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Free vibration analysis of foam-core sandwich structures

Köpük çekirdekli sandviç yapıların serbest titreşim analizi

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Free Vibration Analysis of Foam – Core Sandwich Structures

Highlights

- *Free vibration analysis with finite element method.*
- *Effect of surface layer thickness on sandwich structure natural frequency and mode shapes.*
- *Effect of core thickness on sandwich structure natural frequency and mode shapes.*

Graphical Abstract

In this study, the effects of Al surface layers and PVC Foam core thicknesses on free vibration characteristics of Al-foam core sandwich structures were investigated using the finite element method.

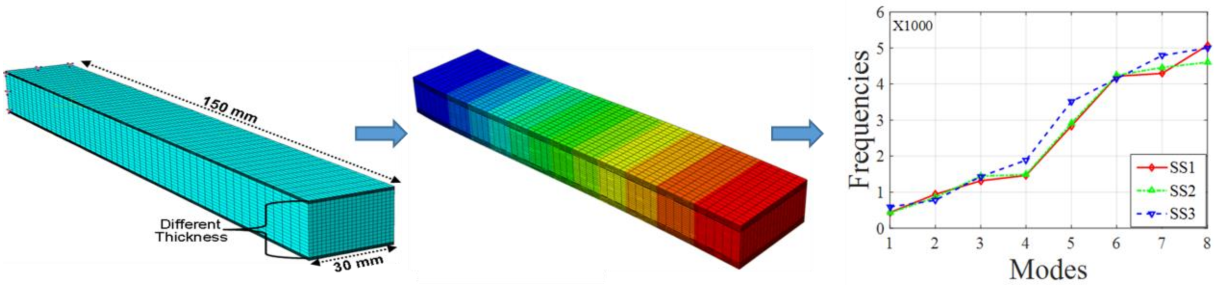

Figure *Effects of Al and Foam layer thicknesses on free vibration characteristics of Al-foam core sandwich structures using finite element method*.

Aim

The aim of this study is to examine the effects of surface layer thickness and core thickness on the natural frequency of the sandwich structure.

Design & Methodology

Three different Al-foam core sandwich structures with SS1, SS2 and SS3 codes were modeled in a combination of two different thicknesses (1 and 2 mm) for the Al surface layers and two different thicknesses (10 and 20 mm) for the foam core structure. A constant thickness (0,25 mm) was used for the adhesive. The free vibration analysis of Al-foam core sandwich structures was performed by ABAQUS / Standard finite element software.

Originality

The free vibration analysis of sandwich structures with foam cores, which is one of the new generation materials, was carried out using the finite element method and the effects of thickness of sandwich structure elements on the free vibration of the sandwich structure were investigated.

Findings

The increase in the thickness of the Al layer caused a decrease in the frequency, but this decrease is not very dramatic. It is negligible. The increase in the thickness of the core has caused a serious increase in the frequency of the sandwich structures and affected type of same mode shape.

Conclusion

It was determined that the core height was the most effective parameter on the sandwich structure's natural frequency. Further, the maximum change of natural frequency was observed in vertical bending modes. Change in other forms (torsional and lateral bending) was minimal.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Free Vibration Analysis of Foam-Core Sandwich Structures

Araştırma Makalesi / Research Article

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ABSTRACT

In this paper, the free vibration analyses of aluminum-foam sandwich structures were completed numerically. Foam and aluminum (Al) were used for the core and surface layers of the sandwich structure, respectively. In addition, an adhesive was used as a thin film. Natural frequencies and mode shapes of the sandwich structure were obtained for different thickness core and surface materials. For this, three different sandwich structures, different thickness of the core with same surface layers and the same core thickness with different surface layers thickness, were modeled as SS1, SS2 and SS3. Analyses were performed by ABAQUS/Standard finite element software. The increase in the thickness of the Al layer generally caused a decrease in the frequency, but this decrease is not very dramatic. The increase in the thickness of the core has caused a serious increase in the frequency of the sandwich structure.

Key words: Foam-core, free vibration, natural frequencies, numeric analysis, sandwich structures.

