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Deformation Behavior in Three-point Bending of Aluminum Alloy Honeycomb Structures

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With the intention of applying aluminum alloy honeycomb structural materials as lightweight structural materials for use in transportation devices, we carried out bending tests using three-point bending, which is the simplest kind of bending deformation, with the objective of obtaining basic findings for the purpose of observing plastic formability. In accordance with the test conditions, deformity was concentrated in a portion of the honeycomb cells during three-point bending tests, giving rise to localized deformity. We also studied the status and formation conditions of this localized deformity, methods for avoiding localized deformity, and springback, which allows for the restitution of plastic formation accuracy. In addition, we carried out bending tests on honeycomb structural materials having differing sizes of cells which form the honeycomb, and then observed the honeycomb structural materials' deformity characteristics.

Keywords: *honeycomb structural materials, three-point bending, local Deformation, cellular solids, aluminum alloy*

1. Introduction

A honeycomb core, formed by a number of aggregated hexagons, is light material that contributes to rectification or shock absorption[1]. A honeycomb sandwich panel, which is formed by placing this core material between sheets of face material, has an improved specific rigidity without impairing the lightness and shock absorption, and can be a trump card for reducing the weight of structures[2]. In addition to a wide variety of its applications by changing the core and face material, it has a sound and vibration insulation effect and a good damping performance because of its shock absorption. Furthermore, because of the large amount of space, it has a heat, sound, and vibration insulation effect[3].

The shape of the aluminum alloy honeycomb core is stable. The core is highly reliable, light, very rigid, smooth, and heat resistant. Aluminum alloy honeycomb structural material using this core is the basic structural element of artificial satellites or airplanes, and it is now being used for land transportation systems such as railways or automobiles[4]. If plastic utility can be imparted to such aluminum alloy honeycomb structural material, the range of its application may be widened dramatically. As demand increases by such secondary processing after the manufacturing process, manufacturing costs, which have been obstacles for application, are expected to reduce.

With regard to the aluminum alloy honeycomb structural material, mechanical analyses and bending work to a large curvature radius have been studied until now[5]. Researches regarding shock absorption have also been reported[6,7]. However, there were few studies regarding secondary work of a small curvature radius after the manufacture. These studies concerned formation of a relatively soft curve with the radius of 1800 mm[8]. Therefore, basic processing data for handling the processing to a smaller curvature radius are required. It is also necessary to know the deformation status of each honeycomb in processes such as the three-point bending. Until now, the three-point bending of honeycomb structural material has been performed for strength assessment, and few studies focusing on its deformation behavior have been conducted.

In this research, with the aim of obtaining knowledge for studying the plastic utility of the aluminum alloy honeycomb structure, the three-point bending test, which is the simplest bending deformation, was performed. Depending on the processing conditions, deformation in the three-point bending test was concentrated on some cells of the honeycomb core, and local compression occurred. Hence, we studied conditions under which this local compression occurs as well as ways to avoid it.

2. Experiment Method

2.1 Sample

As mentioned in the Introduction, an aluminum alloy honeycomb structure is a panel of a honeycomb core made up of an aluminum alloy foil adhesively bonded between two sheets of the same face material. The material of both the honeycomb core and the face material is 5052 aluminum alloy, and the two types of cell sizes of the honeycomb core are 3.175 mm (1/8 in.) and 6.35 mm (1/4 in.). Furthermore, the foil thickness is 0.0381 mm (0.0015 in.), and the three types of honeycomb core thickness are 5 mm, 10 mm, and 15.9 mm (5/8 in.). The thickness of the face material is 1 mm. An epoxy film adhesive is used for binding the honeycomb core and face material, and the curing conditions are 393K (120°C) and 3.6 ks.

2.2 Three-point Bending Test

The three-point bending test was performed using an Instron universal tester. Three-point bending, in which the bending load was applied by exerting concentric load on the center of the aluminum alloy honeycomb structure, which was supported at the supporting points on its left and right. The distance between the supporting points can be altered, and 120 mm, 180 mm, 200 mm, and 250 mm measurements were used for the test. The tip of the indenter applying the concentric load was cylindrical with a radius of 5 mm, and the indentation rate was 1.67×10^{-5} m/s or 3.33×10^{-5} m/s.

Testing piece was milled after being cut out. When milling the piece, its direction was aligned with the hexagonal cell shape. That is, it was aligned to the extending direction in the core production (the direction vertical to the side of a hexagon cell) X_1 and the width direction X_2, vertical to X_1.

