Effect of through-holes on quasi-static axial compression behaviors of aluminum with thin-walled structure

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Abstract. The effect of through-holes position on deformation behaviors and energy absorption of 6063 aluminum alloy with thin-walled structure, taking the same number and different positions of through-holes, will be investigated by quasi-static axial compression using universal testing machine. The experimental results show that the compression behavior of thin-walled structure specimens can be significantly improved by properly opening through-holes and selecting appropriate locations. Based on the experimental data, the fluctuation degree of sample load was reduced. The stability of compression deformation was improved. The first peak load was reduced. And the energy absorption performance of the specimens was improved.

Keywords. Aluminum alloy; Thin-walled structure; Through-holes; Quasi-static compression; Deformation behavior; Energy absorption

1. Introduction

With the rapid development of finite element technology and social needs in recent years, more and more experts and scholars have made important research on the thin-walled structure in the design process of automobile body. Moreover, aluminum materials are distinguished by their relatively low density, high recyclability, design flexibility for mass production and economic benefits. With increasing attention to fuels and strict government emissions regulations, engineers have made extensive use of light weight materials, especially aluminum [1]. Kecman [2] used the experimental and observational analysis method of aluminum alloy thin-walled structural parts to finally obtain the axial compressive bending and crushing model suitable for the section of rectangular aluminum alloy thin-walled structural parts, and established the axial compressive energetic equation for plastic deformation of the thin-walled aluminum alloy structure when axial compressive occurred. Kotelko and Krolak [3] proposed a bending deformation model of a triangular-section aluminum alloy thin-walled structural member, and the deformation model of the thin-walled structural member can accurately describe the deformation mode and load of the aluminum alloy thin-walled structural member. ZHANG and CHENG [4] studied the effects of pre-deformation on the compressive properties of multi-cell square tubes and single-cell square tubes (filled with foamed aluminum). It was found that the pre-deformation grooves effectively reduced the peak force of the two energy-absorbing boxes during compression, and improved the utilization of materials at the same time. Through the study of Magee and Thornton [5], they proposed an empirical model for calculating the nominal load during the deformation of thin-walled
structures, which can help and guide the design of aluminum alloy thin-walled structures in automotive body design. The results of experts such as Mahmood [6] led them to obtain an empirical model on the axial compressive deformation process of aluminum alloy thin-walled structural members during axial compressive deformation of simple-section aluminum alloy thin-walled structural members. What’s more, they successfully applied this theoretical model to the analysis of complex sections of automotive body aluminum alloy thin-walled structures. Through the dynamical model and test of the deformation of thin-walled structural members, the relationship between force and displacement and the relationship between torque and angle for the structure of aluminum alloy thin-walled parts are obtained. Also, they used this data as input data to build a finite element model of thin-walled parts.

In addition, some experts and scholars have carried out extensive research on the thin-walled structural parts of automobile body by finite element numerical simulation technology. Abramowicz W [7] and other scholars carried out an experimental study on the static and dynamic axial crushing, and some elementary theoretical considerations are presented on the initiation of the collapse process for tubes having square cross sections and on the transition from global bending to progressive buckling induced by the local plastic collapse for both circular and square tubes. CHENG [8] and other scholars carried out the experimental research on the extrusion characteristics and energy absorption capacity of the AA6061-T6 aluminum alloy profile in the discontinuity of the central position of the through hole. Three different types of geometric discontinuities are processed for round holes, slotted holes and elliptical holes. In addition, three different spindle lengths (7.14, 10.72, and 14.29 mm) and three different aspect ratios (1.33, 2.0, and 3.0) were also considered. It has been found that the introduction of a pulverization initiator into the structural member can produce a splitting and cutting deformation mode without causing overall bending deformation at the same time. WANG [9-10] and others selected 6063 aluminum alloy thin-walled beam structure as the research object, used quasi-static axial load method to determine the influential law of induced pore structure on the compressive deformation behavior and energetic absorption performance of aluminum alloy thin-walled beams.

Moreover, through the comparison of experimental data, the influential law of induced pore size on critical load is systematically studied, and the quantitative relationship between critical load and moment of inertia of aluminum alloy thin-walled beam structure is established based on linear regressive theory. Ghazijahani [11] studied the axial compressive deformation of aluminum alloy and medium carbon steel tubes with different sizes and heat treatment conditions, they also studied the effects of different diameters, positions and numbers of induction holes on the compressive deformation behavior of the tube. In addition, the relationship between the typical deformation mode and the load curve is discussed. The results showed that the induced hole had an important influence on the crush mode of the thin-walled beam. Through numerical simulation, Kormi [12] studied the deformation behavior of steel pipes when three kinds of different working conditions were opened, and made a detailed analysis of each working condition. XIANG [13] and other scholars studied A1-Mg-Si gold profiles, and they were aged respectively at 180 °C for 30~540 min by. The deformation modes and energy absorption properties of aluminum alloy profiles with different aging conditions under quasi-static compressive conditions were studied. The results showed that the compressive deformation mode of Al-Mg-Si profiles was changed and the energetic absorption performance of profiles was also increased. Sahu [14] studied the effect of induced pores on the deformation behavior of composites, pointing out that the induced pore diameter and boundary conditions have a great influence on the deformation mode of the specimen. LI [15] studied the effectiveness of three new induction designs on thin-walled aluminum square tubes to reduce the initial buckling peak load of the tubes under axial loads. A series of quasi-static and dynamic compression tests were performed using AA 6063 T6 aluminum alloy square tubes. The energy absorption behavior of the aluminum square tube with the axial load of the induction structure is studied, and the load-displacement curve of the original tube and tube with the induction structure is obtained.
2. Experimental program