Köpük Çekirdekli Sandviç Yapıların Serbest Titreşim Analizi

ÖZ

Bu çalışmada, köpük çekirdekli alüminyum yüzey tabakasına sahip sandviç yapıların serbest titreşim analizleri nümerik olarak incelenmiştir. Malzeme olarak modelleme işlemi sandviç yapının yüzey tabakaları alüminyum, çekirdek malzemesi köpük olacak şekilde yapılmıştır. Ek olarak köpük ve alüminyum tabakalar arasına ince bir adeziv film bölgesi tanımlanmıştır. Sandviç yapının doğal frekansı ve mod şekillerinin farklı kalınlıkta yüzey ve çekirdek malzemesi kullanımı ile nasıl değiştiği incelenmiştir. Bu bağlamda SS1, SS2 ve SS3 olmak üzere üç çeşit sandviç yapı modellenmiştir. Bu yapıların bir bölümünde çekirdek kalınlığı sabit tutulup yüzey malzemesi kalınlığı değiştirilmiş geri kalanında yüzey malzemesi kalınlığı sabit tutulup çekirdek kalınlıkları değiştirilmiştir. Analizler ABAQUS/Standard sonlu elemanlar paket programı kullanılarak gerçekleştirilmiştir. Alüminyum yüzey tabakası kalınlığındaki artış genel olarak doğal frekansta bir düşüşe sebep olsa da bu düşüş ihmal edilebilir düzeydedir. Ancak çekirdek kalınlığındaki artış sandviç yapının doğal frekansında dikkate değer bir artış meydana getirmiştir.

Anahtar Kelimeler: Köpük çekirdek, serbest titreşim, doğal frekans, nümerik analiz, sandviç yapı.

1. INTRODUCTION

Today, developments in the industry are advancing rapidly and this is leading to an increasing need for advanced materials. Therefore, the studies on sandwich composites are very concentrated. Sandwich structure comes from a sandwich core, surface plates and adhesive thin film, which ensures that the plates and the core stand together (Fig. 1) [1]. The sandwich structure has properties such as lower density, relatively high strength and hardness than monolithic composites and metals. In this respect, the sandwich structure has high usage potentials in critical areas such as automotive, space, etc. According to a study [2], it is known that a car's fuel consumption is 60% dependent on vehicle weight and 10% weight reduction in vehicle results in 5% fuel saving. This situation makes light materials very important both in terms of environmental health and economy. However, the reduction of weight in the materials brings about an increase in vibrations occurring under working conditions. Increased vibration can cause many negative effects such as damage to the used material, negative effect on human health and noise pollution. For this reason, the use of vibration-damping core material in sandwich structures will provide a solution. In this respect, the foam is a very good candidate material. Foam cores are materials with low thermal conductivity, good absorption, high sound and heat insulation effect. It is also cheaper and more easily used while forming a sandwich structure than honeycomb core materials [3-5]. Some studies conducted in this area are summarized below.

Sakar et al. [6] studied on the natural frequencies and mode shapes of sandwich structures fabricated with different configurations for clamped-free boundary condition. In additional, they examined the effects of lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness on the vibration characteristics. According to their analyses,

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it was seen that when the cell breadth was expanded the first natural frequency diminished. Besides, when the foil thickness and core tallness were expanded the first natural frequency was increased. Finally, they reported that the most effective parameter on the natural frequency on the sandwich beam was core height.

Lashin et al. [7] examined the mode shapes of the sandwich structure and natural frequencies with various boundary conditions. They created three models using MSC-PATRAN/NASTRAN software, 1D beam, 2D shell and 3D solid. They stated that the outcomes demonstrate a good agreement between the analytical models and finite element models for different beams with under 2% error. Finally, they detailed that for AL-CPVC (Aluminum - Chlorinated Poly Vinyl Chloride) sandwich beam the analytical solution was over predict the natural frequencies with 27% for the first mode and increases with increasing the number of modes to reach 40% at the fourth mode.

Khare et al. [8] exhibited isoparametric finite element formulation dependent on a shear deformable model of higher-order theory utilizing a higher order facet shell component for the free vibration investigation of isotropic, orthotropic and layered anisotropic sandwich laminates and composite.

