Available online at www.sciencedirect.com
ScienceDirect
Thin-Walled Structures 45 (2007) 307–320
THIN-WALLED STRUCTURES
www.elsevier.com/locate/tws

Finite element modelling of welded aluminium members subjected to four-point bending

T. Wang[a,*], O.S. Hopperstad[a], O.-G. Lademo[a,b], P.K. Larsen[a]

[a]*Structural Impact Laboratory (SIMLab), Department of Structural Engineering, Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway*

[b]*SINTEF Materials and Chemistry, Applied Mechanics and Corrosion, 7465 Trondheim, Norway*

Received 20 July 2006; received in revised form 22 February 2007; accepted 22 February 2007
Available online 4 May 2007

Abstract

Finite element analyses are performed to predict the structural behaviour of welded and un-welded I-section aluminium members subjected to four-point bending. A modelling procedure using shell elements is established, where careful modelling of the inhomogeneous material properties due to welding is an important ingredient. A material model comprising anisotropic plasticity and ductile fracture is adopted. The yield function and work hardening parameters for the heat-affected zone, weld and base material are determined based on material tests and experimental data available in the literature. The numerical simulations comprise explicit analyses for a basic, relatively coarse mesh and implicit analyses for the same basic mesh and a refined mesh. Simulations are performed with perfect and imperfect geometries, since some beams fail by local buckling. The numerical results are compared with existing experimental data, and, in general, good agreement with the experimental results is obtained. However, the solutions are found to be mesh dependent for members failing by strain localisation and fracture in the tension flange.

Keywords: Aluminium; Welds; Anisotropy; Shell; Implicit; Explicit

1. Introduction

Thin-walled aluminium extrusions are used in several welded structures where low structural weight, high payloads, and in the case of transport applications high speed and low fuel consumption are required. Typical structures are plate girders and bridge decks, living quarters on offshore platforms, high speed ferries and ship superstructures, automobiles and containers. The competitiveness of such aluminium structures is primarily due to modern extrusion technology, new joining technologies and efficient manufacturing processes. Further market penetration of such structures depends upon efficient designs that fully utilise the advantages of aluminium extrusions. However, until recently this has been impeded by the lack of suitable design rules. The development of Eurocode 9 [1] has to a certain extent alleviated this problem, but for situations where design by analysis is required further knowledge about finite element (FE) modelling is needed.

At present, welds are commonly designed according to interaction formulas given in design codes. This procedure gives reasonable estimates for the strength of a welded component, but no prediction of its ductility. No unified approach is available to the problem of modelling of material failure in welded aluminium structures, which considers the mechanical properties of the welds and the heat-affected zones (HAZs), as well as the strain concentrations caused by the inhomogeneous material properties in the HAZ.

Experimental studies on welded connections in aluminium structures up to the year of 1999 were reviewed by Matusiak [2]. The most fundamental contribution is by Soetens [3], but Matusiak's work is also a major contribution and forms a basis for the present investigation. It includes a comprehensive experimental database on material behaviour of weldment and HAZ, and ultimate

*Corresponding author. Tel.: +47 73 59 26 10; fax: +47 73 59 57 76.
E-mail address: ting.wang@marintek.sintef.no (T. Wang).

0263-8231/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tws.2007.02.009

capacity, failure modes and ductility of welded aluminium connections, which only to a very limited extent has been used for assessment of numerical predictions.

Numerical simulations of the deformation behaviour and ultimate strength of welded components have been done by Matusiak [2] (aluminium), Mellor et al. [4] (steel), and Chan and Porter Goff [5] (aluminium) using solid elements and elasto-plastic constitutive models. Ødegård and Zhang [6] successfully predicted the performance of welded aluminium joints for car body applications using solid elements and a constitutive model of elasto-plasticity and ductile damage. More recently, Zhang et al. [7] integrated a thermal–mechanical microstructure analysis with a load-deformation mechanical analysis to predict the fracture behaviour of aluminium joints, employing solid elements and a constitutive model of elasto-plasticity and ductile damage. Good agreement with test data was found.