2.3 Thin Sheet Selection in Three-point Bending Test

When performing the three-point bending test of the honeycomb structure, local buckling of the core may occur at the indenter contacting point. In order to prevent this local buckling, a preliminary experiment for selecting the thin sheet to be inserted between the indenter and testing piece was conducted. In the normal three-point bending test in which the thin sheet is not inserted, local buckling of the core at the center portion, as shown in Fig. 1, was observed in all the testing pieces of the 7-, 12-, and 18-mm-thick honeycombs.

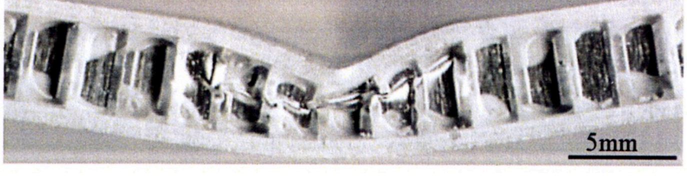

Fig. 1 Condition of local buckling of honeycomb core

In the three-point bending test in which a 1.5-mm-thick aluminum sheet was inserted, as shown in Fig. 2, plastic deflection was confirmed before local buckling of the core material only for the 7-mm-thick honeycomb.

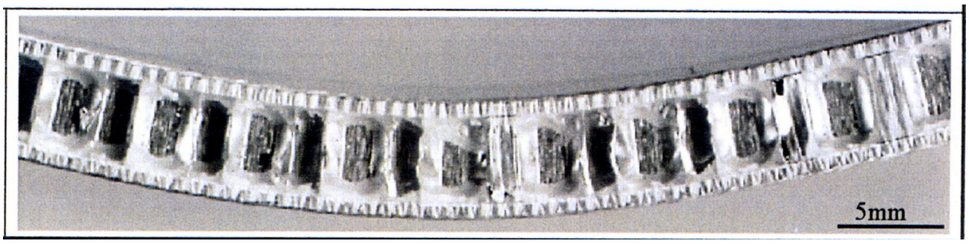

Fig. 2 Good bending work

This research considered the conditions in which the 1.5-mm-thick aluminum sheet was inserted as a favorable result, and in the three-point bending thereafter, the 1.5-mm-thick aluminum sheet was used as the inserted thin sheet.

In order to avoid local compression, the aluminum thin sheet was inserted during the three-point bending test. Thickness of the aluminum thin sheets proposed to be inserted was 1.15 mm and 1.5 mm. The critical value increases by inserting the 1.5-mm-thick aluminum thin sheet. Although it is the same thin sheet, the critical value further increases for thicker honeycomb material. A 1.15-mm stainless thin sheet and a 1.5-mm aluminum thin sheet were inserted into each sample of the 7-, 12-, and 18-mm-thick honeycomb materials. When inserting the 1.15-mm stainless thin sheet, there were some cases when the honeycomb material was deformed at an end of the inserted sheet material because of its excessive strength. Since the inserted thin sheet should distort similar to the honeycomb material, the aluminum thin sheet was more suitable than the stainless thin sheet for an inserted material.

3. Experiment Results and Discussion

3.1 Three-point Bending Test

3.1.1 Relationship with Compression Test

In the compression test, cell walls of the core material are folded into bellows. The test confirmed that the core material was folded from its upper side, i.e., the compressed side.

In any honeycomb material, no increase in stress can be observed right after starting the test because the gaps between the core and face material, such as an adhesive, are being folded. After reaching the maximum compressive stress, the stress decreases and an area of constant stress, called the plateau stage, appears. Cell walls of the core material are being folded here, and that is why no plateau stage can be observed in the 7-mm-thick honeycomb, the thin core material. After the plateau stage, the core material is folded and the density and stress increases.

With regard to compressive strength, the 18-mm-thick honeycomb was the lowest, and it was lower than the compressive strength of the core material alone. In case of the compression test for untouched material, its inherent compressive strength cannot be achieved if it has a high ratio of height to cross-sectional area of the testing piece. Therefore, when performing the compression test, maximum possible cross-sectional area relative to the height is required. The compressive strength is considered to decrease in 12- and 18-mm-thick honeycombs, which have a high ratio of height to cross-sectional area of the testing piece, since the cross-sectional area in this test was 20 mm × 20 mm for all the testing pieces of the 7-, 12-, and 18-mm-thick honeycombs.

