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Simulation Study on Deformation Behavior of Sandwich Panels with Corrugated Cores

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Abstract: In this study, the deformation behaviour of sandwich panels structures with different configurations of corrugated cores under the effect of quasi-static bending loading is investigated numerically. The corrugated core consists of cast polyamide (PA6) material with circular, sinusoidal, square, trapezoid, triangular and honeycomb geometries. An Aluminum 6063-T5 plate is used as the skin of the sandwich panel. According to the analysis results, the sandwich panel with a trapezoidal core provided the highest deformation resistance with 6363.6 N. The circular core sandwich panel showed the lowest deformation resistance with 4262.5 N. The sandwich panel with the highest specific carrying and specific energy capacity is the trapezoidal core panel.

Keywords: sandwich panel, deformation, corrugated core, pa6, aluminium

Oluklu Çekirdekli Sandviç Panellerin Deformasyon Davranışı Üzerine Simulasyon Çalışması

Öz: Bu çalışmada, farklı oluklu çekirdek konfigürasyonlarına sahip sandviç panel yapılarının yarı statik eğilme yükü etkisi altındaki deformasyon davranışı sayısal olarak incelenmiştir. Oluklu çekirdek, dairesel, sinüzoidal, kare, trapez, üçgen ve bal peteği geometrilere sahip dökme poliamid (PA6) malzemeden oluşmaktadır. Sandviç panelde yüzey kabuğu olarak Alüminyum 6063-T5 plaka kullanılmıştır. Analiz sonuçlarına göre en yüksek deformasyon direncini 6363.6 N ile trapez çekirdekli sandviç panel sağlamıştır. Dairesel çekirdekli sandviç panel ise 4262.5 N ile en düşük deformasyon direncini göstermiştir. Özgül yük taşıma ve özgül enerji absorbe etme kapasitesi en yüksek olan sandviç panel trapez çekirdekli panel olarak belirlenmiştir.

Anahtar Kelimeler: sandviç panel, deformasyon, oluklu çekirdek, pa6, alüminyum

1. Introduction

Sandwich structures are widely used in aerospace, marine, automotive, civil engineering, and transportation industries due to their high rigidity, strength, lightness, and energy absorption capacities. Sandwich structures, consisting of two pieces of hard facial skin and a light core, play an important role in energy absorption, weight reduction and structure protection. While facial skin is generally produced from high hardness, strength, and ductility materials, its core structure has low strength and high energy absorption capacity.

Many studies have been carried out on the static and dynamic behaviour of sandwich structures with different core topologies and basic materials under bending, impact/crushing, perforation and

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blast loads in recent years. As the core, metallic or and polymer [1-9] foams, woods [10], hexagonal [11-16] honeycombs, corrugated [17-20] and pyramidal [21-23] structures are used.

Metal or polymer foam is widely used as core material in sandwich panels [1-9]. Zu et al. The effects of different thicknesses of aluminium foam and steel panels of different thicknesses on the three-point bending strength of sandwich panels were investigated. They observed that the bending strength increased with increasing foam and panel thickness. A study examining the effect of high temperature on aluminium foam core sandwich panels determined that the temperature increase had a reducing effect on perforation and deformation. In a study in which corrugated and tubular reinforced polymer foam consisting of composite fiber was used as the core, corrugated and tubular reinforcement significantly increased the impact resistance [2,6,7].

Many studies have been carried out under different loadings where the skin and core material changes in honeycomb core sandwich panels. The effect of core height and density on carbon fiber composite sandwich panel bending behavior with aluminium honeycomb core was investigated [14]. Another study investigated the relationship between GFRP plate thickness and core thickness variation and flexural strength of honeycomb sandwich plates [16]. The low-velocity impact behaviour of polymer sandwich panels with hexagonal, rectangular and auxetic cell geometry was investigated experimentally and numerically. It has been observed that the energy absorption capacity of auxetic structures is 33% higher than that of hexagonal and rectangular structures [17]. In a study that tried to increase the blast resistance by filling with polymeric foams in corrugated core panels, it was seen that the filling made from the front side was more effective on the backside [18]. Studies on sandwich panels with a pyramidal core, not just a corrugated core [21-23]. Experimental and analytical studies have been carried out on panels with different configurations to investigate different damage modes and to determine their mechanical properties [21]. The load capacities and failure behaviours of sandwich panels with pyramidal truss cores were investigated by tensile and shear tests. Compared with honeycomb panels, it has been observed that it can achieve a similar level of tensile strength and higher shear load capacity [23].