Currently, it is not feasible to model thin-walled aluminium structures using solid elements, and shell elements have to be used in FEM-based design. Accordingly, a systematic study is required to achieve an accurate, efficient and robust shell modelling methodology for such structures. The existing literature on the use of the shell elements in prediction of the capacity and failure of welded aluminium components is limited. Using a constitutive model of elasto-plasticity and ductile damage, Hildrum [8] predicted the behaviour of butt-welded stiffened panels made of aluminium extrusions subjected to impact loading. Satisfactory agreement with experimental results was obtained. Moen et al. [9] performed numerical simulations to study the rotational capacity of aluminium beams under moment gradient. The majority of the beams were un-welded, while two had a stiffener welded to the mid-section. In the simulations, the strength of the material was reduced uniformly in the HAZ close to the welded stiffener. These beams failed by necking in the tension flange, and the numerical predictions compared well with experiments. However, the authors doubted that the adopted simplified representation of the HAZ is sufficient to capture accurately the capacity and rotation capacity of welded beams.

The objective of the present study is to carry out an investigation of the accuracy, efficiency and robustness of shell element simulations of welded and un-welded I-section members under four-point bending. The members are analysed with LS-DYNA (LSTC [10]), adopting a material model named the Weak Texture Model 2D (WTM-2D) (Lademo et al. [11,12]) that relies upon the anisotropic yield criterion Yld89 proposed by Barlat and Lian [13]. The yield function and strain hardening parameters of the base material were established on the basis of tension tests in three directions relative to the extrusion direction. The strength and hardening data of the weld and HAZ were obtained by utilising data from the previous study of Matusiak [2]. Explicit analyses were first performed with a basic relatively coarse mesh. Subsequently, implicit analyses were performed with both the basic and refined meshes. Simulations were performed with perfect and imperfect geometries, since some beams fail by local buckling. The numerical results are compared with experimental data from Matusiak [2], and the overall agreement with experimental results is good. However, the solutions are found to be mesh dependent for members failing by strain localisation and fracture in the tension flange.

2. Review of the tests

Matusiak [2] performed four-point bending tests of simply supported I-section beams containing welded details. Fig. 1 shows a picture of the experimental test set-up, and the geometry of the beam specimens is depicted in Figs. 2 and 3. Vertical stiffeners were adhesively bonded to the specimens in order to prevent local failure at the points of load application. A total of six beam configurations were tested; all but one contained welded details. The welded

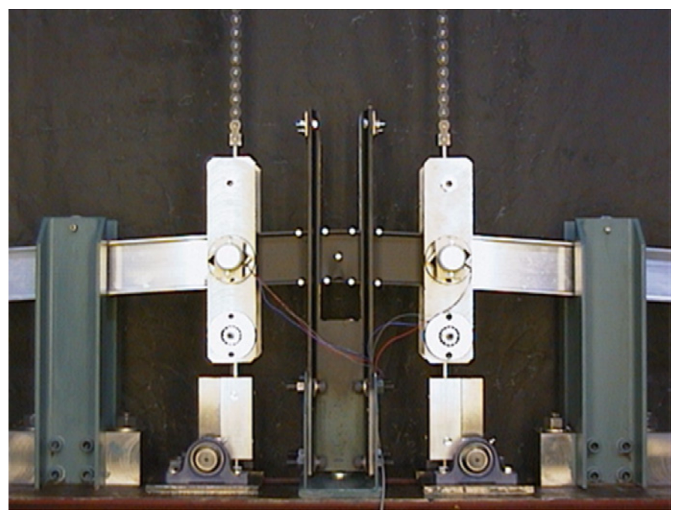

Fig. 1. Test set-up for four-point bending [2].

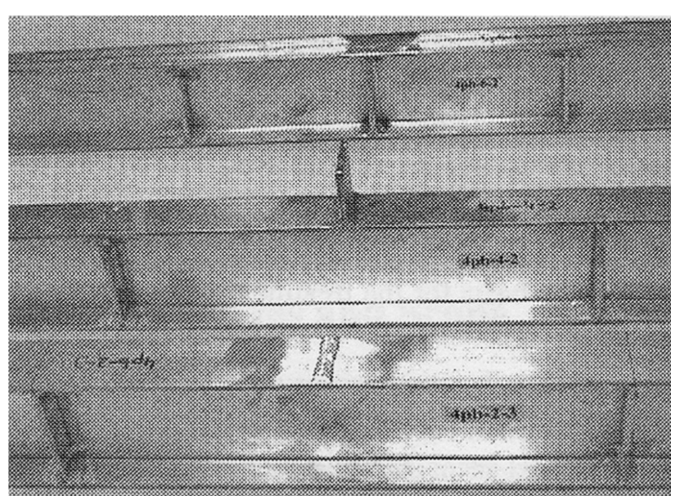

Fig. 2. Welded test specimens [2].