Proceeding of the 14th International Forum of Automotive Traffic Safety, 2017, pp 326-330
No.ATS.2017.409

Influence of Induced Holes on The Crashworthiness of Aluminum Alloy Thin-walled Beams

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Abstract : Taking the influence of the induced holes on the crashworthiness of the thin-walled beam of aluminum alloy as the object of study, a moving trolley for impact crushing is designed to control the consistency of each impact pulse. Radial quantity, hole size, axial spacing and axial quantity are selected as the design variables, using orthogonal design method, the collision performance of peak load, average load, energy absorption and crushing distance is analyzed. The result shows that for the four evaluation indexes, hole size is the main influencing factor and the increase of hole size in a certain range can effectively reduce the load of thin-walled beams. The energy absorption is not sensitive to the four indexes. Meanwhile, in order to achieve better crushing effect in the collision, it is recommended to set more than 4 holes at the radial direction.

Keywords: induced hole, aluminum alloy thin-walled beam, crashworthiness, orthogonal design

Introduction

Thin-walled beam is a common component of automobile structure. It not only plays the role of structural support, but also is an important energy absorbing component in vehicle collision[1]. Research shows that a well designed front beam absorps 50% of crash energy during the whole collision process. Therefore, the design of the thin-walled beam plays an important role in the safety of the whole vehicle[2].

In the collision process, the energy absorption is mainly realized through crushing of thin-walled beams. The peak load of thin-walled beam cannot exceed the load limit, and it is helpful to reduce the peak load by increasing the quantity of induced holes. In this way, the collapse of thin-walled beam is more uniform and thorough. In the past decades, some researches have been done which aim at inducing structure and deformation characteristics, including pre-deformation groove, groove shape and slotted condition[3-5], but the researches mainly concentrate in the steel structure of the thin-walled beams.

Aluminum alloy is a new material in response to lightweight development target in recent years. Compared with steel structure, aluminum alloy has a heavy drop in weight and plays an important role in reducing automobile fuel consumption. But the deformation modes and energy absorption characteristics of aluminum alloy thin-walled beams in collision can be different from those of steel structures. So far, there are different opinions. As for the influence of the induced hole on its crashworthiness, including the size of the induced hole, the arrangement, the spacing, and so on, the related research is very few. Therefore, this paper takes 6063 aluminum alloy thin-walled beam as the research object, through the vertical crushing test, analysis of the influence of induced hole size, density and arrangement on energy absorption is made, providing a reference for the safety design of aluminum alloy car body.

1 Test method

A moving sled for impact crushing is designed, as shown in Figure1. The front end consists of four jaw chuck, for clamping beams, back end is a moving part in the slide for impacting thin-walled beam, the total mass of the moving part is 80kg. The whole sled is placed on the acceleration simulator and the speed of the impact moment is set 20km/h by controlling the pulse of the simulator, so as to ensure the same test environment for each test. The moving part is equipped with an acceleration sensor to measure the crushing distance and crushing force of the thin-walled beams during the collision.

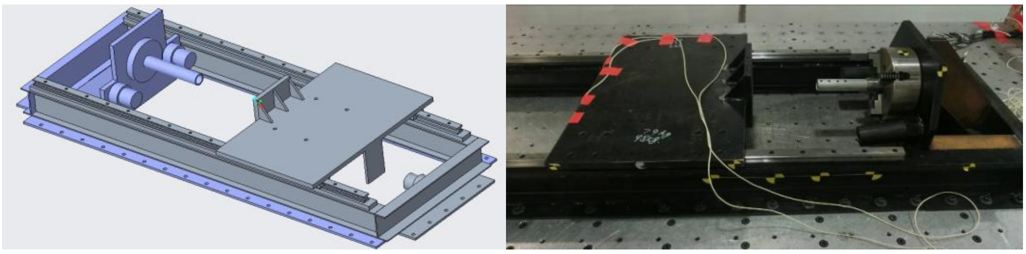

Figure1 Test device

The test specimen is 6063 aluminum alloy thin-walled beam with a length of 270mm, diameter of 40mm and thickness of 2mm, as shown in figure 2.

Figure2 Test sample

2 Test matrix design

This paper selects four factors, including radial quantity, hole size, axial spacing and axial quantity, using $L_9(3^4)$ orthogonal experimental design, each factor selects three different levels. A total number of 9 tests are designed and test matrix is as shown in table 1.

Table1 Test matrix

Number	Radial quantity	Hole size	Axial spacing	Axial quantity
1	2	2	15	2
2	2	5	20	3
3	2	8	25	4
4	3	2	20	4
5	3	5	25	2
6	3	8	15	3
7	4	2	25	3
8	4	5	15	4
9	4	8	20	2

3 Test result analysis

3.1 Overall deformation model analysis

As shown in Fig. 3, from the force-displacement curve of the sample, it can be found that the crushing process has undergone three steps: elastic deformation, plastic deformation which lead to collapse and a complete folding after the peak. The process corresponds to the starting point of the test curve - the first wave crest - the first trough. From the overall trend of the curve, the first peak force is basically greater than the subsequent two peaks.