In this paper, we present the deformation behaviour of composite sandwich panels with six different corrugated cores under the effect of quasi-static bending loading. A core with circle, square, triangle, trapezoidal, sinus and honeycomb geometries is used in the sandwich panel with an aluminium skin.

2. Numerical Methods

Sandwich panels used in simulations are generated as six different corrugated cores. Corrugated cores are in circle, square, triangle, trapeze, sinus and honeycomb geometries. The material used for the aluminium skin is Aluminium 6063-T5. The material used for the core is cast-polyamide (Pa6). Material properties of Pa6 used as a core and skin (Al 6063-T5) material is given in Table 1.

Table 1. Material properties of the 6063-T5 Aluminium and Pa6 [24].

Material	Density (g/m3)	Elastic Modulus (GPa)	Yield strength (MPa)	Tensile Strength (MPa)	Elongation at Break (%)
Al	2.70	69	200	247	15
Pa6	1.15	2.25	60	72.5	13

Al: Aluminium, Pa6: Cast polyamide

The width and length of the panel are 220 mm. Corrugated core height is 20 mm. Aluminium skin thicknesses are 1 mm and core tube height is 20 mm. Corrugated core thickness is 1 mm in each core type. While determining the dimensions of the sandwich panel, sizing was done by paying attention to the fact that the panel heights were the same in all and the panel weights were close to each other. The boundary condition of the finite element analysis model is given by fixing all edges from all directions. Fixed support was defined by selecting the areas on the four sides of the sandwich panel. The diameter of the spherical mandrel that will deform in the middle of the sandwich panel is 50 mm. A displacement movement of up to 10 mm is given to the spherical mandrel at 1 mm intervals in the vertical direction. As a result of the analysis, the reaction force corresponding to the mandrel displacement was obtained. The finite element models are generated and analysed using ANSYS™ 20.0. Finite element models of sandwich panels are given in Figure 1. The sandwich panels were modelled using a 3-D 20-node solid element (Solid186). No adhesive material was used between the core and the skin in the simulations. The contact between the core and the skin is defined as bonded. Contact definition is selected as bonded in ANSYS program. Also, no commands were used. Also; the mesh sensitivity analysis was carried out. 4 mm element size was considered in the current study. During the analysis, the non-linear geometry feature is kept open because the problem contains large deformation. The deformation rate was taken into account as 1 mm/s in the analyses. Schematic view of simulation model and boundary conditions used in the analysis is given Figure 2.