2.1. Preparation of sample

The material of 6063-T6 aluminium alloy thin-walled structure used in this experiment which geometrical shape and size are shown in figure 1. The experimental sample’s length 80mm, the width is 60mm and wall thickness is 2mm, and the sample must intercept 150 mm in the direction of squeezing is to ensure the parallelism of both ends when intercepting. The actual chemical composition of 6063 Aluminium alloy are listed in table 1.

![Figure 1. Dimensions and geometric shape of 6063 aluminum profile (Unit: mm).](image)

(a) Practicality diagram  (b) Cross-section dimensions

Table 1. Chemical composition of 6063 aluminum alloy (Mass Fraction, %).

|     | Si  | Mg  | Fe  | Cu  | Cr  | Zn  | Ti  | Ni  | Al   |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
|     | 0.23| 0.14| 0.03| 0.06| 0.02| 0.08| 0.01| 0.02| Bal  |

2.2. Experimental method

In this experiment, a total of 4 experiments were carried out to research the influence of the position of through-hole and base on loading capacity and energy absorbing properties of the thin-walled aluminum alloy structure. The circular used in the experiment ensure that the area is the same, that is to say, the through-holes size is uniform. The experiment adopts quasi-static axial compression test method. The test is carried out on a universal testing machine with a compression speed of 5 mm/min and a compression distance of 100 mm. This experiment record by universal testing machine in real time. The data acquisition frequency of the testing machine is 100 Hz. To respectively obtain the change of corresponding loading’s capacity when the sample is deformed. The test principle is shown in figure 2.

![Figure 2. The test principle of quasi-static axial compression.](image)
3. Experimental results and analysis

3.1. No through-hole structure

The sample’s structure of the base is shown in figure 1. The load-displacement curve and the energy absorption of no through-hole sample (Base) is shown in figure 3. It can be seen from figure 3 that the initial loading to the first peak (point A, 1.40 mm, 78.30 kN). The load of the sample during the compression process increases rapidly. As the compression displacement increases, the thin wall beam is reached after the maximum load is reached. The structure is destabilized at the upper end. The sample is convexly deformed toward the outer surface and narrowed toward the inner surface. As the amount of compression increased to 25.74 mm, the sample formed the first complete pleat at point B (12.96 kN). The second load peak (point C, 50.94 mm, 43.68 kN) is significantly smaller than the first peak, and the second fold formation time is longer than the first fold. When the compression distance is 100 mm (point F), the load is in the descending section. The bottom of the sample is deformed into a bone shape (wide-face concave, narrow-face convex), as shown in table 2. The sample formed the first complete pleat energy absorption of 0.65 kJ, and the energy absorption performance was significantly improved during the formation of the second pleat.

![Figure 3. Compression behavior and absorbed energy of base sample.](image)

![Table 2. Compression result of base sample.](table)

| Sample No. | Front | Upper End | Lower End |
|------------|-------|-----------|-----------|
| Base       | ![Image] | ![Image] | ![Image] |

3.2. Effect of the circular through-holes position

The through-holes with diameters of 10mm are opened on the four surfaces of the thin-walled aluminum alloy structure, respectively 15mm, 25mm and 35mm from the top. And the Numbers of samples are respectively named that Circular-15, Circular-25 and Circular-35, as shown in figure 4.
The load-displacement curve and the energy absorption of the Circular-15 sample is shown in figure 5. The results of the circular compression deformation of aluminum alloy is shown in table 3. From the initial loading to the first peak (point A, 1.53 mm, 85.28 kN), the sample has the same tendency as the non-porous sample. After the peak, the load on the specimen was rapidly reduced to point B (15.62 mm, 16.70 kN), and a complete fold was formed. In the range of 100mm compression deformation, there are 4 complete peaks, but only two complete folds are actually formed. Combined with the record of the compression process, it can be found that the B point to the D point stage is the continued compression process of the first wrinkle. The formation of the second pleat also has two stages, one is the formation phase and the other is the re-compression state. When the compression amount reaches 100 mm, the sample load is in the rising section. As can be seen from figure 4, the first pleat of the sample Circular-15 is at the lower edge of the through-holes, and the width is 20 mm. The lower end surface is square, one side of which is concave by 5 mm. The second pleat is 21 mm from the lower end surface.
Table 3. Compression result of circular samples.

