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Experimental and Numerical Investigation of the Effect of Blast Loading on Sandwich Structures with Metallic Lattice

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Abstract

Sandwich structures with metallic lattice cores, due to their lightweight and high strength, are widely used in aerospace, automotive, and dynamic load-resistant applications. In this research, the effect of blast loading on sandwich structures with trapezoidal and triangular lattice cores has been investigated both experimentally and numerically. Experimental tests were conducted using the free-air explosion method, and the mechanical response of these structures, including deformation and energy absorption, was analyzed. For numerical simulation, Abaqus software and the CONWEP method were employed to model the blast effects. The results indicate that the geometry of the lattice core significantly influences the mechanical behavior of the sandwich structure. Trapezoidal and triangular lattice cores exhibit nearly similar behavior in terms of energy absorption and back face sheet deflection under blast loading. A comparison of experimental and numerical data demonstrates the high accuracy of the numerical model in predicting the structural response. The findings of this research can be utilized in the optimal design of blast-resistant structures.

Keywords: Free-air explosion; Sandwich Panel; Trapezoidal lattice core; Triangular lattice core; CONWEP method

1. Introduction

Sandwich structures with metallic lattice cores are extensively used in various industries such as aerospace, automotive, and blast-resistant structures due to their high strength-to-weight ratio, excellent energy absorption capacity, and desirable mechanical performance. These structures consist of two thin and stiff face sheets reinforced by a lattice core. An optimized core design plays a key role in enhancing the mechanical behavior and energy absorption capacity of the structure. In operational environments, sandwich structures may be subjected to blast loads resulting from military threats, terrorist attacks, or industrial accidents. Investigating the performance of these structures under blast loading can contribute to the design and development of more blast-resistant structures.

In recent years, extensive research has been conducted on sandwich structures under dynamic loads. Some of the most notable studies in this field are summarized below:

Khandanabi et al. [1] experimentally and numerically studied the effect of core and face-sheet thickness in sandwich panels with foam cores and aluminum face sheets under blast loading. Their study involved preparing polyurethane foams of different thicknesses and fabricating sandwich panels using aluminum sheets and polyurethane foam cores. Using a shock tube apparatus and conducting a series of targeted blast tests, they investigated the effect of foam thickness on the back-face displacement and energy absorption of the sandwich structure.

Hossein Khodarahmi et al. [2] conducted an experimental and numerical investigation into the energy absorption capability of sandwich structures with a polyurethane foam core reinforced with scoria under blast loading. This paper studied the deformation and energy absorption of sandwich structures with aluminum and steel face sheets and a core made of polyurethane foam filled with two types of scoria of different sizes (termed pea-sized and almond-sized) under free-air blast loading, using experimental methods and numerical simulation via the ABAQUS finite element software.

Mostafa Sayah Badakhor et al. [3] examined the effect of explosive charge stand-off distance on the deformation of circular metal plates. This paper presents an experimental study and regression analysis of the dynamic response of metal plates under blast loading.

Mahmoud Kafash Mirza Rahim et al. [4] experimentally investigated the mechanical behavior of a composite core made of polyurethane foam and scoria for use in sandwich plates as blast energy absorbers. This paper introduces a new type of sandwich plate for blast energy absorption and studies it experimentally.

Mohammad Solooki [5] studied the numerical modeling of sandwich panels with different face sheets and graded cores under blast impact. This research numerically investigated the failure modes and deformation of sandwich panels subjected to blast impacts and compared the results with experimental data.

In this paper, the effect of blast loading on sandwich structures with trapezoidal and triangular corrugated cores is investigated experimentally and numerically. Experimental tests were conducted using free-air blast methods, and for the numerical analysis, ABAQUS software with the CONWEP method was used to simulate blast effects. The aim of this research is to study the influence of the core geometry on the mechanical behavior, energy absorption, and back-face deflection of the sandwich panels under blast loading. Comparing the numerical and experimental results helps evaluate the accuracy of the numerical modeling in predicting the dynamic response of the structure. The findings of this research can serve as a basis for the optimal design of blast-resistant structures. In the experimental method, 30 grams of C4 explosive were used at a stand-off distance of 10 cm from the target.

