



# Experimental Study of Structure Parameters' Influence on SPAH Mechanical Properties

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**Abstract.** This paper focuses on the steel plate-honeycomb sandwich structure, combining static experiments, theoretical analysis, and observations of deformation phenomena during composite structure experiments to study the impact of different parameters on the mechanical properties of the composite structure. The main work includes: investigating the effects of variable parameters such as core size, specimen thickness, and cross-sectional area on related stress and deformation curves before and after filling with polyurethane; analyzing the mechanical performance and energy absorption characteristics under various working conditions; providing theoretical guidance and technical support for the application of composite structures in protective engineering fields.

**Keywords:** steel plate-aluminum honeycomb (SPAH); polyurethane; aperture size; specimen thickness

## 1 Introduction

Honeycomb aluminum is light quality, high specific strength, large stiffness<sup>[1-4]</sup>, is an efficient buffer energy absorption material<sup>[5-8]</sup>, is also a recycling ideal environmental protection material<sup>[9-10]</sup>; polyurethane material is relatively small density, shock absorption<sup>[11]</sup>, silencing, easy processing, rust resistance, impact resistance<sup>[12-13]</sup> and other excellent characteristics, is the protection engineering has a wide application prospect. In this paper, polyurethane foam material is selected as the sandwich filling material and added to the honeycomb aluminum plate as a steel plate structure. Using the good bonding curing characteristics of polyurethane foam at room temperature, the honeycomb sandwich structure and steel plate are bonded together to form the steel plate-aluminum honeycomb (SPAH) sandwich composite structure, and study the mechanical behavior and energy absorption characteristics of the structure through tests.

## 2 Composite Structure Materials and the Preparation Process

In the SPAH sandwich structure, the steel plate should adopt 3mm thick Q235 ordinary carbon steel. Through the semi-automatic cutting machine, cut the whole steel plate to a square size of 50mm, 70mm, 100mm and 120mm. After cutting, repeatedly polish the front and back of each steel plate with sandpaper to remove the rust spots on the surface and ensure the smooth surface. The experimental air core honeycomb aluminum material is domestic 5052H9 aluminum foil, which is characterized by good pressure resistance, low density, high accuracy, high flatness and strong shear resistance. Four different specifications of honeycomb aluminum plate: thickness 30mm, aperture 3mm; thickness 60mm, pore diameter 8mm; thickness 90mm, aperture 8mm; thickness 120mm, aperture 8mm. The specimen is designed according to the area of steel plate and the number of aperture. The square steel plate size of 50mm is 7; side length of 70mm test is 14,3 holes and 4 holes are 4 rows; 100mm test is 30,5 holes, 6 rows; side length of 120mm is 42,6 holes, 7 rows. The area of each honeycomb hole was calculated according to the size of the steel plate, and the area of each honeycomb hole was 357mm<sup>2</sup>, 350mm<sup>2</sup>, 333mm<sup>2</sup>, and 342mm<sup>2</sup>, respectively. The polyurethane foam from left to right, from top to bottom, S uniform spraying on the honeycomb core surface, the polyurethane foam into the honeycomb core with steel plate, according to this operation again for spraying, pressure, three to four times, the lower surface of the honeycomb core polyurethane foam overflow, that the internal space of the honeycomb core has been filled with polyurethane foam. Weigh the polyurethane honeycomb aluminum specimens, compare the weight before and after filling, and ensure that the data measured in Table 1.

**Table 1.** Test piece numbers and parameter values

Experiment number	Thickness/mm	cross-sectional area/mm <sup>2</sup>	Aperture/mm
A1	30	100×100	3
A2	30	100×100	8
A3	60	100×100	8
A4	90	70×70	8
A5	90	100×100	8
A6	90	120×120	8
A7	120	100×100	8
B1	30	100×100	3
B2	30	100×100	8
B3	60	100×100	8
B4	90	70×70	8
B5	90	100×100	8
B6	90	120×120	8
B7	120	100×100	8
Experiment number	Specimen material	Weight/g	filling rate
A1	SPAH	21.1	-