3.1.2 Three-point Bending Test for 7-mm-thick Honeycomb Material

The load linearly increases immediately after starting the test and rapidly decreases thereafter. This linear part is an elastic deformation range. Furthermore, buckling of the core occurs when the load decreases. Next which is the condition wherein the aluminum thin sheet is inserted, a low-gradient elastic/plastic deformation range occurred immediately after the linear elastic range and the load decreased. Under the conditions, wherein the distance between the supporting points L is lengthened , an elastic/plastic deformation range could be observed immediately after the elastic deformation range.

The elastic/plastic deformation range could be observed under the conditions other than [L = 120 mm, thin sheet noninserted]. Furthermore, by inserting the thin sheet or increasing the distance between the supporting points, the elastic/plastic deformation range increases. Under the conditions of [L = 250 mm, thin sheet inserted], since the testing piece almost came in contact with the base of the test fixture, the test was terminated although it was in the middle of the elastic/plastic deformation range.

Under the conditions of [L = 120 mm, thin sheet noninserted], wherein an elastic/plastic deformation range could not be observed, plastic deflection did not occur but local buckling of the core material occurred. Under other conditions, local buckling of the core material occurred after plastic deflection.

From the conditions of [L = 200 mm, thin sheet noninserted] and [L = 250 mm, thin sheet noninserted], the maximum bending stress was about 300 MPa. Since the load decreased due to the local buckling of the core in the middle of the test, the stress may have increased by further increasing the distance between the supporting points. On the other hand, under the conditions of [L = 120 mm, thin sheet noninserted], the maximum bending stress was about 255 MPa, and the local buckling of the core occurred before the stress increased sufficiently. From the conditions of [L = 200 mm, thin sheet inserted] and [L = 250 mm, thin sheet inserted], the maximum bending stress was about 340 MPa, and the load caused by inserting the thin sheet increased.

Therefore, in order to determine the bending strength of the 7-mm-thick honeycomb, we assume that the conditions of [L = 250 mm, thin sheet noninserted] draws a curve similar to that of the conditions of [L = 250mm, thin sheet inserted], without decreasing the stress . As a result, the maximum bending stress of the expected curve was approximately 315 MPa. This is assumed to be the bending strength of the 7-mm-thick honeycomb.

Based on the conditions of [L = 200mm, thin sheet noninserted] and [L = 200 mm, thin sheet inserted], when looking at the indenter contact area at the center, although the thin sheet noninserted has a lesser displacement than the thin sheet inserted, damage of the face and core material is more intense. Thus, it can be observed that damage of the core and face material is decreased by inserting the thin sheet. In addition, the apparent damage was only confirmed at the indenter contact area at the center.

Next, when looking at the conditions of [L = 250mm, thin sheet inserted], no apparent damage of the core and face material could be seen. The curvature radius in this case was 88 mm. Soundness of the core is maintained under bending of this degree.

The testing pieces under the conditions of [L = 120 mm, thin sheet noninserted], [L = 120 mm, thin sheet inserted], and [L = 250 mm, thin sheet noninserted] show the similar deformation behavior to the conditions of [L = 200 mm, thin sheet noninserted] or [L = 200 mm, thin sheet inserted].

3.2 Local Deformation

Depending on the processing conditions, in the three-point bending test, deformation was concentrated on some cells of the honeycomb core, and local compression occurred. The critical values for the occurrence of local compression are 900 N for the 7-mm-thick honeycomb material, 1200 N for the 12-mm-thick honeycomb material, and 1280 N for the 18-mm-thick honeycomb material. The critical values increase by inserting the 1.5-mm-thick aluminum thin sheet. Although it is the same thin sheet, the critical value increases more in thicker honeycomb material. The-1.15-mm stainless thin sheet and 1.5-mm aluminum thin sheet were inserted into each sample of 7-, 12-, and 18-mm-thick honeycomb material. When inserting the 1.15-mm stainless thin sheet, the honeycomb material was deformed at the end of the inserted sheet material because of its excessive strength. Since the inserted thin sheet should deform similarly to the honeycomb material, the aluminum thin sheet was more suitable as inserted material than the stainless thin sheet. The elastic/plastic deformation range increases by inserting the 1.5-mm aluminum thin sheet, and hence, a better processing result can be obtained. Under the conditions of a particularly large distance between the supporting points of 250 mm, no local buckling could be observed during the processing, and the good processing result could be obtained. Thus, when inserting the thin sheet, no apparent damage of the core and face material can be observed, and the structure of the core part is maintained.