2. Experimental Investigation

The free-air explosion experimental method is a common technique for studying the effects of blast loading on structures, in which the explosive is detonated in an open environment without lateral confinement. In this method, test specimens are placed at a specified distance from the blast center to be subjected to the resulting shock waves. This approach allows for the examination of structural behavior under realistic conditions, free from the reflective effects of confining walls.

In this research, the face sheets of the sandwich panel were fabricated from 1-mm-thick ST12 cold-rolled steel sheets. Furthermore, two types of corrugated cores were used: trapezoidal and triangular. The cores were prepared from 0.5-mm-thick ST12 cold-rolled steel sheets. The dimensions of the trapezoidal corrugated core are shown in Figure 1.

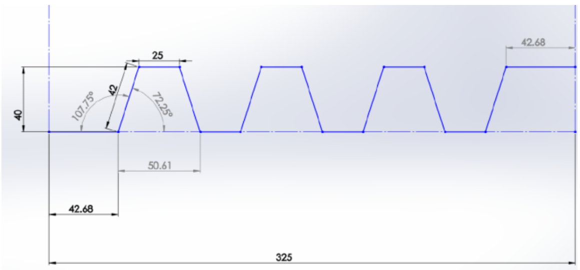

Figure 1. Dimensions of the trapezoidal corrugated core

Similarly, the dimensions of the triangular corrugated core are shown in Figure 2.

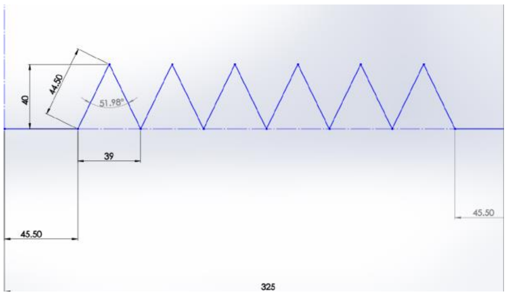

Figure 2. Dimensions of the triangular corrugated core

In the experimental test of the sandwich panel with the triangular corrugated core, since it was not feasible to drill holes into the core for fastening bolts, a 20-cm-diameter circular section from the center of the core was cut out. This section was then placed inside a 4-cm-thick wooden mold, corresponding to the height of the core (Figure 3).

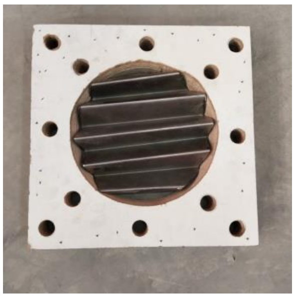

Figure 3. Triangular core placed inside the wooden mold

The thickness of both sandwich panel structures with triangular and trapezoidal cores is identical. The total thickness of each sandwich panel is 42 mm, which remains constant in all numerical analyses.

The explosive material used in the experimental blast tests consists of 30 grams of C4, placed at a distance of 10 cm from the target. This study investigates the effects of explosive mass, standoff distance, core sheet thickness, and the material properties of the face sheets and core on the numerical analysis results. An electric detonator was employed to initiate the explosive.

After fabrication, the sandwich panel structure is securely fastened to a specially designed stand using high-strength bolts and nuts (Figure 4).

Figure 4. Sandwich panel constrained onto the stand

3. Numerical Simulation

In this research, the CONWEP method in Abaqus software was used to simulate the effects of blast loading on sandwich structures. This method is an empirical model for applying blast loads that simulates the effects of shock waves from explosions on the structure without the need to directly model the air environment. In this model, the blast wave pressure is determined as a function of distance, explosive mass, and environmental conditions, and is applied to the structure's surface. In the software, the equivalent pressure is input through the equivalent TNT mass. Since Abaqus software only uses the properties of TNT explosive, other explosives must be converted to TNT using conversion factors. In the experimental tests, 30 grams of C4 explosive were used, which has a TNT conversion factor of 1.34. Therefore, in Abaqus software, the equivalent TNT mass should be entered as 40.2 grams.

