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ORIGINAL ARTICLE

Effect of end-clamping constraints on bending crashworthiness of square profiles

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Abstract
The bending crashworthiness performance of thin-walled structures is affected by several factors such as the end-clamping constraints. The end-clamping configuration should be carefully investigated since it is an important part of the real working condition of a structure under bending loading. End-clamping fixtures (pads) can be used intentionally as complementary energy dissipating mechanisms to trigger new plastic deformation. The present article explores the use of pads to improve the crashworthiness of square tubes under lateral loads. For this purpose, internal, external, and combined pads were located at the profile ends which were subjected to a modified three-point bending test using finite element simulations. The effect of assembly force (f_N) and pad length (l_p) on the energy absorption was investigated. The structures were made of aluminum 6063-T5 and modeled with elasto-plastic properties considering ductile and shear damage criteria with evolution. Additionally, the numerical results were validated by an experimental three-point bending test on a square profile with constrained and free ends. Our results for a structure with end-clamping fixtures show an improvement of crashworthiness performance in a range from 42.38 – 57.89% relative to a structure with free-ends. The best crush force efficiency (CFE) of 0.78 was obtained when external pads were implemented. Moreover, the importance of f_N on the end-clamping pads was noticed since CFE is increased by 9.30% when a normalized force of 0.109 is applied. The importance of pad length was also demonstrated. An improvement of 69.38% in CFE was achieved when a normalized length $\overline{L}_p = 0.138$ was implemented. Finally, with the findings of our work, a design of end-clamping fixtures for an automobile's side-door impact beam is presented and analyzed.

Keywords Crashworthiness · End-clamping constraint · Three-point bending test · Finite element simulation

1 Introduction

Lateral impacts are among the most common scenarios in car crashes causing serious passenger injuries and fatalities [1]. To counter these harmful effects, thin-walled structures have been extensively used in automobiles due to their large energy absorption by plastic deformation. In this way, several automobile components such as pillars and side-door beams are crashworthy designed for bending load conditions [2, 3]. In addition to their large energy absorption capacity, thin-walled structures must also satisfy the lightweight requirement demanded by the automobile industry. This condition is necessary to obtain a high mechanical performance to fuel consumption ratio in a car. For this reason, the use of aluminum alloys has increased. The crashworthiness behavior of structures under side impacts can be improved by geometrical [4, 5], material [6, 7], and the addition of extrinsic properties [8]. Wang et al. [9] investigated the bending resistance of multi-

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