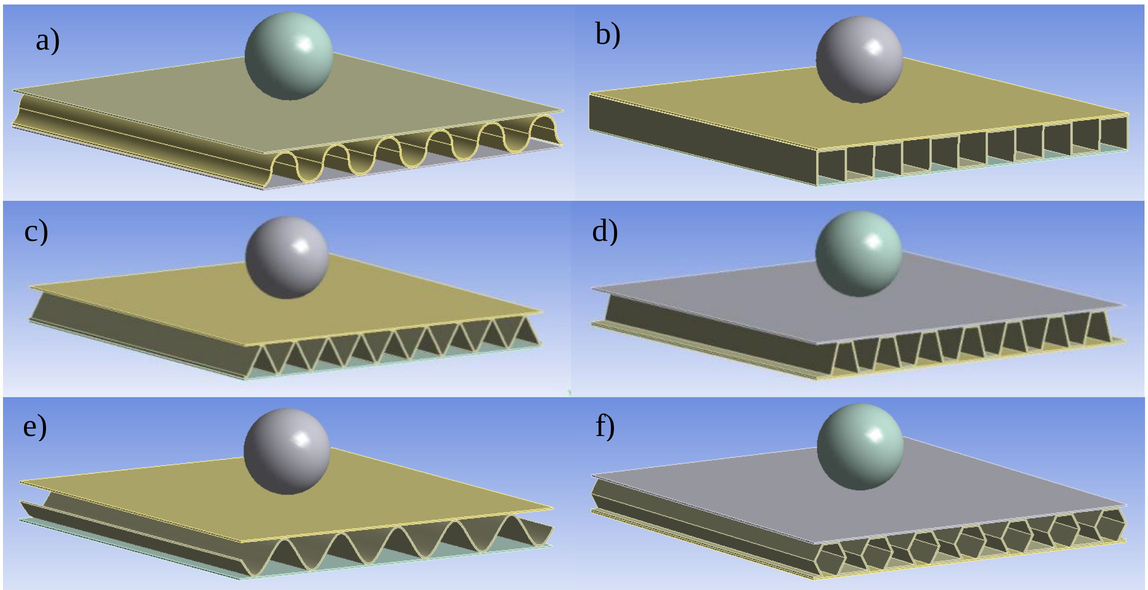

Figure 1. Finite element model of sandwich panels a) Corrugated circle core panel, b) Corrugated square core panel, c) Corrugated triangle core panel, d) Corrugated trapeze core panel, e) Corrugated sinusoidal core panel, f) Corrugated honeycomb core panel

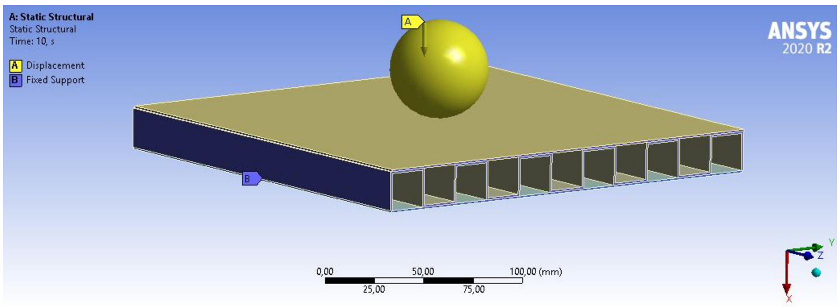

Figure 2. Schematic view of simulation model and boundary conditions used in the analysis

3. Results and Discussion

In this section, the results obtained from finite element analyses will be explained as a result of the 10 mm deformation of sandwich panels with circle, square, triangle, sinus, hexagon and trapezoidal core geometries by a spherical impactor. Load-Displacement curves of sandwich panels obtained from finite element analyses are given in Figure 3.

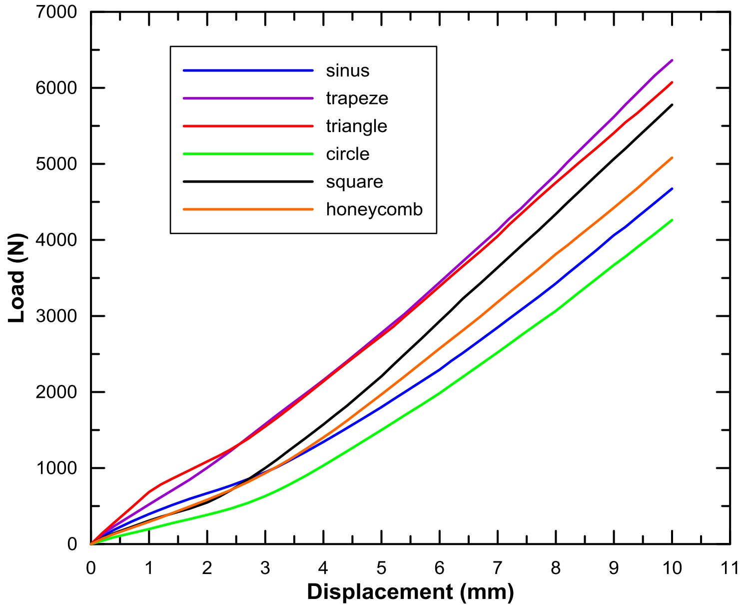

Figure 3. Load-displacement curves of sandwich panels

When the load-displacement curves of the sandwich panels are examined, it is seen that the load-carrying capacity of the trapezoidal core panel is the highest under 10 mm deformation. The panel with the lowest load carrying capacity is the circular core sandwich panel. The triangle core sandwich panel is closest to the trapezoidal sandwich panel in terms of load carrying and energy absorption capability. When the curves are examined, it is seen that the change of load changes approximately linearly with the applied displacement. The bending rigidity of sandwich panels increased with increasing bending load. Sandwich panels, where the core geometry is more curved, such as circular or sinus geometry, have less resistance to deformation. The high load capacity seen in panels with sharp geometries such as triangular and trapezoidal is not seen in curved geometries [25]. The data obtained from the simulation results are given in Table 2.