A2	SPAH	8.4	-
A3	SPAH	16.5	-
A4	SPAH	13.2	-
A5	SPAH	25.6	-
A6	SPAH	29.4	-
A7	SPAH	34.2	-
B1	SPAH filling polyurethane	43.5	51.49%
B2	SPAH filling polyurethane	22.3	62.33%
B3	SPAH filling polyurethane	42.2	60.91%
B4	SPAH filling polyurethane	32.8	59.75%
B5	SPAH filling polyurethane	57.9	55.78%
B6	SPAH filling polyurethane	89.2	67.11%
B7	SPAH filling polyurethane	80.9	57.72%

The weighing results show that the ratio of the mass after filling polyurethane to the mass before filling is about 2.3 to 2.5, indicating that the filling degree of polyurethane of each specimen is similar, and there is no case that the filling degree of individual specimens differently from that of other specimens. Combined with the test results of transverse cutting method and longitudinal cutting method, it can better indicate that the specimens made through this process have high filling degree and meet the requirements of the experiment. Figure 1 shows the components of the experimental specimen and the finished product pictures respectively.

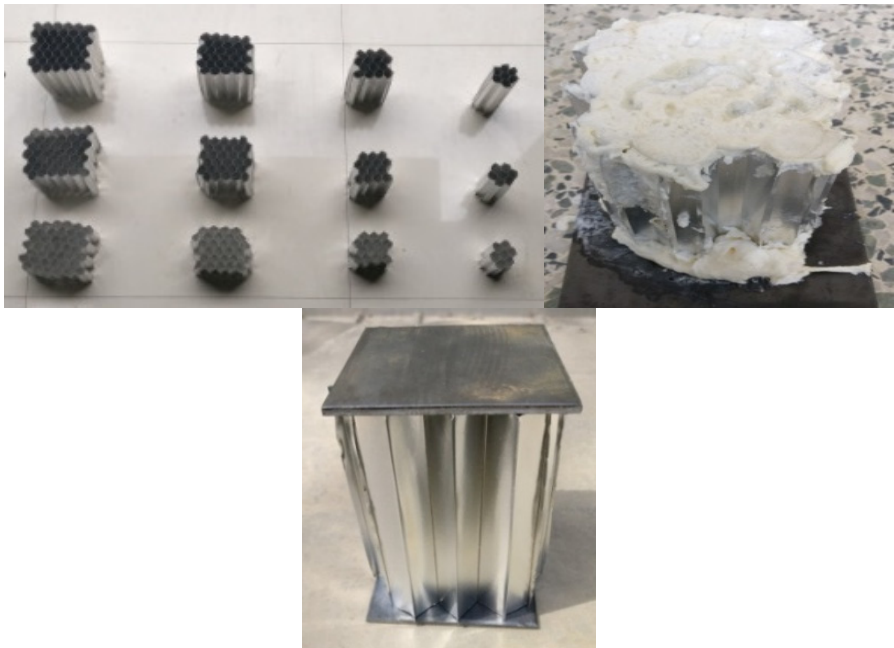


Fig. 1. Specimen components and finished product diagram

### 3 Factors Affecting the Mechanical Properties of Steel Plate-Honeycomb Aluminum Structure

In order to study the mechanical properties of the steel plate-honeycomb sandwich structure under axial static load, the aperture, the thickness of the structural specimen and the sectional area, and the influence of each condition on the mechanical properties of the structure were analyzed.

#### 3.1 Analysis of the Influence of Aperture Size on Mechanical Properties

Groups A1 and A2 are steel plate-honeycomb aluminum specimens with pore diameter of 3mm and 8mm and the same thickness and cross-sectional area respectively. Figure 2 shows the stress-strain curves of these two specimens at the compression speed of 0.3 mm/s. It can be seen that the stress value of A1 group under the same strain is greater than that of A2 group, that is, the peak stress and plastic collapse stress of 3mm small aperture honeycomb structure are greater than 8mm large aperture honeycomb structure. Among them, the first peak stress of group A1 is 1.182MPa, the average plastic collapse stress is 1.143MPa, the plastic collapse stage accounts for 71% of the whole process; the first peak stress of group A2 is 0.354MPa, the average plastic collapse stress is 0.242MPa, and the plastic collapse stage accounts for 79% of the whole process

From the experimental data, the peak stress and plastic collapse stress A1 group, there is no obvious peak shape on the stress-strain curve, analysis that A1 group test before plastic buckling, namely the online elastic deformation stage test whole has instability and lost bearing capacity, there is no obvious plastic stage, as shown in Figure 2. The reason for this deformation mode is that the small aperture steel plate-honeycomb aluminum composite structure density is large, the number of honeycomb holes contained in the same size material is large, the stiffness of the structure increases, the integrity is enhanced, the force capacity is improved, but the ability of plastic deformation is reduced. Therefore, there is no inelastic buckling in the 3mm small aperture steel plate-honeycomb aluminum composite structure, and it directly enters the plastic collapse stage from the linear elastic deformation stage.

