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INTERACTION MECHANISM OF HONEYCOMB SANDWICH PANELS UNDER IMPACT LOADING

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1. INTRODUCTION

Owing to the increasing development in automotive, transportation and aeronautics engineering, analyzing the energy absorption capacity in structures has become an important field of research [1]. Sandwich panels are one of the most important types of energy absorbers which can be defined as constructions which have light and complex structure with two limited plates on both sides and a light thick core made of different materials as well as several shapes in the middle of structure [2]. They are high-strength and low-weight structures with a wide variety due to the geometrical shape and material type of their core. Despite the remarkable lightness of them, these panels have great resistance against all types of pressure and impact loading [3].

In this paper, numerical studies of impact loading on the sandwich panels with the foam filled honeycomb core and unfilled honeycomb core have been conducted. The structural elements used in this research were aluminum plate, aluminum 5052 honeycomb structure, and polyurethane foam which honeycomb cores were filled with this foam. Numerical modelling and analysis of high velocity penetration process was carried out by a nonlinear explicit finite element code, LS-DYNA. The impact loading was simulated and analyzed on unfilled and foam filled sandwich panels by flat ended projectile. In addition, the destruction mechanisms and damage modes, the ballistic limit velocities and the energy absorption were studied. Also, the effect of foam filling on impact loading response of the honeycomb sandwich panels was discussed. The results of numerical simulation are compared with impact loading experiments.

2. MATERIALS

Aluminum Plate

The aluminum plate used in this project was 1200 Arak with 0.5 mm thickness. This aluminum plate was subjected to tensile measurement according to the ASTM E8M-04. The test results are, E=76 GPa, σ_y=131.33 MPa, σ_u=133 MPa, ϵ_u=0.08 and ρ=2637 kg/m^3.

Honeycomb Structure

The honeycomb structure was constructed by 5052-H38 aluminum with corrugated process. The properties of 5052-H38 aluminum are, E=70 GPa, σ_y=255 MPa, σ_u=290 MPa, τ_u=165 MPa, ν=0.3 and ρ=2680 kg/m^3.

Polyurethane Foam

Commercially available closed-cell polyurethane foam (SKC501) was utilized in the current study. The apparent density of polyurethane foam which is selected for filling of honeycomb panel is 137.13 kg/m^3. Density of foam is determined based on ASTM D1622 standard.

3. NUMERICAL ANALYSIS

In this study, the numerical analysis was carried out by a nonlinear explicit finite element code, LS-DYNA. Also, the geometric modeling consists of two parts; first the projectile, second the target and its components. The modelled projectile was rigid and flat-ended cylinder with 15 mm length and 10 mm diameter. The projectile was modeled with 8 node solid elements. The modelled aluminum skins were 75×75 mm^2 with 0.5 mm thickness. The aluminum skins were modeled with 4 node shell elements. The modelled honeycomb structure was 75×75×19.15 mm^3 and the geometry of a cell is demonstrated Fig. 1. The honeycomb structure was modeled with 4 node shell elements. The polyurethane foam was modeled with 8 node solid elements. Material model 20 (*MAT_RIGID) was chosen for projectile. Aluminum skins, aluminum honeycomb structure and polyurethane foam were modeled with material model 3 (*MAT_PLASTIC_KINEMATIC), material model 3 (*MAT_PLASTIC_KINEMATIC) and Material model 63 (*MAT_CRUSHABLE_FOAM) respectively.

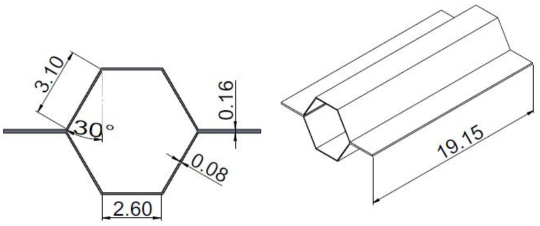

Fig. 1: The geometry and dimension of a honeycomb cell (all dimensions are in mm) [4].

4. RESULTS AND DISCUSSION

Process of Destruction

According to Fig. 2(a), the numerical analysis of perforation in the honeycomb structure was similar to that observed in experimental tests. The projectile, after colliding with upper of the honeycomb structure, created a stress wave and began to damage the structure. Because of the lattice structure and the adhesive bonding between the walls of each cell, the entire structure was resilient; this condition was completely visible in the numerical analysis at lower velocities than the ballistic limit velocity. At higher velocities than the ballistic limit velocity, the projectile passed through the target, compressed the honeycomb core and finally caused to cut and crumple the projectile surrounding cells.

In the numerical analyses of the unfilled honeycomb sandwich panel, at first step, the projectile perforated aluminum skin and formed a plug on it. Then, a local debonding happened between aluminum skin and core due to the projectile high velocity. Subsequently, the projectile along with the plug and the damaged parts of core exited from the rear aluminum skin and formed petals. Fig. 2(b) shows that the asymmetric petal shape of unfilled sandwich panel in both experimental and numerical analyses were similar to each other.

Fig. 2(c) shows the cut out view of the sandwich panel filled with foam. The destruction steps of the foam filled sandwich structure resembled unfilled ones with the difference that the foam was increased the strength of core. The destruction of the core led to a large local debonding between the core and the rear skin, which was completely visible in both experimental and numerical modes.