Nilsson et al. [9] introduced a technique for the expectation of eigen frequencies and modes of vibration for rectangular and orthotropic sandwich plates. They determined the eigen frequencies utilizing the Rayleigh Ritz method expecting frequency dependent material parameters. They analyzed anticipated and estimated results.

Li et al. [10] investigated the impacts of the thickness of the face sheets and core, and delamination on damping. Estimations on honeycomb– foam sandwich beams with various arrangements and thicknesses had been performed and the outcomes compared with the theoretical predictions.

Lai [11] aimed to research the vibrations of honeycomb panels. They utilized ANSYS for examination. The 3-D model was introduced to validate the continuum model commonly used in studying the vibrational of a honeycomb panel.

In this study, Al and foam were used for surface material and core respectively. In addition, an adhesive was used as a thin film. The purpose of this study is to examine the effect of Al surface material and foam core material thickness on the free vibration frequency.

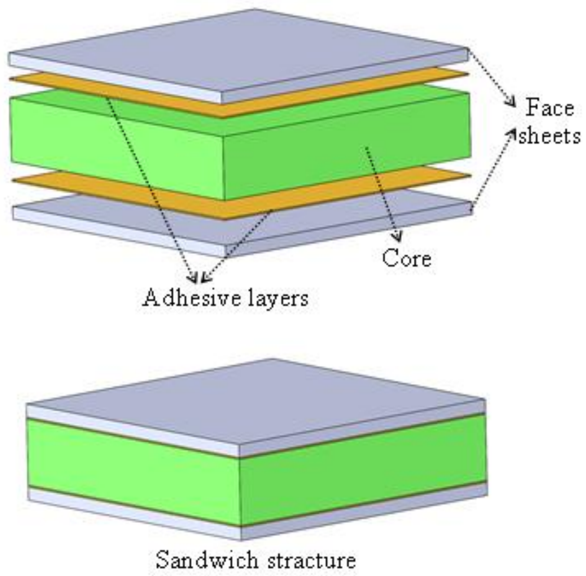


Figure 1. Schematic view of sandwich structure.

2. NUMERİCAL STUDY

Three types of sandwich structures (SS) shown in Table 1 were modeled with the help of ABAQUS package program and subjected to free vibration analysis. The surfaces of these sandwich structures, which are coded as SS1 SS2 and SS3, consist of Al layers and the cores are composed of foam PVC (H200) material. SS1 form: Two layers surface with 2 mm thickness of Al, foam core with 10 mm thickness and two adhesive layers of 0.25 mm thickness holding Al layers and core together. SS1 has a total thickness of (2x2)+10+(2x0.25)= 14.5 mm. SS2 form: Two layers surface with 1 mm thickness of Al, foam core with 10 mm thickness and two adhesive layers of 0.25 mm thickness holding Al layers and core together. SS2 has a total thickness of (2x1)+10+(2x0.25)= 12.5 mm. SS3 form: Two layers surface with 1 mm thickness of Al, foam core with 20 mm thickness and two adhesive layers of 0.25 mm thickness holding Al layers and core together. SS3 has a total thickness of (2x1)+20+(2x0.25)= 22.5 mm. Thanks to this variety of samples, it is aimed to examine the effect of surface layer thickness on natural frequency by keeping the core thickness constant by using SS1 and SS2. On the other hand, the effect of core thickness on natural frequency was investigated using SS2 and SS3 which have the same surface and different core thicknesses.

Table 1. Layer Thicknesses of Sandwich Structures.

Sandwich Structures (SS)	Al Layer Thicknesses (mm)	PVC (H200) Foam Core Thicknesses (mm)	Adhesive Thicknesse s (mm)
SS1	2	10	0,25
SS2	1	10	0,25
SS3	1	20	0,25

The sizes of the beam were modeled as length 150 mm, depth 30 mm and the different layer thicknesses as shown in Fig. 2. The properties of the used material in free vibration analysis were density, young module and poisson ratio. The mechanical properties of Al, foam and adhesive materials were given in Table 2.