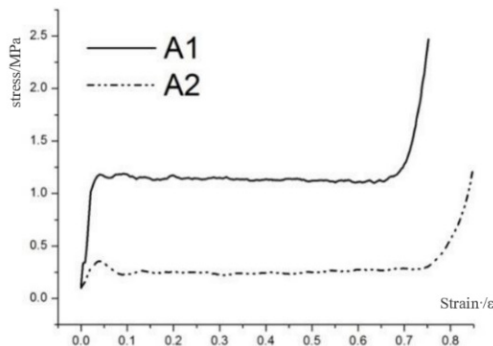


Fig. 2. Stress-strain curves of specimens with different pore sizes before filling

The linear elastic deformation stage and inelastic flexion stage of group A2 specimen are very obvious, which belongs to the typical static compression process of honeycomb aluminum, as shown in Figure 3-5. The proportion of plastic collapse stage is larger than that of A1 group, indicating that the large aperture honeycomb structure reaches the compaction stage late and the energy absorption time is long. The results of the above two groups of experiments show that the influence of the aperture size on the mechanical properties of the structure is very obvious, as the compression ability and yield strength of the steel plate and honeycomb aluminum composite structure decreases, and the honeycomb aluminum structure of the small aperture shows the deformation failure mode of directly entering the plastic collapse stage from the linear elastic deformation stage.

### 3.2 Analysis of the Influence of Specimen Thickness on Static Mechanical Properties

Groups A3, A5 and A7 are steel plate-honeycomb aluminum specimens with thickness of 60mm, 90mm and 120mm and the same pore diameter and cross-sectional area. Figure 3 shows the morphological change diagram of these three groups of specimens at the same compression speed.

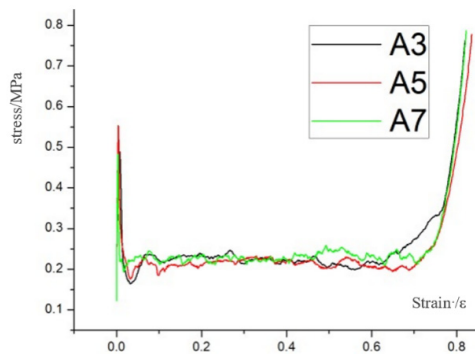


Fig. 3. Stress-strain curves of specimens with different cross-sectional thicknesses before filling

Groups A3, A5 and A7 have the same pore diameter and cross-sectional area, with thickness of 60mm, 90mm and 120mm-stress-strain curve is about 0.55MPa and 0.22MPa, respectively. It is concluded that the thickness of honeycomb structure has little influence on stress strain under quasi-static uniaxial compression load.

### 3.3 Analysis of the Influence of the Cross-Sectional Area on the Static Mechanical Properties

Group A4, A5 and A6 specimens are steel plate-honeycomb aluminum specimens with the same cross-sectional area of 702mm, 902mm, 1202mm, pore size and thickness. Figure 4 shows the experimental force-displacement curve and the corresponding

stress-strain curve of the three specimens at the same compression speed. From the experimental force-displacement curve, the yield stress of the specimen decreases as the cross-sectional area increases. Because of the increase of cross-sectional area, the number of honeycomb increases, the pressure per unit area is bound to reduce, which is the general rule of materials. The stress-strain curve was obtained by treating the experimental force-displacement curve, which shows the stress peak and the minimum platform area stress in group A4 specimen, and A5 group was slightly less than A6 group. The peak stress size is successively: A6(0.562MPa)(A5(0.553MPa)(A4(0.387MPa). In terms of the difference, the A5 and A6 groups were almost the same, and the peak difference between the A4 and A6 groups was 43.4% of the A4 group. Therefore, the cross-sectional area has a certain impact on the compressive ability of the specimen, that is, the compressive capacity increases with the increase of the cross-sectional area, and the peak stress and platform stress also increase.

