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ScienceDirect
International Journal of Mechanical Sciences 49 (2007) 554–566
International Journal of Mechanical Sciences
www.elsevier.com/locate/ijmecsci

Experimental investigation of plastic collapse of aluminium extrusions in biaxial bending

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Received 31 January 2006; received in revised form 24 July 2006; accepted 26 September 2006
Available online 30 November 2006

Abstract

In this work results of an experimental study on the bending collapse of thin-walled beams subjected to biaxial bending (i.e. moment with components with respect to the section principal axes) are reported. The objective of the present work is to get a fundamental understanding of the phenomenon with particular enphasis to the test loading conditions and to the identification of the most suitable parameters for the description of such a large rotation collapse. The test equipment, specifically designed and build to execute biaxial bending tests, is briefly described. A series of tests was made on thin-walled aluminium structural components, with square and rectangular section. The study is focused on the description of the collapse and the post-collapse behaviour under in-plane and biaxial loading conditions. The adopted loading procedures, of the constrained bending plane type allows to study the evolution of the resisting moment (and of its components) developped during the collapsing process.

The behaviour was analyzed under two points of view: a global one, with the determination of the structural response as per generalized loads and displacements, and a local one, through the study of the kinematic of the plastic hinge mechanism.

Keywords: Biaxial bending; Thin-walled beam; Deep bending collapse

1. Introduction

The plastic bending collapse constitutes the more frequent mode of yielding in thin wall tubular members for vehicular and mechanical structures. The specific energy that characterizes this mode of collapse is, infact, much smaller than in the case of compression (axial folding).

The mechanisms of bending collapse have been widely analysed in the scientific literature [1–8] for cases in which the bending moment acts about one of the two principal axes of inertia of the section and therefore the collapse develops in a pure plane modality. The first experimental and analytical study of planar bending collapse was conducted by Kecman in 1979 [1,2].

The structural members of the vehicle frame designed to dissipate the energy in case of accident are generally subjected to combined loads, in the complex dynamic of the impact, due to the action of external forces or, indirectly, due to the internal loads which develop in the structure after the impact. Combined loads often occure, for example in a vehicle frontal offset impact or in a rollover.

In this perspective it is of interest to analyse the behaviour of thin walled boxed beams subjected to biaxial bending i.e. collapse under the action of bending loads about a non-principal axis. In case of biaxial bending load the collapse phenomenon is quite complex: the localized zone of the tube where the most part of the phenomenon takes place cannot be easly associated with a rotational joint with a certain resistant moment M function of the rotation angle θ (as it could be done in case of the planar bending). In plastic, as well as in the elastic range, the neutral axis and the bending moment vector are not parallel; therefore the number of parameters, necessary for the characterisation of the phenomenon is greater than the two (M and θ) while was sufficient in case of uniaxial bending.

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0020-7403/$ - see front matter
doi:10.1016/j.ijmecsci.2006.09.025

Nomenclature

a, b	sides of the beam
t	thickness
L	length of the beam
w, s	principal axes of inertia of the section
I_w, I_s	principal moment of inertia of the section
z	longitudinal axis of the beam
x, y	reference system
α	angle between x,y and w,s
M	resistant moment
NA	neutral axis
BP	bending plane
β	deviation angle
γ	orientation of NA in w, s system
M_w, M_s	components of resistant moment respect w and s
M_{NA}, M_{BP}	components of resistant moment respect NA and BP
λ	$\gamma-\beta$
θ	bending angle
σ_0	equivalent flow stress
χ, ψ	parameters for biaxial bending case description

As first solution of multiaxial bending problem, Todorovska-Azievska and Kecman [9], Vignjevicz [10,11] and Markiewicz et al. [12] proposed the use of an ellipsoidal limitcurve derived only from the uniaxial collapse characteristics. Because of the particularities of the bending collapse of thin walled structures, which involve wall buckling phenomena and deformation kinematic mechanisms, it is clear that in multiaxial bending the various types of deformation mechanism interact each other and the global behaviour cannot be obtained by simple summation of two independent phenomena, but the collapse must be studied as a whole.

More recently some studies have been devoted specifically to this type of problems [13–25].

The experimental analysis of multiaxial phenomena is more complex respect to the simple planar bendingcases, both for the multiaxial nature of the phenomenon and for the greater number of tests requested for its characterization. An increment in the variable number implies an increment in the test number. For this reason the works [13–25] are mainly of numerical type, by FE analysis.

In the literature, some attention has been devoted to the interaction between the axial collapse and the plane bending collapse [16,18–20], while the biaxial bending problem and the interaction between bending and torsion have been less studied [22].

The failure of thin-walled rectangular beams under biaxial bending was investigated experimentally for two different loading cases by Brown and Tidbury [17] up to the initial failure and yield loci were constructed from the peak moment data. In the loading case 1, side stays were used to costrain the direction of the deflection. The moment axis changed under load. In the loading case 2, a sliding device was used to permit the deflection axis to be free and to keep the moment axis fixed.

A comprehensive finite element simulation of deep biaxial bending collapse has recently been performed by Kim and Wierzbicki [21] and their results were compared with the test results reported by Brown and Tidbury [17].

The objective of the present work is to get a fundamental understanding of the phenomenon with particular enphasis on the test loading conditions and on the identification of the most suitable parameters for the description of such a large rotation collapse. The interest is mostly devoted to the determination of the maximum structure strength, to the energy absorption capacity during the collapse phase and to the deformation mechanisms and subsequent deformation path. These points are of great interest in the analysis of automotive energy absorption systems.

Recently the authors have produced a fully numerical and analytical solution of biaxial deep bending of thin-walled rectangular tubes [24,25]. That work, quite similar to Kim and Wierzbicki one [21], has been very helpful in the testing equipment design: in the following paragraphs some results of such study will be recalled, to better understand the experimental results.

Differently from Brown and Tidbury [17], thank to the greater possibilities offered by modern transducers and acquisition systems, it has been possibile to obtain more detailed results for the post-collapse phase, both for the collapse mechanism evolution and for the entities of interest (loads and displacements). The considered type of beam is also different: in [17] electrically resistence butt-welded bright steel tubing (BS 1775 Grade ERW11) were tested, while in the present work 6060 aluminium alloy extrusions are testedas discussed in the following paragraphs, this type of material may present critical deformation conditions, different from ductile steel.

2. Biaxial bending

For the biaxial bending problem definition, let us consider a thin walled beam (Fig. 1) with transverse rectangular cross section where a and b are the two sides (measured on the middle plane of the walls) and t is the wall thickness; the length of the beam is L. Let us suppose that the thin walled beam is loaded in bending about a generical direction not coincident with one of the two principal axes of inertia of the cross section. w (*weak*) and s (*strong*) are the two central axes of inertia of the cross section, z the longitudinal axis x and y constitute a second reference system, generically rotated by an angle α with respect to the system $w-s$, which is intented to identify the