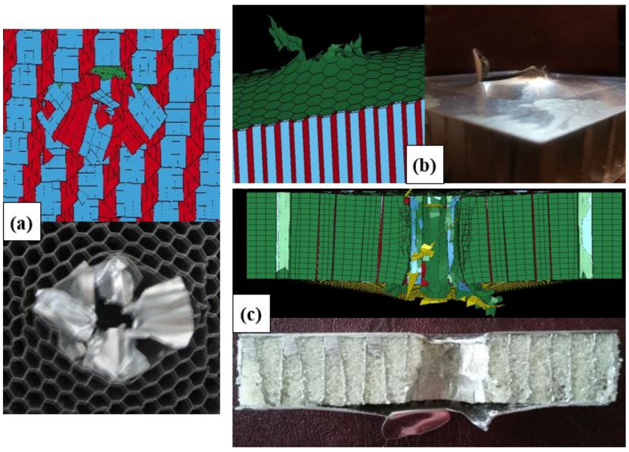

Fig. 2: The specimens (a) Honeycomb structure, (b) Unfilled honeycomb sandwich panel (c) Foam filled honeycomb sandwich panel.

Ballistic Limit Velocity

According to Table 1, the ballistic limit velocities of the numerical findings were in good agreement with experimental data. Obviously, the ballistic limit velocities of foam filled sandwich panel is more than unfilled ones. This is due to the interaction effect among the aluminum skins, the honeycomb core and the polyurethane foam.

The Absorbed Energy Corresponding to the Ballistic Limit

Using the ballistic limit velocity and the projectile mass, the ballistic energy is calculated from the kinetic energy of projectile ($E = mv^2 / 2$).

The numerical and experimental absorbed energy of each structure is given in Fig. 3. The interaction between foam and honeycomb structure as well as the interaction between foam and face sheets caused the significant increase in energy absorption and strength of the sandwich panel. Accordingly, foam filled sandwich structure as one of the suitable energy-absorbing structures could be proposed in various industries.

Table 1: Results of ballistic limit velocity of the specimens.

Specimens	Numerical Ballistic limit velocity (m/s)	percentage change with respect to honeycomb structure (numerically)	experimental Ballistic limit velocity (m/s)	percentage change with respect to honeycomb structure (experimentally)
Honeycomb structure	45.38	-	50.50	-
Sandwich panel with unfilled honeycomb core	63.11	39	72.75	44
Sandwich panel filled with foam	82.00	82	98.25	95

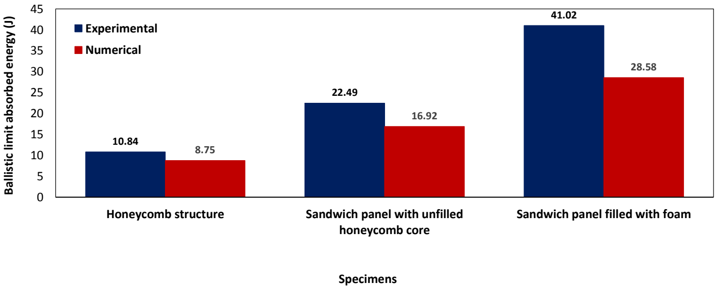

Fig. 3: Comparison of the energy absorption for each specimen.

5. CONCLUSIONS

In this study, the effect of polyurethane foam as filler material in the honeycomb structure used in the sandwich panel was investigated numerically. The results of numerical simulation are compared with impact loading experiments. This research is about the ballistic limit conditions under impact loading. Ballistic limit velocity, destruction shape and ballistic limit energy absorption in sandwich structures with unfilled and foam filled honeycomb core were obtained. The results of this research are as follows:

The dynamic strength of sandwich structure was increased using the polyurethane foam. The absorbed energy of foam filled sandwich panels would be enhanced by increasing the foam density. Indeed, the interaction effect between foam and honeycomb core, as well as the interaction between aluminum skins and foam, enhanced the energy absorption considerably.

Comparison of the unfilled and foam filled sandwich panels with honeycomb structure indicates that the numerical ballistic limit velocity of unfilled and foam filled sandwich panels are 39% and 82% more than honeycomb structure, respectively.

Comparison of the unfilled and foam filled sandwich panels with honeycomb structure indicates that the experimental ballistic limit velocity of unfilled and foam filled sandwich panels are 44% and 95% more than honeycomb structure, respectively.

The difference between the amount of experimental and numerical energy absorption related to honeycomb structure, unfilled and foam filled sandwich panels are 19%, 25%, and 30%, respectively.

Using foams and honeycomb structures each alone causes some limitations that make their using scope less than when they are utilized together. In this study, it was found that combining these two materials together results in produce of structures with superior properties and resistance.

REFERENCES

[1] A. Niknejad et al., “Experimental study of Poly-orthan foam filler on hexagonal honeycomb structure behavior under axial load with constant rate”, *10th Iran Aerospace Conference, AERO2011, Tarbiat Modares University*: 2011.
[2] A. Petras, “Design of sandwich structures. Diss. University of Cambridge”, 1999.
[3] YS. Tian et al., “Optimal design of compression corrugated panels”, *Thin-walled structures*, 2005; 43: pp. 477-498.
[4] F. Hassanpour Roudbeneh et al., “Experimental investigation of impact loading on honeycomb sandwich panels filled with foam”, *International Journal of Crashworthiness*, 2018; ISSN: 1358-8265: pp. 1-12.