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A study on an axial crush configuration response of thin-wall, steel box components: The quasi-static experiments

B.P. DiPaolo *, J.G. Tom

US Army Engineer Research and Development Center, Vicksburg, MS 39180, USA

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Abstract

An experimental investigation was performed to study a specific axial crush configuration response of steel, square box components under quasi-static testing conditions. For a specific cross-sectional geometry/fabrication process, test specimens were obtained from commercially produced, welded tube lengths of ASTM A36 and ASTM A513 Type 1 plain low-carbon steels and AISI 316 and AISI 304 austenitic stainless steels. Removable grooved caps were used to constrain tube test specimen ends, and collapse initiators in the form of shallow machined grooves were used to control the initial transverse deformations of the test specimen sidewalls. The progressive plastic deformation for all of the test specimens was restricted to the prototype configuration response (fold formation process and the corresponding axial load-axial displacement curve shape) of the symmetric axial crush mode. Crush characteristics were evaluated and, for each material type, observed differences were less than 7% for maximum and minimum load magnitudes and less than 2% for energy absorption, displacement, and mean load quantities in both the initial phase and the secondary folding phase cycles. Overall, results of the study indicate that for a significant range of material strengths, a controlled and repeatable energy absorption process can be obtained for commercially produced steel box components undergoing symmetric axial crush response.
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Keywords: Axial crush; Configuration response; Thin-wall box components; Steel; Progressive collapse; Plastic deformation; Energy absorption; Quasi-static experiments

1. Introduction

Axial crush response of thin-wall, ductile metallic alloy components (specific geometry and material combination) has been extensively studied for irreversible directional energy absorption capability (Coppa, 1968; Ezra and Fay, 1972; Johnson and Reid, 1978; Reid and Reddy, 1986; see overview of dynamic progressive buckling in Jones, 1997). Because significant energy can be absorbed by plastic deformation during the progressive fold formation process that is characteristic of this response, axial crush has many important engineering safety applications in areas including crashworthiness and blast-resistant design of structures.

* Corresponding author. Tel.: +1 601 634 4021; fax: +1 601 634 2309.
E-mail address: Beverly.P.DiPaolo@erdc.usace.army.mil (B.P. DiPaolo).

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An example of the symmetric axial crush response mode (Abramowicz and Jones, 1984) for an AISI 304 stainless steel, welded square box component tube specimen is shown in Fig. 1. A crush specimen showing the fold formation is next to an undeformed tube specimen in Fig. 1a and, the corresponding axial load-axial displacement curve (subsequently referred to as the load–displacement curve) is shown in Fig. 1b and c. Axial crush response can be considered to consist of phases or stages (Pugsley, 1960). For the current investigation, the type of response shown in Fig. 1 is divided into an "initial" phase and a "secondary" phase. The initial phase includes the pre-collapse response prior to the occurrence of the peak or maximum load, the change from axial to bending load-resistance in the sidewalls, and the formation of the first few interior and exterior folds on sets of opposite sidewalls with corresponding increases and decreases in the load–displacement curve. The secondary folding phase consists of the "steady state" fold formation process. In this phase, adjacent sidewall interactions and contacting of folds produce subsequent fold formations of constant wavelength along the remaining length of the specimen. For the current investigation, a cycle in the curve (see Fig. 1b) corresponds to the formation of one exterior or one interior fold on both sets of opposite sidewalls with load magnitudes fluctuating between minimum and maximum values. Cycles can be further divided into sections. Each section represents the formation of an exterior fold on a specific set of opposite sidewalls and the corresponding formation of an interior fold on the other opposite sidewall pair.

For axial crush response, investigators have used or defined "crush characteristics", also called indicators or parameters, to evaluate and compare the performance of components (Pugsley, 1960; Coppa, 1968; Magee and Thornton, 1979). These characteristics include both direct data and derived quantities. The emphasis of the current investigation is on the direct data quantities from the load–displacement curve. These characteristics of interest are shown in Fig. 1c for the square box component and include: the initial phase peak load, $P_{\max}$ (or P_{02}); maximum and minimum loads, P_{ij}; mean or average loads, $P_{\text{mean}i}$; energy absorptions, EA_i; and axial displacements, δ_i. The subscript i refers to the initial phase if $i = 0$ and the ith cycle in the secondary

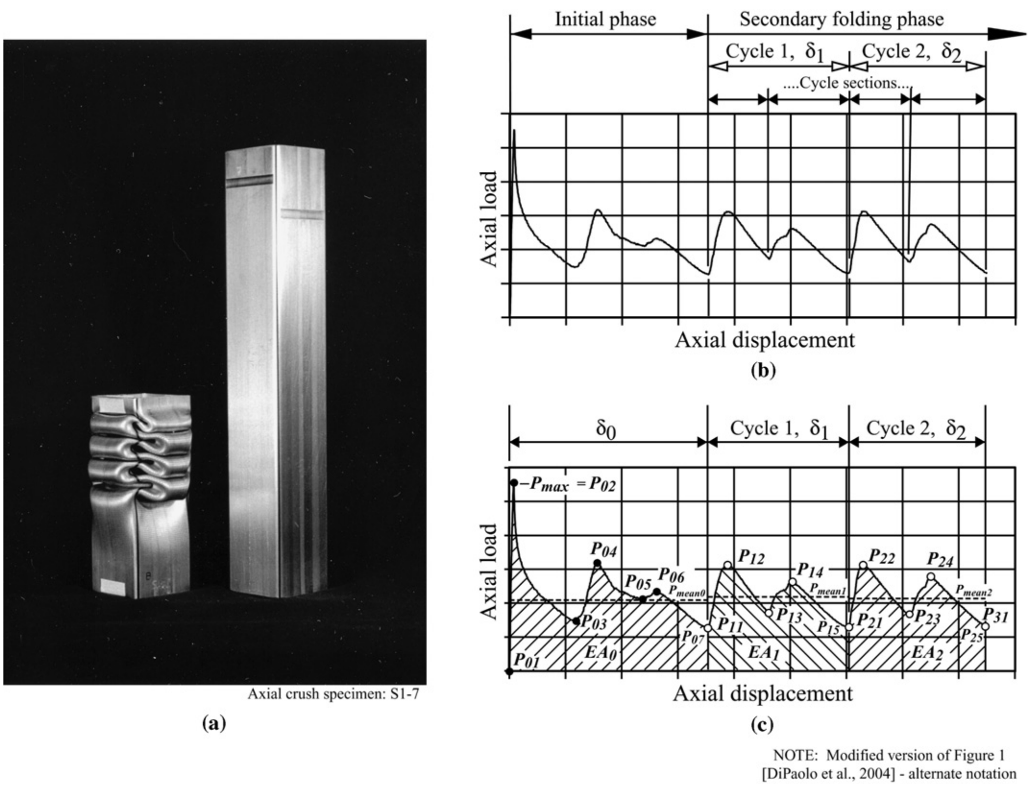

Fig. 1. Symmetric axial crush response mode – ductile metalic alloy, square box component: (a) axial crush and undeformed tube specimens, (b) curve sections and (c) crush characteristics.