The mechanical properties of materials play a crucial role in the final response, and the influence of these parameters on the accuracy of the results obtained from numerical simulation is significant. In this study, the Johnson-Cook model was employed as a suitable constitutive model for simulating the plastic deformation of the metallic components of the sandwich structure under blast loading. The mechanical properties of the metals used in this research, along with their Johnson-Cook parameters, are presented in Table 1.

Table 1. Mechanical properties of the metals used

Material Property	Symbol	ST37 Steel	ST12 Steel	1050 Aluminum
Density (kg/m³)	ρ	7890	7850	2700
Young's Modulus (GPa)	E	200	208	71
Poisson's Ratio	ν	0.3	0.29	0.33
Yield Stress Parameters (MPa)	A	350	175	110
	B	275	380	150
	n	0.36	0.33	0.36
Strain Hardening Parameters	$\dot{\varepsilon}_0$ (1/s)	1	1	1
	C	0.12	0.06	0.014
Temperature Parameters	T_0 (K)	293	293	293
	T_melt (K)	1811	1809	918
	m	1	1	1

In the sandwich panel with a metallic corrugated core, due to its geometry, the core has only one plane of symmetry. Consequently, the numerical simulation is performed on half of the model. The boundary conditions for the outer edges of the sandwich panel are considered fully fixed in all directions. A symmetry boundary condition is also applied to the symmetry plane. To simulate the contact between different parts of the numerical model, a general contact interaction without a friction coefficient was used in the software.

In the numerical analysis of sandwich structures under blast loading, appropriate meshing plays a fundamental role in the accuracy of the results. The selection of element type and size must be such that it can correctly simulate the dynamic behavior of the structure, including stress wave propagation and large deformations. In summary, the face sheet elements were chosen as 8-node linear brick elements (C3D8R), while the core elements were selected as 4-node quadrilateral shell elements (S4R). Investigating the mesh independence of the solution is an essential part of numerical analysis, which has been carried out. Based on the results, an element size of 2 mm is suitable for both structures.

4. Experimental and Numerical Results

This section presents the results of the experimental tests and numerical analysis of the sandwich panel under blast loading. After validating the numerical analysis results against the experimental test data, various parameters are investigated. These include the influence of explosive mass, the effect of changing the material of the face sheets and core, the standoff distance of the explosive from the target, and the impact of the corrugated core thickness on the blast loading response of the sandwich panel.

A comparison between the numerical analysis and experimental test results shows good agreement. A detailed examination of the results, including the deformation of the front and back face sheets and energy absorption, is comprehensively provided in the full paper.

5. Conclusion

This research investigated the effects of blast loading on the deflection behavior of sandwich panels with two types of corrugated cores—trapezoidal and triangular—using both experimental and numerical simulation methods. A comparison between the numerical analysis results and the experimental test data showed good agreement. The experimental results demonstrated that metallic corrugated cores are suitable under blast loading, as the displacement of the sandwich panel's back face sheet is less than that of the front face sheet, and the cores exhibit good energy absorption capabilities.

The findings from the analysis of the face sheets under various conditions can be summarized as follows:

1. In all analyses, for all core types, an increase in the explosive charge mass leads to an increase in the back face deflection.
2. In all analyses, for all core types, increasing the standoff distance between the explosive and the target results in a significant reduction in back face deflection.
3. For sandwich panels with metallic corrugated cores, changing the face sheet material from steel to aluminum adversely affects the displacement of both the front and back face sheets.
4. For sandwich panels with corrugated cores, changing the core material from ST12 steel to AL1050 aluminum has a favorable effect, reducing the displacement of the back face sheet.
5. For sandwich panels with corrugated cores, changing the material of the entire panel (both face sheets and core) from steel to aluminum has a highly detrimental effect on the displacement of both the front and back face sheets.
6. The energy absorption of the trapezoidal core is greater than that of the triangular core.
7. Since the displacement of the back face sheet is critically important, the trapezoidal corrugated core performs better than the triangular core.

6. References

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