Table 2. Simulation results for sandwich panels.

Corrugated core type	Maximum load (N)	Weight (g)	Specific load capacity (SLC)(N/g)	Absorbed Energy[a] (J)	Specific absorbed energy (SAE)(J/g)
Circle	4262.5	355.8	11.98	17.1	0.048
Triangle	6073.9	372	16.33	28.8	0.077
Square	5779.2	380.7	15.18	24.5	0.064
Honeycomb	5081.2	400.3	12.69	21.7	0.054
Sinus	4673.2	348.3	13.41	20.1	0.058
Trapeze	6363.6	374.7	16.98	29.3	0.078

[a]Energy values are calculated up to 10 mm displacement.

The trapezoidal core panel carries a load of 636.6 N, while the SLC value is 16.98 N/g. While the circle core panel has the lowest strength value of 4262.5 N, the SLC value is 30 % lower than the trapezoidal core panel. While the trapezoidal core panel has the highest energy absorption capacity with 29.3 J, it ranks first with 0.078 J/g in terms of SAE. The SAE value is approximately 1.62 times that of a circular core panel. The triangular core panel comes right after the trapezoidal in terms of the SAE value. Total absorbed energy values of sandwich panels are given in Figure 4.

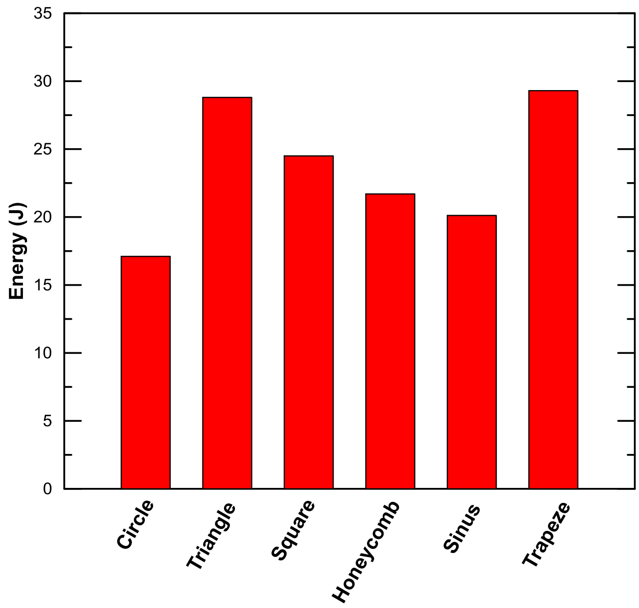

Figure 4. Energy-displacement curves of sandwich panels

It is clearly seen in the graph that the highest energy absorption capacity is seen in panels with trapezoidal and triangular cores (Figure 4). In a similar study examining different core geometries in the literature, it has been reported that the trapezoidal corrugated sandwich panel has a high energy absorption ability under a low-velocity impact. It also has better performance under lateral compression than other geometries [25]. The stress distribution of the sandwich panel with a circular channel core is given in Figure 5-10.