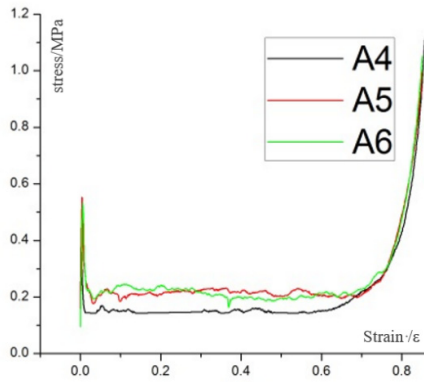


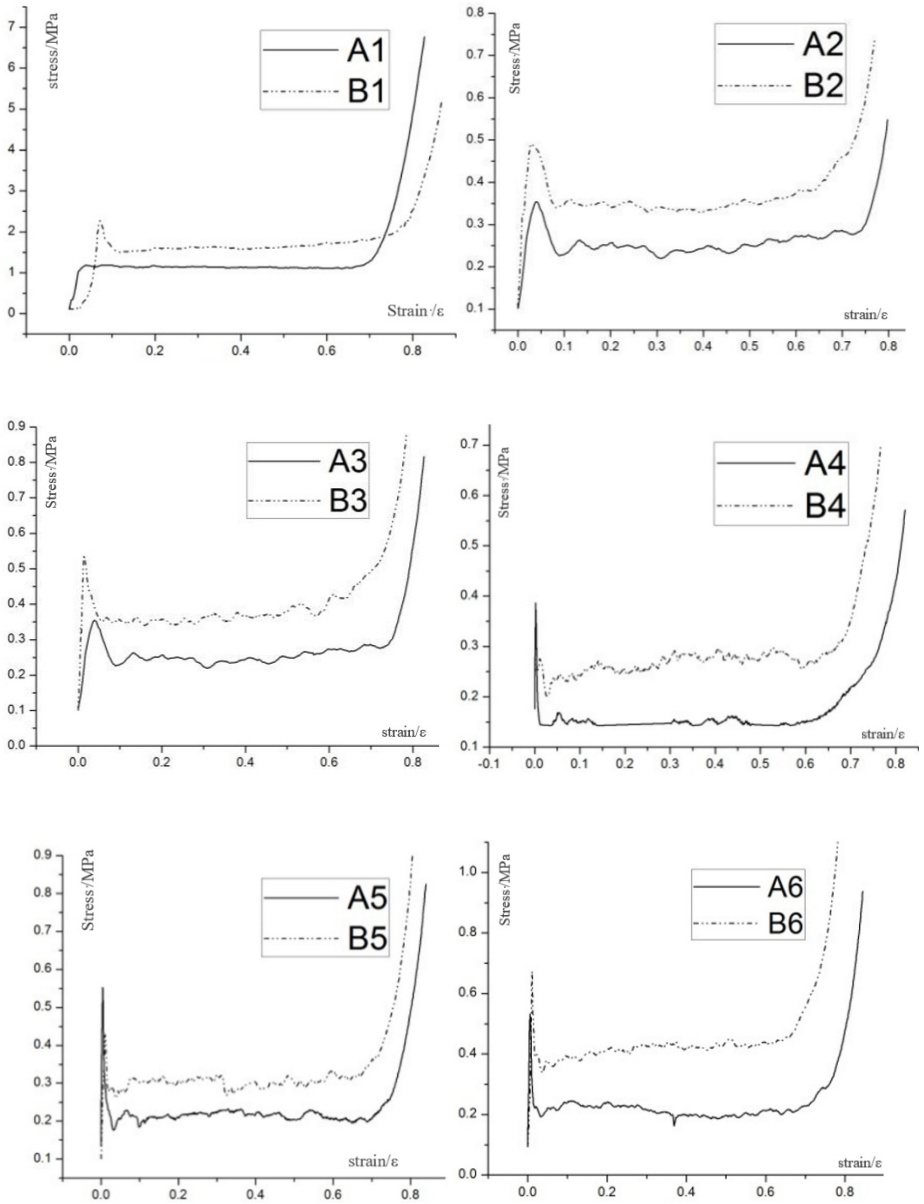
Fig. 4. Stress-strain curves of specimens with different cross-sectional areas before filling

