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Materials

Fabrication and compressive performance of plain carbon steel honeycomb sandwich panels

Yu'an Jing [1,2], *Shiju Guo* [1], *Jingtao Han* [1], *Yufei Zhang* [2], *and Weijuan Li* [2]

1) School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing 100083, China
2) School of Materials Science and Engineering, University of Science and Technology Liaoning, Anshan 114044, China
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Abstract: Plain carbon steel Q215 honeycomb sandwich panels were manufactured by brazing in a vacuum furnace. Their characteristic parameters, including equivalent density, equivalent elastic modulus, and equivalent compressive strength along out-of-plane (z-direction) and in-plane (x- and y-directions), were derived theoretically and then determined experimentally by an 810 material test system. On the basis of the experimental data, the compressive stress-strain curves were given. The results indicate that the measurements of equivalent Young's modulus and initial compressive strength are in good agreement with calculations, and that the maximum compressive strain near to solid can be up to 0.5-0.6 along out-of-plane, 0.6-0.7 along in-plane. The strength-to-density ratio of plain carbon steel honeycomb panels is near to those of Al alloy hexagonal-honeycomb and 304L stainless steel square-honeycomb, but the compressive peak strength is greater than that of Al alloy hexagonal-honeycomb.

Key words: steel honeycomb sandwich; brazing; compressive strength; elastic modulus; stress-strain curve

1. Introduction

The honeycomb structure is a type of cellular materials with a regular and periodic array of hexagonal cells and is composed of two thin, stiff, strong sheets serving as the primary load carrying elements and a thick layer of low density core providing shear resistance and stiffness [1-2]. It has a wide range of applications, such as aerospace, shipbuilding, vehicle, construction, energy absorbers, thermal isolation components, and packaging materials, because of its excellent structural efficiency, *i.e.*, high strength- and stiffness-weight ratio, elimination of welding, superior insulating quality, and design versatility. A number of reports have focused on the development and research of sandwich structures with honeycomb core [3-6]. From those references, current honeycomb matrix materials mainly included polymer composites, aluminum alloys, titanium, stainless steel, and so on. Many kinds of methods are also available to fabricate sandwich panels because of the difference of demands for mechanical properties and use of matrix material, such as adhesive bond, resistance welding, brazing bond, and transient alloys diffusion [7-10].

In general, the adhesive bond is usually used to manufacture honeycomb because of its low cost, but sometimes, the adhesive bond can not meet the demands for strength. Thus, to increase the bond strength, plain carbon steel honeycomb sandwich panels are brazed using Ag72Cu foils, and their compressive characteristics are investigated in this article. The outline of this article is as follows. First, the procedure used to manufacture plain carbon steel regular hexagonal-honeycombs is described. Second, the elastic parameters are derived, and the compressive behavior is experimentally investigated, including relative density, equivalent elastic modulus, and equivalent compressive strength. Finally, the calculated values are compared with the measurements.

2. Manufacturing route

In this study, the regular hexagonal honeycombs were manufactured by brazing in a vacuum furnace, using Q215 plain carbon steel sheets, with a thickness of 0.49 mm. The sheets were cropped into rectangles, widths of 15-25 mm, corresponding to the height of honeycomb panels, and lengths in the range 80-210

Corresponding author: Yu'an Jing, **E-mail:** jyachina@163.com

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mm, corresponding to the width of specimens. The rectangle strips were cold-crimped into corrugated ligaments with cell size a=5 mm by corrugated dies. The corrugated ligaments and the brazing foils were then assembled and clamped tightly to assure stability. The brazing foils were clamped among the corrugated ligaments, the upper and the bottom skinning face. In the vacuum furnace, brazing was carried on with Ag72Cu (wt%) at 830-840 °C for 20 min under 10^{-3}-10^{-2} Pa (as shown in Fig. 1). Capillarity drew the melted braze into the gap at joints, resulting in an excellent bond. The cell size, wall thickness, and relative density of compressive honeycomb specimens manufactured in this study are listed in Table 1.