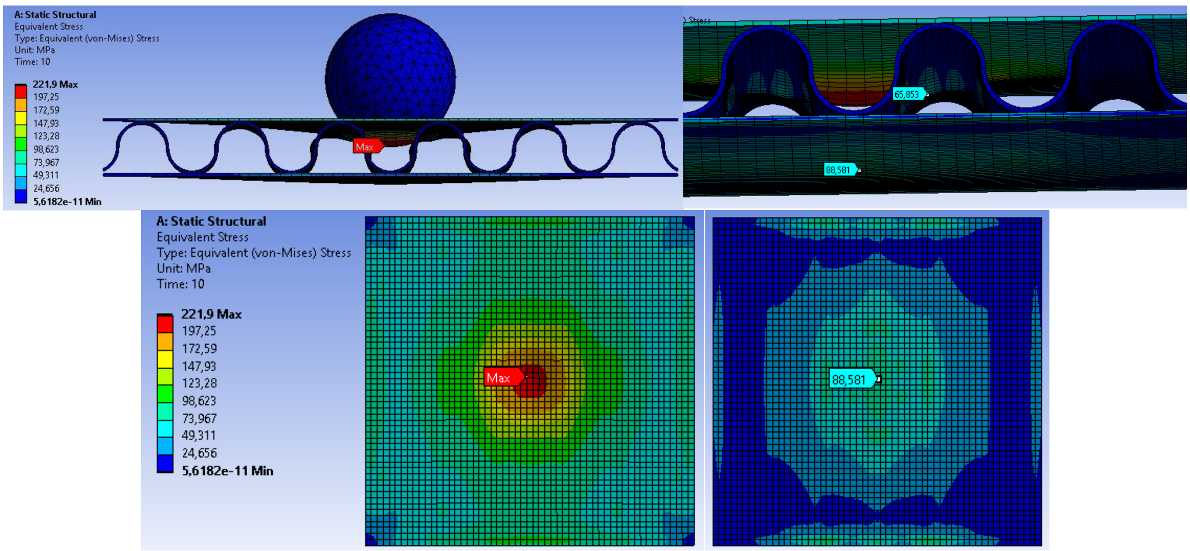

Figure 5. Von-Mises stress distribution of circle corrugated core sandwich panel.

As a result of the 10 mm deformation of the spherical impactor in the circular core sandwich panel, the maximum stress on the upper surface where the impactor contacts increase to 221.9 MPa. On the lower surface of the panel, the stress is at the level of 88 MPa. The maximum stress formed in the circular core is around 65 MPa (Figure 5).

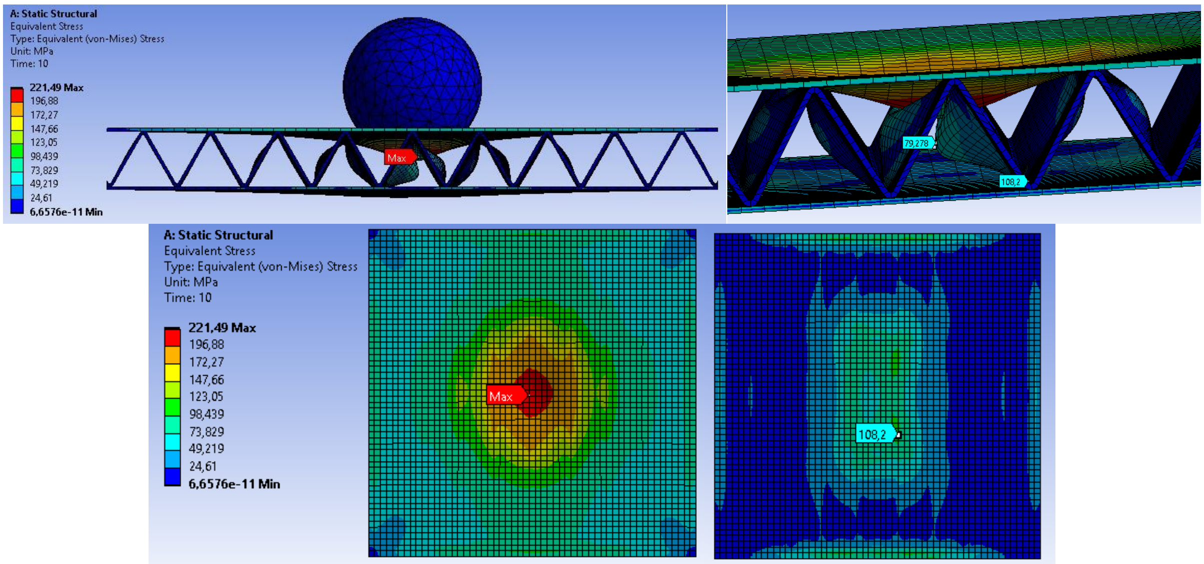

Figure 6. Von-Mises stress distribution of triangle corrugated core sandwich panel