Table 2. Mechanical properties of Al and Foam materials.

	Al	PVC (H200) Foam	Adhesive
Density (Kg/m^3)	2710	200	2500
Young Module (GPa)	70	0,23	4,39
Poisson Ratio	0,33	0,33	0,34

Sandwich beam was modeled as cantilever from the left end. The structure has totally 5 layers which are 2 surface layers, 2 layers of adhesive, 1 core and divided into also 35000 elements. The most applied mesh was the Al layer and the least applied was the core layer. Sandwich structures were modeled with eight-noded brick element (C3D8R). The layers were bonded with an adhesive layer.

3. RESULTS AND DISCUSSIONS

It is important for the design to know the mode shapes and vibration frequency values in case of free vibration in engineering constructions. According to the first eight modes, the frequencies were given in Table 3. Figures for the first eight modes for SS1, SS2 and SS3 were given in Table 4.

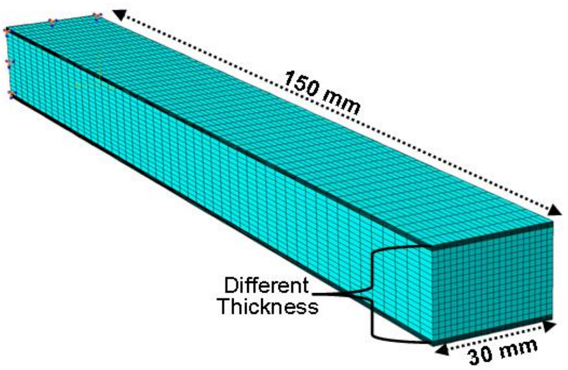


Figure 2. Sandwich beam model.

The effect of varying thicknesses of Al and foam layers on free vibration is as follows: Although there is a general decrease in the frequency with the increase of the thickness of the Al layer, this is not very dramatic, and in some modes even increased. Therefore it would be more accurate to examine each mode separately. The increase in the thickness of the core has caused a serious increase in the frequency of the sandwich structure. This was attributed to the fact that the increase in thickness is too great. It should not be overlooked that mode 3 and mode 6 are contrary to this general situation. When the modes are compared among them, for all three sandwich structures where mode 8 has the highest frequency value, mode 1 has the lowest frequency value. In addition, since a frequency magnitude cannot be ordered between SS1, SS2 and SS3, it is better to have the modes switch between them. As it shown in Fig. 3 the frequency values of all three sandwich structure increase as modes progress.

Table 3. Free Vibration Frequencies of Sandwich Structures.

Sandwich Structures (SS)	SS1	SS2	SS3
Mode 1 (Hz)	437.76	428.55	592.40
Mode 2(Hz)	941.71	855.12	776.62
Mode 3(Hz)	1315.90	1447.40	1433.00
Mode 4(Hz)	1465.10	1487.90	1889.00
Mode 5(Hz)	2835.70	2909.10	3514.60
Mode 6(Hz)	4218.60	4240.40	4149.00
Mode 7(Hz)	4294.20	4459.40	4790.00
Mode 8(Hz)	5070.40	4602.90	5002.70

As can be seen in Table 4. The SS1 experiences bending modes at the natural frequencies of mode 1 (ω_1 = 437.76 Hz), mode 2 (ω_2 = 941.71 Hz), mode 4 (ω_4 = 1465.10 Hz), mode 5 (ω_5 = 2835.70 Hz), mode 7 (ω_7 = 4294.20 Hz) respectively. The torsional modes were detected at the natural frequencies of mode 3 (ω_3 = 1315.90), mode 6 (ω_6 = 4218.60). Only one lateral bending mode occurs at a natural frequency of mode 8 (ω_8 = 5070.40 Hz). Similarly as can be seen in Table 4. The SS2 experiences bending modes at the natural frequencies of mode 1 (ω_1 = 428.55 Hz), mode 2 (ω_2 = 855.12 Hz), mode 4 (ω_4 = 1487.90 Hz), mode 5 (ω_5 = 2909.10 Hz), mode 7 (ω_7 = 4459.90 Hz) respectively.