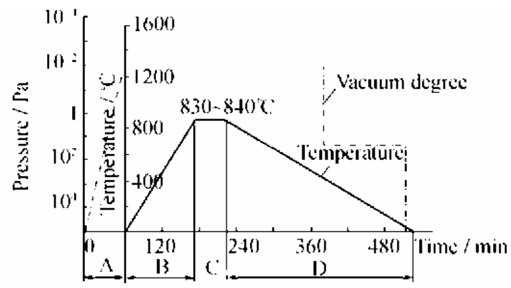

Fig. 1. Temperature and vacuum curves for brazing honeycomb panels: A—pumping time for vacuum; B—heating time; C—holding time for brazing; D—cooling time.

Table 1. Geometry of the regular hexagonal steel honeycomb specimens

No.	Core			Face	Specimens			
	Cell size/ mm	Wall thickness/ mm	Height/ mm	Thickness/ mm	Length/ mm	Width/ mm	Height/ mm	Real density/ ($kg \cdot m^{-3}$)
T1	5.0	0.49	14.69	0	42.24	38.62	14.69	1030
T2	5.0	0.49	15.00	0.45	39.52	39.00	15.90	1508
T3	5.0	0.49	15.00	0.45	147.49	38.48	15.90	1506
T4	5.0	0.49	15.00	0.45	148.96	44.49	15.73	1503

3. Theoretical analysis and mechanical measurements

3.1. Mechanical properties of parent material and brazing joints

The plain carbon steel Q215 was used as the parent material of hexagonal steel honeycombs, including core and skin plates. To measure the change of mechanical properties from parent material, first, the tensile tests were conducted. Tensile specimens of plain carbon steel were cut using electro-discharge machining and subjected to the same brazing cycle used to manufacture the regular hexagonal honeycombs. The measured tensile stress was taken as an elastic linearly hardening stress: Young's modulus E=202 GPa, yield strength σ_s=213 MPa before vacuum brazing, Young's modulus E=198 GPa, yield strength σ_s=165 MPa after vacuum brazing. The bond strength of brazed joints was measured by tension and shear tests. The tensile strength was 255 MPa, and the shear strength was 144 MPa.

3.2. Theoretical analysis

With the aim to understand the mechanical properties of honeycomb sandwich panels in the preliminary structural design stage, the present study gave firstly the Young's modulus and the strengths of steel honeycomb sandwich panels using simplified mechanic approaches. For simplicity, the detailed procedures were abbreviated, and the schematic view of a honeycomb panel and the size of a cell unit of the honeycomb core are shown in Figs. 2 and 3, respectively.

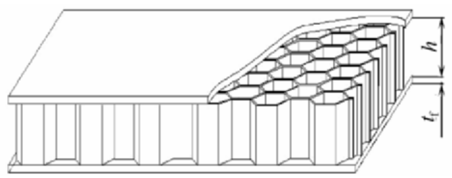

Fig. 2. Schematic view of a honeycomb panel.

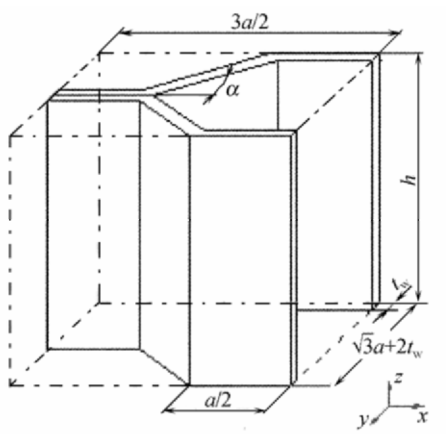

Fig. 3. A cell unit of the honeycomb core and its geometry.

By the equivalent weight method, neglecting the weight of brazing foils, but considering the wall thickness of the honeycomb core, the equivalent density ρ_c of the hexagonal steel honeycomb core is well described by

$$\rho_c = \frac{8t_w}{3(\sqrt{3}\ a + 2t_w)} \cdot \rho_0 \qquad (1)$$

Similarly, the equivalent density ρ of the hexagonal