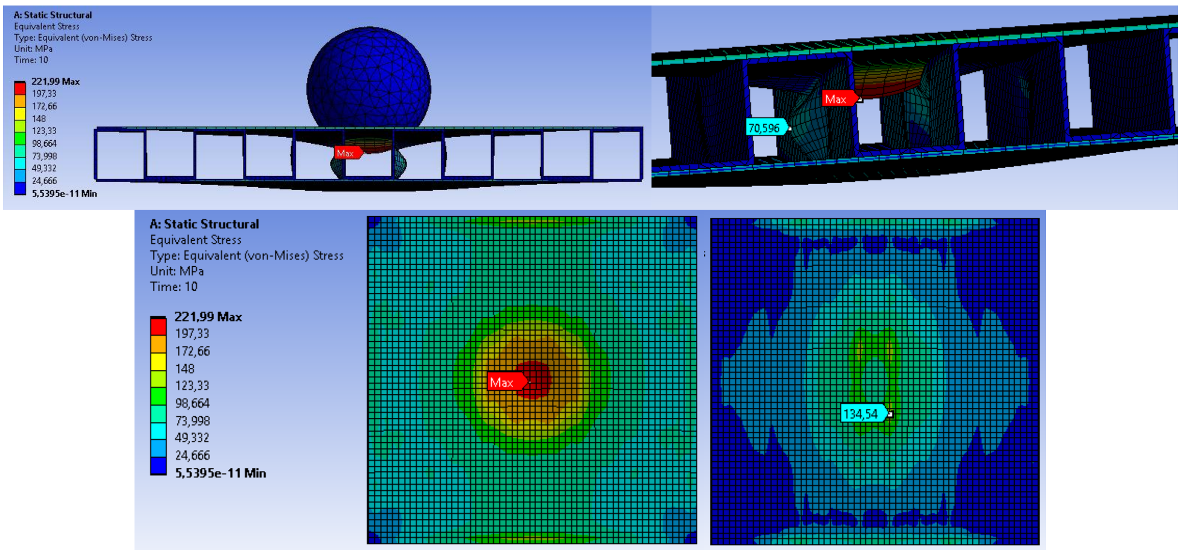

Figure 7. Von-Mises stress distribution of square corrugated core sandwich panel

In the sandwich panel with a triangular core, the maximum stress of 221.49 MPa occurs on the aluminum upper surface. On the lower surface of the panel, the stress is at the level of 108 MPa. The maximum stress formed in the triangular core is around 79 MPa (Figure 6). In the sandwich panel with a square core, the maximum stress of 221.99 MPa occurs on the aluminum upper surface. On the lower surface of the panel, the stress is at the level of 134 MPa. The maximum stress formed in the square core is around 70 MPa (Figure 7). The stress of 220 MPa occurs on the aluminum upper surface of the panel with a honeycomb core, while the stress of 86 MPa occurs on the lower surface. The highest stress formed in the honeycomb core is at the level of 76 MPa (Figure 8).