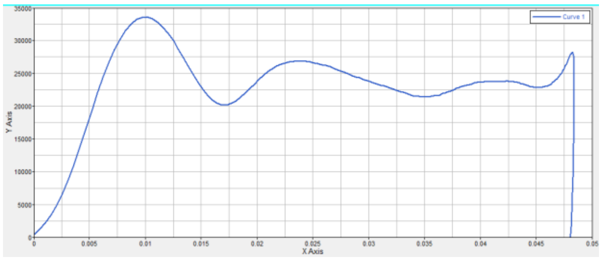

Figure3 Force-displacement curve

From the experimental sample, most of the test specimens which have 3 or more radial holes have formed two complete folds and the third fold has not completely formed. The deformation mode is accordion, as shown in Figure 4 a). There are also some beams that failed to effectively crush, which have 2 or less radial holes. After the first fold formation, due to local weakening effect induced by holes, thin wall inverses in the area of induced holes and the deformation mode of mixture occurs[6], as shown in Figure 4 b).

a) Crushing form (4 induced holes)

b) Crushing form (2 induced holes)

Figure4 Comparation of different test beams

Figure 5 shows the force-displacement curves of the 9 tests. It can be seen from the curves:

1) The change of the induced holes has a significant influence on the crushing distance of the thin-walled beams. The minimum crushing distance of 40mm occurs in the fourth test, the maximum crushing distance of 53mm occurs in the sixth test.

2) The peak value of initial crushing force has great difference, which needs further analysis;

3) The change of the induced holes influences the increasing rate of the force before the formation of the first fold, that is, the crushing speed and the carrying capacity.

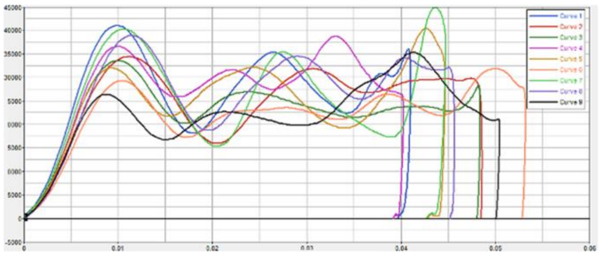

Figure5 Force-displacement curves of 9 tests

3.2 Orthogonal analysis

Range analysis is a method of visual analysis. For carrying out range analysis, three symbols are introduced, namely, K_i, k_i and R. Among them, K_i is the sum of the experimental results corresponding to a certain level in a certain column, k_i is the arithmetic mean value of a certain level of test result in a certain column, R is the extreme difference of k_i in a column. Generally speaking, there is some difference between different columns. Through the range analysis, the factors that have an appreciable effcet on the test result are screened out.

Generally, in the energy absorption design of automotive structures, on the one hand, the bearing capacity of the structure must be investigated, on the other hand, the energy absorption capacity of the structure must be taken into account, which can be achieved through the rational design of induced holes. Therefore, the peak load, average load, energy absorption and crushing distance are chosen to quantify the collision performance of the sample. Range analysis is made, as shown in table 2.

Table2 Test result range analysis

Index	Value	Radial quantity	Hole size	Axial spacing	Axial quantity
Peak load (N)	k_1	36333.3	41500	37233.3	38866.7
	k_2	36966.6	37900	36100	37000
	k_3	39633.3	33533.3	39600	37066.7
	Range	3300	7966.7	3500	1866.7
Average load (N)	k_1	24949.4	26572.2	25197.1	24580.6
	k_2	24989.1	25697.3	25028.7	24263.9
	k_3	24749.4	22418.5	24462.1	25843.4
	Range	239.7	4153.7	734.9	1579.5
Energy absorption (J)	k_1	1138.6	1111.5	1163.5	1107.1
	k_2	1134.1	1184.3	1145.1	1173.8
	k_3	1156.9	1133.8	1120.9	1148.7
	Range	22.8	72.8	42.6	66.7
Crushing distance (mm)	k_1	0.046	0.042	0.047	0.045
	k_2	0.046	0.046	0.046	0.049
	k_3	0.047	0.051	0.046	0.045
	Range	0.001	0.009	0.001	0.004

From the range analysis, it can be seen that different levels of different factors have great influence on peak load and average load, while the impact on energy absorption and crushing distance is relatively small. Specifically:

1) For the four indicators of the peak load, average load, energy absorption and crushing distance, the influence of the hole size is the largest.

2) The influence of radial quantity and axial spacing on the peak load index is relatively large.

3) The axial quantity of the induced holes has relatively great influence on the average load.

4) The influence of different levels of different factors on the crushing distance is relatively small. It has little influence on the energy absorption.

5) Increasing the size of induced holes in a certain range can effectively reduce the load and increase the crushing distance of the thin-walled beam.

6) There is no direct correspondence among axial spacing, axial quantity and load.

From the analysis of the deformation mode, as shown in Figure 6, crushing deformation of thin-walled beam which has 2 induced holes is not ideal and the deformation mode is mixed. The thin-walled beam which has 3 holes has formed a better accordion deformation pattern .

Figure6 Deformation comparation of 9 tests

4 Conclusion

This paper selects aluminum alloy thin-walled beam as the research object, through the method of sled impact test, 9 orthogonal tests have been done and analyzed. The axial quantity, hole size, axial spacing and axial quantity of induced holes are selected as design factors, while peak load, average load, energy absorption and crushing distance are set as collision performance indexes. The following conclusions have been drawn:

1) In the four factors, the hole size has the greatest impact on the collsion performance. The increase of hole size in a certain range can effectively reduce the load of thin-walled beams, and increase crushing distance, contributing to the safety of vehicle occupants. So we should take hole size into consideration in the primary design.

2) The adjustment of peak load and average load can be realized by the change of radial quantity, axial spacing and axial quantity of the induced holes, but the range of adjustment is small.

3) Different factors and different levels have almost no influence on energy absorption. That is to say, the energy absorption of the thin-walled beams is insensitive to the change of the induced holes.

4) In order to make thin-walled beams get better crushing effect, it is recommended to set more than 4 induced holes at the radial direction, so that the crushing deformation is closer to the accordion mode and the energy absorption will be more thorough.

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