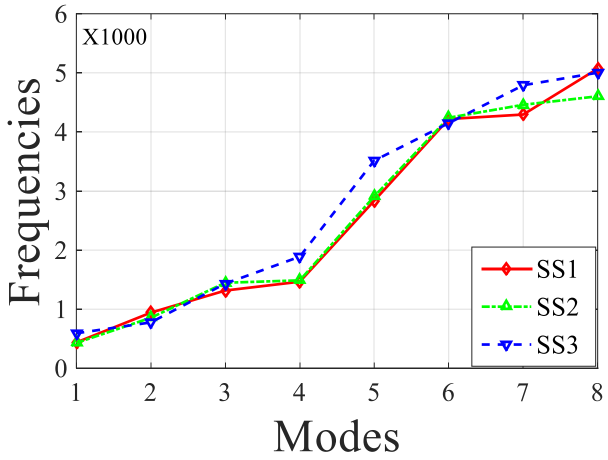
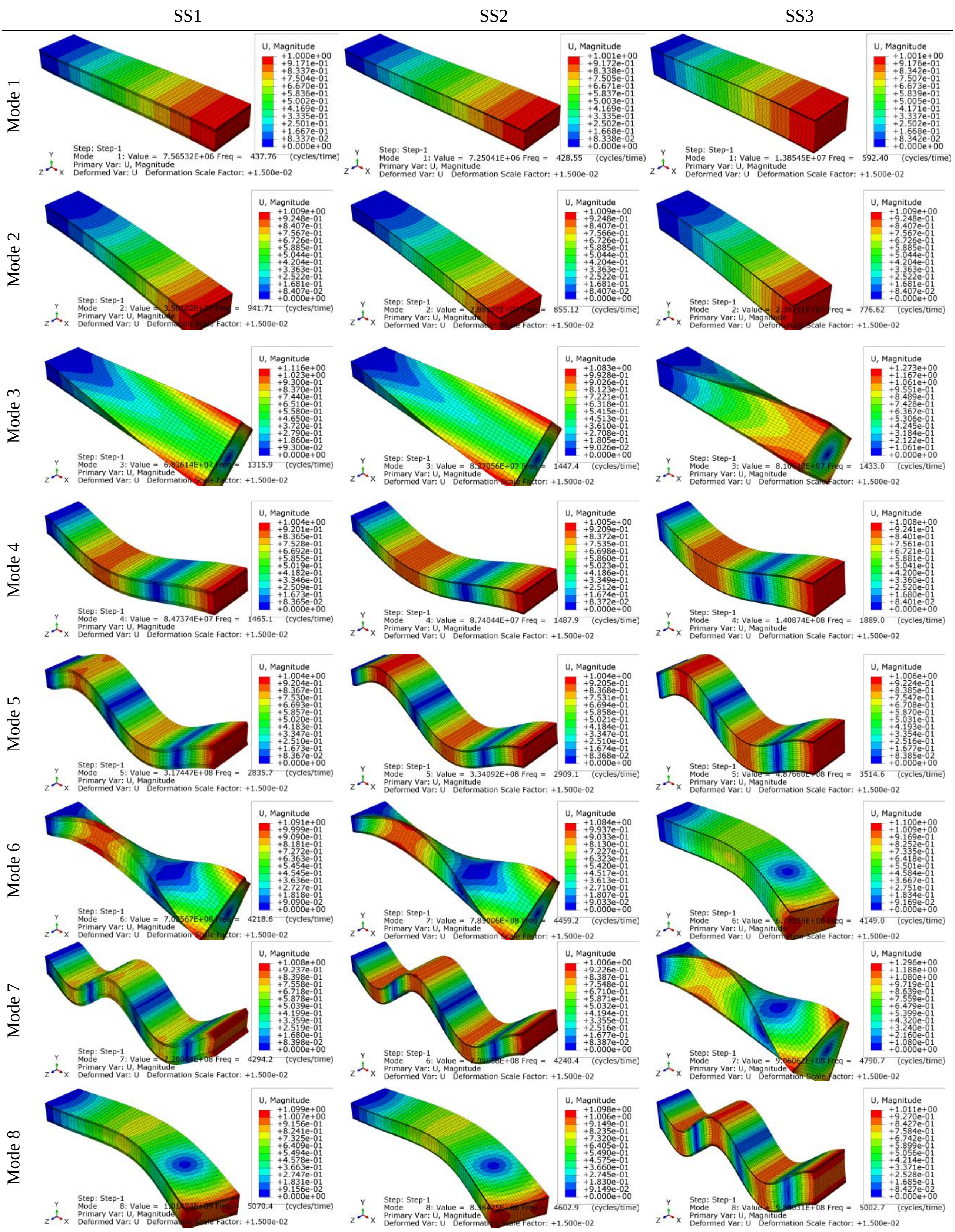


