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Crashworthiness assessment of square aluminum extrusions considering the damage evolution

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Abstract

Combining the pivotal tests and FEM technology, crashworthiness of aluminum extrusions was studied for an automobile safety plan. Experiments under static axial loading conditions were carried out for square thin-walled tubes with different thicknesses, section dimensions, with various impact velocities were conducted as well. Crush behavior of this structure under axial static and dynamic loads was studied. FEM code was used for crash analysis, which gave deformation and load prediction. Geometric imperfection and damage model were introduced to simulation. Results show that experiment and numerical model have good agreement with each other.

Keywords: Thin-walled aluminum extrusion; Crashworthiness; Inflectional distortion; FEM

1. Introduction

As a result of energy shortage and environmental problem in the world, automotive manufacturers should pay more attention to the new concept about lessen fuel consumption and lower carbon dioxide (CO_2) emissions. Light weight vehicle such as aluminum space-frame cars attract designer's eyeballs, because of that their weight savings of as much as 25% may be possible compared with conventional steel structures. What's more, aluminum alloy has good corrosion resistance and high capability of energy absorbing.

Aluminum extrusions are wildly used in energy-absorbing systems for automobile, due to that complicated cross-sections, these members show good performance on energy absorbing. When crash accident occurs, distortion such as bending, torsion and folding would be mainly concentrated to these sections and minimal acceleration is transferred to the occupants. So the crashworthiness of aluminum extrusions has great effect on the energy absorbing of absorber. A great amount of research has been carried out on this object. M. Langseth and O.S. Hopperstad have studied the behavior of aluminum extrusions under axial loading conditions in detail, and gave test data for validation of a numerical model in code LS-DYNA. Furthermore, they also studied the combined distortion of extrusions and aluminum foam filler [1–5,8]. Deb and Mahendrakumar presented a design of an aluminum-intensive vehicle platform for front impact safety, which addressed to the crashworthiness of a space frame structure with welded extrusions [6]. Their experimental observations on aluminum tubes with T joints show good agreement to the numerical simulation results which identified that the design approach of component-level testing combined with finite element and lumped parameter-based simulations could be an effective way in new vehicles safety evaluation.

Common to the work so far on the crashworthiness of aluminum extrusions, experimental results show that in front impact accident, girders and beams made of extrusions are mainly components for energy absorbing. Crashworthiness of aluminum extrusions is affected by material microstructure, loading speed and geometrical dimensions. In addition, the material damage evolution and deformation inconsonance should also be considered as well, which will lead more accurate simulation results, when a reasonable numerical model is established. In the following parts of this paper, a test program is represented to examine the folding process of aluminum extrusions. The experimental data would be combined with a

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Table 1
Sample list

Test/simulation	Thickness	Length	Cross-section	Sample No.	Load condition	Static/impact velocity
Test data	1	100	76 × 25	1-L1-2S-T	S	St
				1-L1-1D-T	Q–S	1.4909
				1-L1-2D-T	Q–S	2.1112
				1-L1-3D-T	Q–S	2.2889
				1-L1-4D-T	Q–S	2.3185
				1-L1-5D-T	Q–S	2.3537
				1-L1-6D-T	Q–S	3.3339
	2	200	76 × 44	2-L2-1S-T	S	St
Numerical model	1	100	76 × 25	1-L1-1S-N	S	St
				1-L1-1D-N	Q–S	1.4909
				1-L1-2D-N	Q–S	2.1112
				1-L1-3D-N	Q–S	2.2889
				1-L1-4D-N	Q–S	2.3185
				1-L1-5D-N	Q–S	2.3537
				1-L1-6D-N	Q–S	3.3339
	2	200	76 × 44	2-L3-1S-N	S	St

numerical model considering the damage initiation and evolution as well as geometric imperfection.

2. Crash test

2.1. Test program and experimental setup

For aluminum extrusions subjected to axial loading, the reported experimental data as well as the experimental details are limited. Most of the published work is related to circular tubes and spot-weld-bonded box sections. Therefore, an extensive experimental research project has been carried out to study the behavior of thin-walled aluminum extrusions subjected to axial loading and to provide data for validation studies of computer codes.

The objective of this part of the research project was: (1) To study the static and dynamic behavior of square thin-walled tubes subjected to axial loading in conditions varying the wall thickness specimen, length, and impact velocity. (2) To study any difference in behavior between static and dynamic tests.

Two different wall thicknesses and lengths of extrusions were tested under dynamic and static axial loading conditions. Furthermore, large amount of numerical models have been carried out under different geometric and load conditions (Table 1). Among these models, some of them are of test validation. By comparing the computation results to the test data, it was sure that the simulation supplied good predication. Others were useful testing complements, which predict the in case crashing behavior of the square tubes. Fig. 1 shows the experiment boundary conditions: the square tube was placed on the worktable with a steel plate covering on the top. For static crashing, the crosshead of test machine would go down to compress the tube with a velocity of 1 mm/min; for quasi-static and dynamic loading, a drop hammer would impact the tube on the top with the muzzle velocities range from 0.6033 to 3.3339 m/s. since the buckle of thin walled extrusions is sensitive to the initiation structure. Prior to testing, thickness of the specimens was measured carefully and the error of average thickness of qualified specimens is less than 5% according to reference document [3].

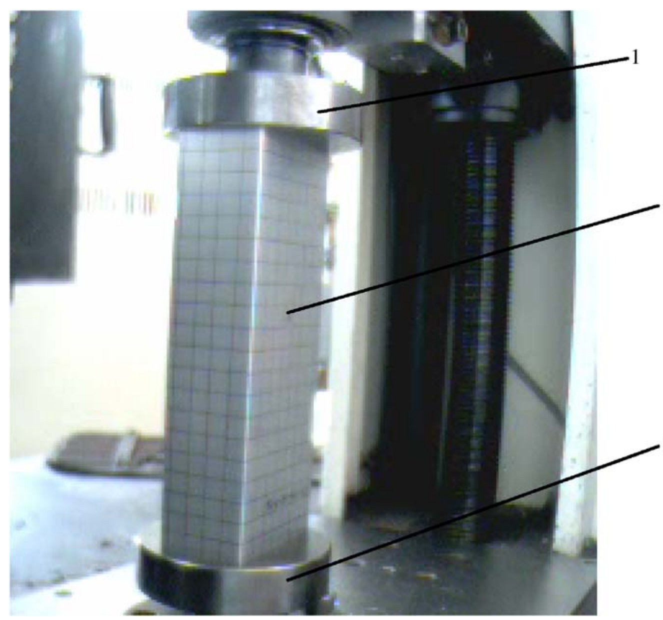

Fig. 1. Test device: (1) up plate, (2) extrusion and (3) support plate.

2.2. Material properties

Test specimens were made of the aluminum alloy 6063 tempers T6. Fig. 2 shows the typical engineering stress–stain curve for the material tested. After extrusion the profiles were air cooled and stretched to an elongation of 1–2%, Temper T6 means that the alloy was aged for 2 h at 195 °C.