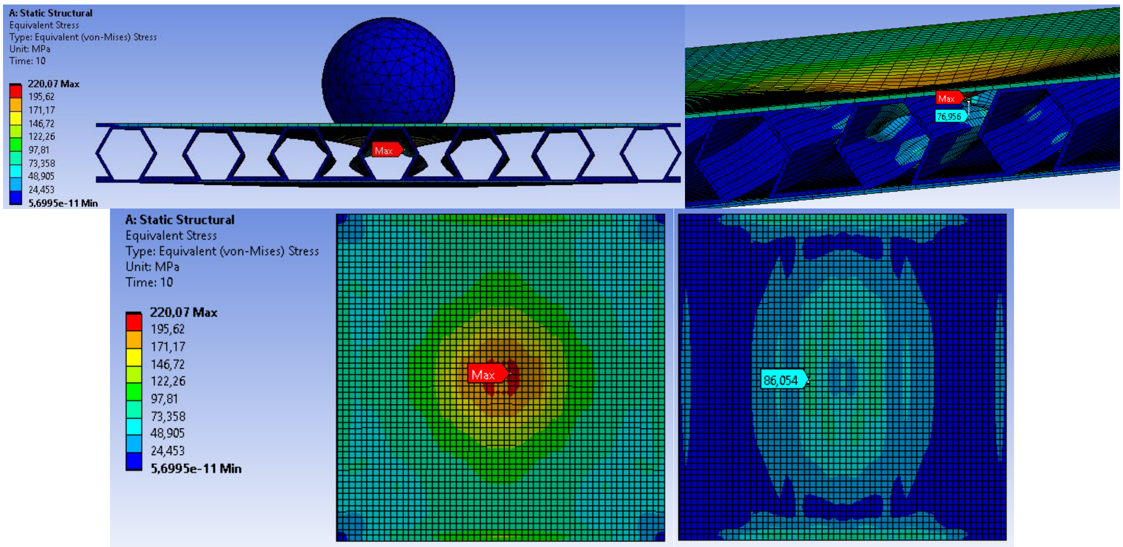

Figure 8. Von-Mises stress distribution of honeycomb corrugated core sandwich panel

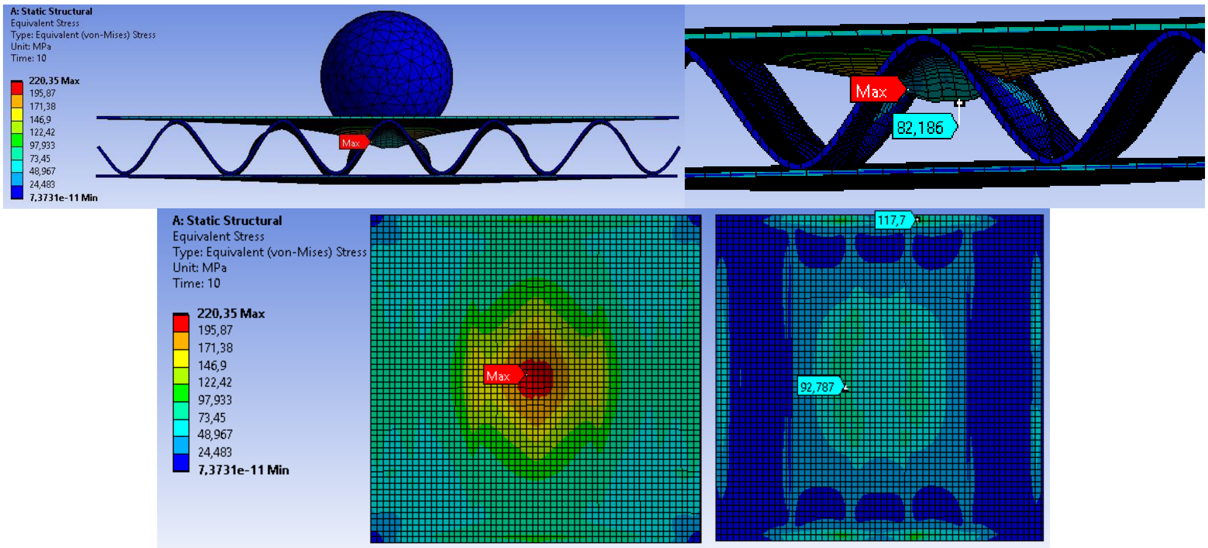

Figure 9. Von-Mises stress distribution of sinus corrugated core sandwich panel

On the other hand, in the sandwich panel with sinus geometry, aluminum is formed at the top surface at a maximum of 220 MPa, and on the lower surface of the panel, the maximum stress of 92 MPa occurs. The stress of 82 MPa occurs in the sinus core.

Finally, when the trapezoid core sandwich panel is examined, the stresses on the upper and lower surfaces of the panel are around 221 MPa and 123 MPa. The maximum stress of 85 MPa occurs in the core (Figure 10).

It is seen that the maximum stress on the upper surface of the aluminium skin in all sandwich panels is around 221 Mpa (Figure 5-10). Since the yield stress of aluminium is 200 MPa, the resulting stress is in the plastic deformation region. But it is to such a degree that it does not cause damage. When all sandwich panels are examined, the stress formed in the aluminum material on the bottom surface of the panel is in the range of 86-135 MPa. The maximum stress formed in the core material is between 65-82 MPa. This stress range is not at a level to cause a fracture in the Pa6 core. Von-Mises stress levels of corrugated core sandwich panels are given Table 3.