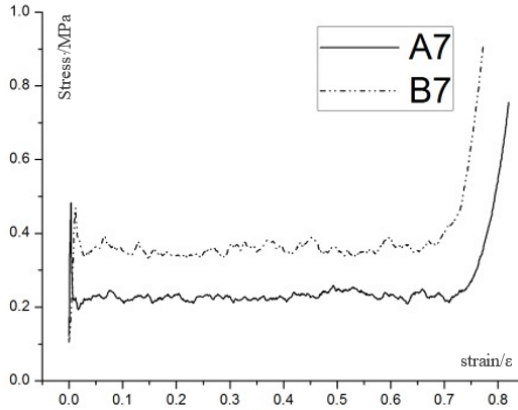
### 3.4 Comparison of the Mechanical Properties Before and After Polyurethane Filling

Figure 5 is the stress-strain curve of seven different specification specimens (including aperture, thickness, cross-sectional area) before filling (group A) and filling (group B), obviously, the steel-honeycomb sandwich structure after filling polyurethane, peak stress, plastic collapse stress, yield stress, compressive strength are much higher than before filling, the increase is slightly different. Among them, the stress value of A1-B1 group increased the least, and the stress value of other groups was about twice the value before filling. Because A1 and B1 are 3mm small aperture and low thickness specimens, the relative density of the specimen itself is larger than that of other specimens. According to the weighing work in the specimen production process, the filling rate of A1-B1 specimens is the least (51.49%), which is about 10% smaller than that of other specimens. In the stress-strain curve, the area Q formed from the transverse axis from

the compression start to the end of the buckling end represents the energy absorption before the failure of the structure. E can be given by the following equation:

$$E = \int_0^{\epsilon_i} \sigma d\epsilon \tag{1}$$





**Fig. 5.** Comparison of stress-strain curves of each group before and after filling with polyurethane

Taking A5 and B5 specimens as examples, the absorption energy of the steel plate honeycomb sandwich structure before and after polyurethane filling by (1) is  $0.18174 \text{ MJ} / \text{m}^3$  and  $0.26449 \text{ MJ} / \text{m}^3$ , respectively. Considering that the pure polyurethane material itself also has a certain energy absorption effect, by testing the pure polyurethane material, the absorption energy of the pure polyurethane material is  $0.01364 \text{ MJ} / \text{m}^3$ . From the perspective of algebraic relationship, the sum of energy absorption of the two materials before filling is  $0.19538 \text{ MJ} / \text{m}^3$ , and the energy absorption size of the steel plate-honeycomb sandwich structure after polyurethane filling is  $0.26449 \text{ MJ} / \text{m}^3$ . By comparison, the energy absorption of the material after filling is 1.35 times that of the sum of the two materials before filling. This shows that the enhancement effect of polyurethane material on the plate-honeycomb sandwich structure is not simply superimposed. After filling with polyurethane material, the structure can be regarded as a whole to play the role of buffer energy absorption. The composite structure has a greater enhancement effect compared with the energy absorption sum of the single material before the composite. From the perspective of mechanical mechanism, the filling of the steel plate-honeycomb sandwich structure greatly strengthens the solid phase characteristics, and improves the stress characteristics of the whole structure (there is a small amount of gas inside the filled polyurethane foam); the stress-strain curve: the inelastic buckling stage decreases, and the stress value of the trough increases before filling, that is, and the stress level corresponding to the buckling platform is increased exponentially. The stress deformation of buckling platform is an important index of structural buffer energy absorption properties. The increased stress of the yield platform indicates that the buffer energy absorption performance of the composite structure is greatly improved. This is the excellent feature of the steel plate-honeycomb sandwich structure filled with polyurethane material as a protective material.

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## 4 Conclusions

Through theoretical analysis and experimental research, in conclusion, the following conclusions can be obtained:

1. The yield stress of the composite structure decreases with the increase of the aperture, cross-sectional area and thickness of the honeycomb sandwich structure, and the energy absorption level decreases correspondingly, with the influence from large to small order: aperture size > cross-sectional area > specimen thickness.
2. The peak stress, plastic collapse stress, yield stress and compressive strength of the steel plate-honeycomb sandwich structure are higher than those before the filling. The corresponding stress of the buckling platform is worth increasing exponentially, and the buffered energy absorption performance is greatly improved.
3. Through the calculation of energy absorption of a single material and composite structure, the algebra sum of energy absorption of composite structure is greater than that of a single material, indicating that the enhancement of composite structure is not a simple superposition, but has a large overall enhancement effect.

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