Figure 3. Frequency (Hz) values of the first eight modes of the SS1, SS2 and SS3.

Table 4. The First Eight Mode Shapes of Sandwich Structure 1-2-3.



The torsional modes were detected at the natural frequencies of mode 3 (ω_3 = 1447.40), mode 6 (ω_6 = 4240.40). Only one lateral bending mode occurs at a natural frequency of mode 8 (ω_8 = 4602.90 Hz). Unlike

SS1 and SS2, differences in mode patterns of SS3 were observed. When Table 4 is examined carefully, it can be observed that some modes change their behavior. For example, while mode 6 for SS1 and SS2 was torsional, it became lateral bending in SS3. In another example, for SS1 and SS2, mode 8 was lateral bending, whereas SS3 was just bending. The possible causes of this change may be as follows: i) The change in the thickness of the core is more effective than the change in surface thickness. ii) The thickness increase rate in SS3 is much more than the other two. The first eight natural mode shapes and frequencies showed that the SS1, SS2 and SS3 tend especially to modes of perpendicular bending and torsional vibration, whilst the horizontal modes were rare. As can be seen in Fig. 3, when the modes were examined separately, the following results were achieved: The frequency of SS3 in mode 1 increased compared to SS1 and SS2. A regular decrease was observed for the SS1, SS2, SS3 at mod 2. In mode 3, a negligible frequency change was detected for SS1, SS2, SS3. When the mode 4 was examined, the difference between SS1 and SS2 was quite low, but this value has increased considerably in SS3. Also in mode 5, SS1, SS2 and SS3 exhibited similar behavior. The frequency values of the sandwich structures in mode 6 have changed to a negligible level similar to that of mode 3. It is thought that the little in the amount of this change is due to the fact that the mode shapes are torsional and lateral bending. The maximum change was observed in vertical bending modes. Change in other forms was minimal. When examined carefully, it can be seen that mode 7 and mode 8 show parallel behavior to this view. To be summarized, SS1, SS2, SS3 s surface layer thickness did not change the frequency values significantly, but the increase in the core layer caused an increase in frequency values. This situation coincides with experimental and numerical studies in the literature. For example, Şakar and Bolat [6] examined numerically and experimentally the free vibration analysis of sandwich structures with honeycomb cores and reported that the increase in core thickness caused an increase in frequency values. A similar result was experimentally and numerically verified by another group [12] using glass fiber reinforced composite material as core material. Some studies conducted using different materials with similar results can be found in ref [13, 14].

4. CONCLUSIONS

In this study, the effect of the core and surface layer thickness of the sandwich structures consist of Al surfaces and foam core on natural frequency change was studied with finite element method. The results obtained by using ABAQUS / Standard finite element software are as follows. According to free vibration analysis results of SS1, SS2 and SS3 the increase in the thickness of the Al layer caused a decrease in the frequency, but this decrease is not very dramatic. It is negligible. The increase in the thickness of the core has caused a serious increase in the frequency of the (SS1, SS2 and SS3) sandwich structures and affected type of same mode shape. It was determined that the core height was the most effective parameter on the sandwich structure's natural frequency. Further, the maximum change of natural frequency was observed in vertical bending modes. Change in other forms (torsional and lateral bending) was minimal. In future studies, experimental study can be carried out for verification and comparison purposes, besides, the analysis can be made safer by increasing the variety of surface and core material thickness.

ACKNOWLEDGEMENT

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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