N. Otherwise, the value of P_1 obtained using the compression modulus obtained using the experimental result is 843 N. The main mechanical properties are the experimental compression test results for the PVC foam used. Therefore, the force value was obtained with an error of 23% in the first calculation method.

As a result, the PVC foams tested under compression are within the value range given in the datasheet. However, using the datasheet values in analytical applications for design estimations increases the error rate in obtaining actual values. The core yield loads obtained in the case study are an excellent example.

On the other hand, PVC foam materials used as core materials in sandwich applications do not only require compressive mechanical properties. The shear modulus of the core material of a sandwich beam is required to obtain the force–deflection curve under flexural loading. The maximum load that a sandwich failing in core shear failure mode can carry depends on the shear strength of the PVC foam. Moreover, the compression modulus and strength are required to determine the maximum load a sandwich with indentation failure can carry. The mechanical properties of the PVC foam used as the core material must be known for accurate and precise estimation of all these parameters applicable to the sandwich design. In this context, this study explains the necessity of determining the mechanical properties of PVC foams from experimental data, although the mechanical properties are given in the foam manufacturers' datasheets.

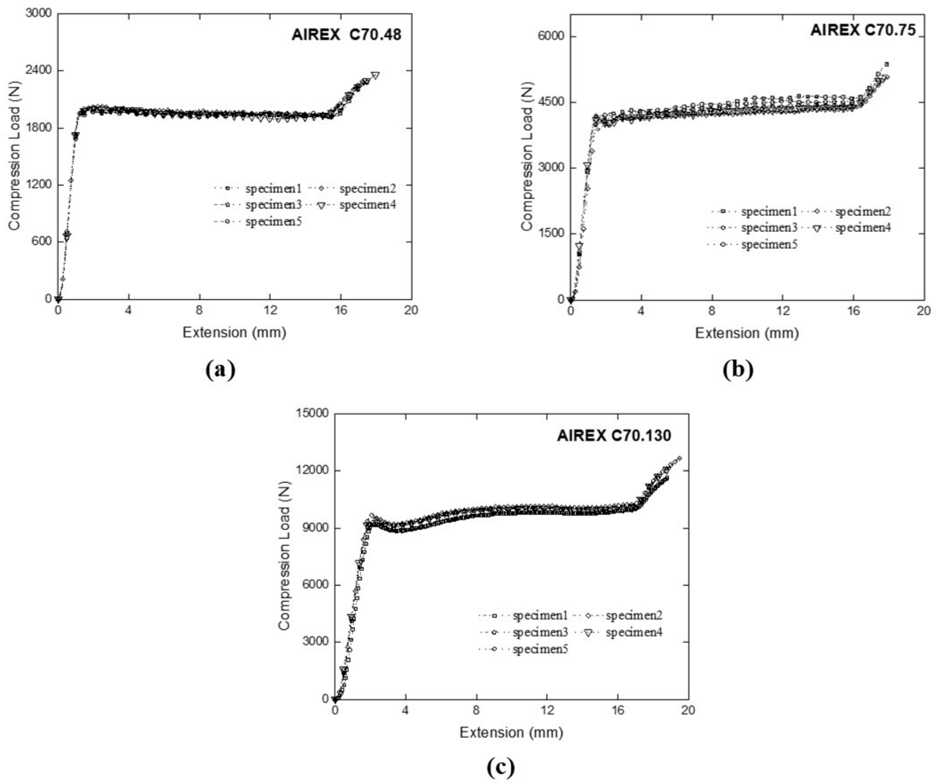

Figure 4. PVC foams compression load– extension curves a) 48 kg/m^3 density b) 80 kg/m^3 density c) 130 kg/m^3 density

Table 2. Compressive modulus and strength of the AIREX C70 PVC foams

AIREX C70	**Data sheet**			**Experimental results**	
	Density (kg/m^3)	Comp. strength (MPa)	Comp. modulus (MPa)	Comp. strength (MPa)	Comp. modulus (MPa)
C70.48	48 (min 43)	0.60 (min 0.50)	48 (min 35)	0.55	42
C70.75	80 (min 72)	1.45 (min 1.10)	104 (min 80)	1.10	82
C70.130	130 (min120)	3.0 (min 2.6)	170 (min 145)	2.60	145

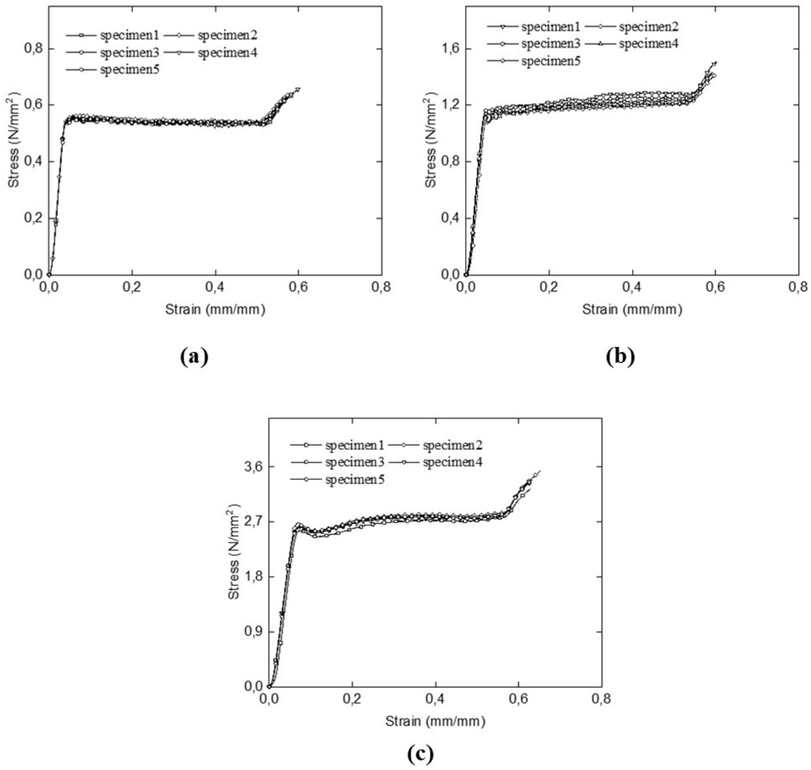

Figure 5. PVC compression stress-strain curves a) 48 kg/m^3 density b) 80 kg/m^3 density c) 130 kg/m^3 density

4. CONCLUSION

Compression tests of the PVC foam materials used in sandwich panel applications were conducted. Three different densities of PVC foam were used in this study. The mechanical property dataset of these foams obtained from the supplier company is provided in the study. However, the range between the average and minimum values of the mechanical properties is very large. Therefore, the actual compression modulus and strength values of the tested PVC foams were obtained. The compression properties of 48 kg/m^3 density foams obtained from the experimental results are between the average and minimum values in the datasheet, whereas the others are close to the minimum values.

A case study was also conducted to emphasize the importance of correctly determining the mechanical properties of PVC foams when designing for application fields. A sandwich panel was designed, and the core yield load of this panel was obtained by an analytical method using the compressive mechanical properties of the PVC core material. Two different calculations were performed. The first method used the average compression modulus and strength values in the datasheet. Second, compression properties obtained from the experimental data were used. The load value obtained using the dataset data was 23% inaccurate.

Thus, the study proved that even though the dataset presents the mechanical properties of PVC foams, the mechanical properties of the core used in the sandwich panel need to be obtained by testing.

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