| Sample No.  | Front | Upper End | Lower End |
|-------------|-------|-----------|-----------|
| Circular-15 | ![Image](image1) | ![Image](image2) | ![Image](image3) |
| Circular-25 | ![Image](image4) | ![Image](image5) | ![Image](image6) |
| Circular-35 | ![Image](image7) | ![Image](image8) | ![Image](image9) |

The load and the change in energy absorption performance of Circular-25 sample is shown in figure 6. As can be seen from the figure 6, from the initial loading to the first peak (point A, 1.29 mm, 75.65 kN), the sample has the same tendency as the non-porous sample. After the peak, the load on the sample was rapidly reduced to point B (23.63 mm, 12.14 kN), and a complete fold was formed. The fluctuation from point B to point C is the continued compression of the first fold. The second pleat formation stage is from point C to point E (formation stage), and point E to point G (re-compression). When the compression amount reaches 100 mm, the sample load is in the rising section. The first pleat of the Circular-25 sample was at the center of the induction hole, and the width was 25 mm. The lower end surface was square-shaped to the bone-shaped excessive shape, one side of which was concave 13 mm. The second pleat was 16 mm from the lower end surface.

The load-displacement curve and the energy absorption of the Circular-35 sample is shown in figure 7. As can be seen from the figure 7, from the initial loading to the first peak (point A, 1.44 mm, 82.38 kN), the sample has the same tendency as the non-porous sample. After the peak, the load on the sample was rapidly reduced to point B (27.22 mm, 15.53 kN), and a complete fold was formed. The subsequent load-displacement repeats the above process, exhibiting periodic peaks. The fluctuation from point B to point C is the continued compression of the first fold. The second pleat formation stage is from point C to point E (formation stage), and point E to point G (recompression). When the compression amount reaches 100 mm, the sample load is in the rising section. The first fold of the sample Circular-35 was formed at the center of the through-hole with a width of 35 mm. The lower end surface was bone-shaped. The second pleat was 9 mm from the lower end surface.
The compression behavior of samples for Base and Circular through-hole is shown in figure 8. It can be seen from figure 8 that the change trend from the initial loading to the first peak point A is basically the same. But the fluctuation amplitude is reduced, the load change is gradually gentle. The maximum peak load from the largest to the smallest is Circular-15 (85.28kN), Circular-35 (82.38kN), Base (78.30kN), Circular-25 (75.26kN). The deformation of the first fold is completely formed, the order of the order is Circular-25 (1.29 mm, 23.63 kN), Base (1.4 mm, 25.74 kN), Circular-35 (1.44 mm, 27.22 kN), Circular-15 (1.53 mm, 15.62 kN). It can be seen from table 3 and figure 8 that when the deformation amount reaches 100 mm, the rising or falling section of the sample load corresponds to the final shape of the lower end surface of the sample. And the rising section is the initial stage of the bottom deformation, which is not completely deformed. It is square or Approximate square (one side concave), such as the sample Circular-15 and Circular-25. The descending section is the end of the lower end deformation. It has been or nearly completely deformed, which is bone-shaped (two sides concave, other sides convex), such as sample Base and Circular-35.
The comparison of the energy absorption performance between the circular and the non-circular (Base) at different positions is shown in figure 9. It can be seen from figure 9 and figure 4 that due to the difference in the position of the circular and the change in the structure and compression behavior of the thin-walled beam caused by the Base. The energy absorption performance of the four samples is different. The Circular-15 can absorb more energy, Circular-35 times, and significantly exceeded the Base sample. The energy absorption of Circular-25 and Base sample is not much different, but in the process of the second fold formation, there is a significant difference. The Circular-25 is superior to the Base sample. Therefore, it is reasonable to slot the circular through-holes on the thin-walled structure, which can effectively reduce the peak load or improve the energy absorption performance. Table 4 illustrates the quasistatic test results of samples for base and circular through-hole.

![Figure 8. Compression behavior of samples for base and circular through-holes.](image)

![Figure 9. The absorbed energy of samples for base and circular through-holes.](image)
Table 4. Quasistatic test result of samples for base and circular through-hole.

| Sample No. | First peak load /kN | Absorbed energy /kJ | Initial position of collapse |
|------------|---------------------|---------------------|-----------------------------|
| Base       | 78.30               | 2.40                | Up                          |
| Circular-15| 85.28               | 2.74                | Up                          |
| Circular-25| 75.65               | 2.43                | Up                          |
| Circular-35| 82.38               | 2.63                | Up                          |

4. Conclusion

- The results of static axial compression test of through-holes at different positions has different effects.
- Reasonable designing the position of the through-holes can effectively improve the sample’s compression behavior of the thin-walled structure, reduce the first peak load, and improve the energy absorption performance.

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