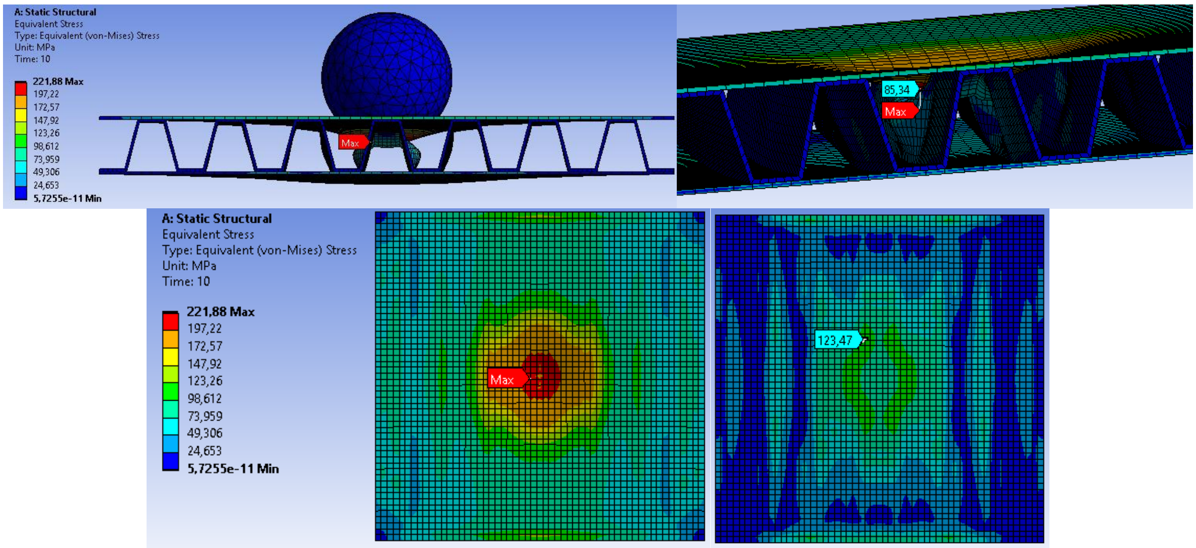

Figure 10. Von-Mises stress distribution of trapeze corrugated core sandwich panel

Table 3. Von-Mises stress levels of corrugated core sandwich panels.

Corrugated core type	Maximum Stress under the spherical mandrel (MPa)	Maximum Von-Mises Stress under the sandwich panel (MPa)
Circle	221.9	88.5
Triangle	221.49	108.2
Square	221.9	134.5
Honeycomb	220.07	86
Sinus	220.3	92.78
Trapeze	221.88	123.4

4. Conclusions

In this study, the deformation behavior of sandwich panels with corrugated cores with different geometries was investigated by finite element analysis. Aluminum alloy is used as the outer skin, and cast polyamide is used as the core. The deformation behavior of the sandwich panels as a result of a 10 mm displacement application by the spherical impactor is listed below.

- As a result of the simulation, it has been observed that the core geometries have a great importance in the deformation behavior of the sandwich panels.
- It has been observed that the load-carrying capacity and energy absorption capacity increase according to the core geometry.
- The trapezoidal core panel provides the highest deformation resistance among other models with its 6363.6 N load carrying capacity and 29.3 J energy absorption capacity.
- The trapezoidal core panel takes first place in terms of specific load-carrying capacity and specific energy absorption capacity.
- The triangular core panel provided the highest load-carrying capacity with 6073 N after the trapezoidal core panel.
- Circular core sandwich panel showed the lowest load carrying capacity and energy absorption capacity.
- The specific load-carrying capacity of the trapezoidal core panel is approximately 1.42 times higher than that of the circular core panel. Likewise, its specific absorbed energy is 1.62 times higher than the circular core panel too.

Authors' Contributions

CK and SE designed the structure. SE carried out the numerical work. CK and SE wrote up the article. Both authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

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