When pushing the honeycomb material by applying the load, the honeycomb structure is deformed as the load increases, but it rapidly decreases over time. This is considered where the local compression occurred. This part, where the load rapidly decreases, can be covered by inserting the thin sheet. In the sample with its distance between the supporting points of 250 mm, local compression did not occur within the range of the experiment.

The bending load is greater for the thicker sample. In addition, the bending load is greater for the shorter distance between the supporting points. As already mentioned, the bending load rapidly decreases after the sample is gently bent by the applied bending load. This is where the local compression occurs. As could be observed in the figures and pictures, in the local compression, it deforms such that it is folded from the upper side of the core part of the cells, which is similar to the deformation of the honeycomb structure being compressed. Despite that, the compressive stress is smaller for the thicker core part in the compression. It is considered that the higher the cell walls, more possible is the buckling. The reason why the tendency is different in three-point bending and compression is suspected to be the effect of stress occurring at the bonded portion of the face material and the honeycomb core during the local compression of the three-point bending.

The similar three-point bending test was performed for the honeycomb material of doubled cell size. For the 18-mm-thick testing piece, the sinking depth of the aluminum surface sheet was 8.6 mm [thickness of the core material (measured value) 15.6 mm − the remaining thickness of the core material (measured value) 7.0 mm]. Compared to the conventional honeycomb material, the sinking depth of the aluminum surface sheet was 9.45 mm [thickness of the core material (measured value) 15.6 mm − the remaining thickness of the core material (measured value) 6.15 mm]. Hence, it was found that although the angle of local compression is sharper than that of the conventional ones, the sinking depth is shallower. This is because although the sinking depth of the face material decreased because the cell size doubled, the number of cells decreased, and thus, the size of each buckling cell increased, and the extension of the face material increased instead.

3.3 Springback

When the load is removed after the bending work, the processed object flexibly recovers and its shape returns. This return of shape was regarded as springback and is evaluated. It was measured as shown in Fig. 3. If the pushing load is small, the springback may become half the amount of pushing, but as the number of times increases, the springback gradually decreases. The measured part is the plastic deformation range, which is believed to be a part where the three-point bending work is favorably performed. Although the elasticity of the entire material is assumed to be gradually decreasing, no apparent deformation was confirmed in the core part. This tendency continues until local compression occurs. In case of the die bending, the springback occurs at the both ends, and not at the center part.

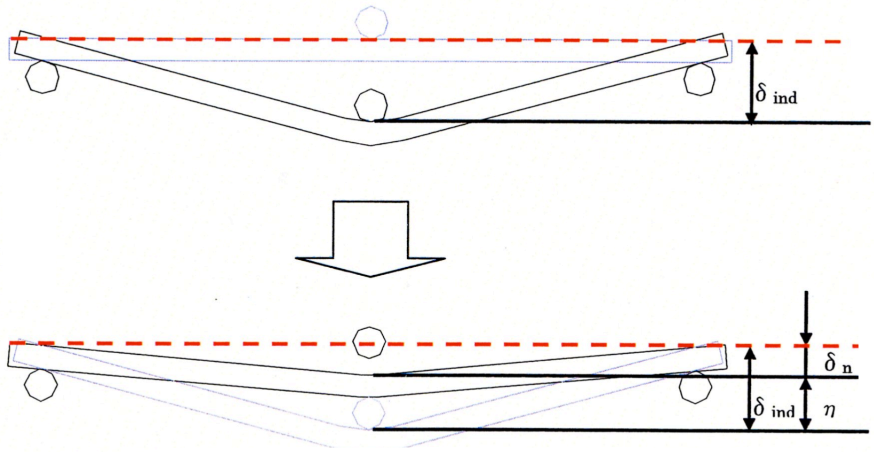

Fig. 3 Springback evaluation method

4. Conclusion

(1) Although the honeycomb material in the three-point bending test may cause local buckling of the core at the indenter contact area of the central part, by increasing the distance between the supporting points or inserting the thin sheet between the indenter and testing piece, it can be flexibly deformed without causing the buckling of the core.
(2) Although the rigidity increases as the honeycomb material becomes thicker, presence of the elastic/plastic deformation range becomes unlikely, and the formability becomes worse.
(3) Compared to the untouched material of 5052 aluminum alloy, the bending rigidity became 2.8 times in the 7-mm-thick honeycomb material, 4.2 times in the 12-mm-thick honeycomb material, and 5.6 times in the 18-mm-thick honeycomb material.
(4) Although the springback increases as the deformation goes on, its increasing rate gradually decreases, and it becomes constant in the perfect plastic deformation range.

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