International Journal of Mechanical Sciences 53 (2011) 75–82

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

journal homepage: www.elsevier.com/locate/ijmecsci

Hydroforming of anisotropic aluminum tubes: Part I experiments

Yannis P. Korkolis [1], Stelios Kyriakides *

Research Center for Mechanics of Solids, Structures & Materials, WRW 110, C0600, The University of Texas at Austin, WRW 110, Austin 78712, TX, USA

A R T I C L E I N F O

Article history:
Received 20 August 2010
Received in revised form
23 November 2010
Accepted 27 November 2010
Available online 4 December 2010

Keywords:
Hydroforming
Aluminum tubes
Manufacturing
Process design

A B S T R A C T

Hydroforming of aluminum tubes, despite its appeal in weight-sensitive applications, presents challenges such as the reduced ductility of Al in comparison to steel and its more complex constitutive behavior. This two-part series of papers details a combined experimental and analytical study of the process and its limits. Part I presents a custom laboratory-scale facility used to conduct a series of hydroforming experiments on relatively long Al-6260-T4 tubes. The initially circular tubes are inflated against a square die with rounded corners while simultaneously they are axially compressed in order to delay wall thinning and burst. A 2D numerical model was used to optimize the loading histories considered. Despite careful design of the process, burst proved to be a limiting factor as friction prevented uniform material feeding to the expected levels. Furthermore, prediction of burst was found to require the calibration and implementation of non-quadratic, anisotropic yield functions in the constitutive modeling and the use of numerical models that include all 3D effects of the setup. These models and their performance in predicting all aspects of the experimental results are discussed in Part II.

1. Introduction

Tube hydroforming is a relatively modern forming process for shaping initially circular tubes into structural members of chosen longitudinal and cross-sectional shapes. In the simplest form of the process, the circular tube is expanded by internal pressure and forced to conform to a shaped die that surrounds it. Expansion causes wall thinning that can result in burst. Wall thinning and burst are delayed by simultaneously compressing the part. Axial shaping is achieved by pre- or post-bending the tubular component.

Although the process has a history of more than 100 years [1,2], advances in high-pressure technology and in controls achieved within the last two decades [3,4] have increased the accuracy and efficiency of tube hydroforming making it a viable competitor to traditional stamping. The added stiffness and crashworthiness offered by the closed cross section, the part consolidation for a given design plus the avoidance of spot welding are significant additional advantages [5–8], while the slower cycle of the process (10–15 s) is a minor impediment. Thus today, a variety of load bearing car body components are manufactured by hydroforming including chassis beams, engine cradles, roll bars, suspension subframes, exhaust systems, etc. [3] while numerous other applications have blossomed as well [9,10].

The pursuit of lighter and more fuel-efficient vehicles has made aluminum an attractive alternative to steel [6,11–13]. However, aluminum is less ductile and in sheet form has a more complex constitutive behavior than steels, and consequently requires more advanced constitutive description. The objective of the present study has been to evaluate the performance of Al alloys in tube hydroforming.

During hydroforming, the tube under high internal pressure and axial compression comes in partial contact with the surrounding die and inevitably experiences also some frictional forces. The induced deformation can result in a variety of failure modes including bursting, axial wrinkling and overall buckling. Consequently, the development of a working envelope that excludes the limit states of a given part is essential for its safe forming. Fig. 1 shows schematically an example of such an envelope in the axial force–pressure space (adapted from Refs. [9,14]; see Ref. [15]). The lower bound of this envelope is traced by the axial force required to react the internal pressure, ensuring sealing at the tube ends. At higher pressure levels, the burst limit of the tube is reached, drawn as a vertical line. If the axial load becomes excessive, the tube will wrinkle (e.g. see Fig. 8 in Ref. [16]) or buckle in an overall manner. Establishing such limit state boundaries for individual parts can be somewhat involved as it depends on the geometric and material parameters of the tube as well as the shape of the die. This task naturally requires a combination of analysis and experimentation (e.g. Ref. [14–21], among others).

This two-part series of papers presents an experimental and analytical investigation into limit states of aluminum tube hydroforming. Part I outlines a custom hydroforming facility developed for

* Corresponding author.
E-mail address: skk@mail.utexas.edu (S. Kyriakides).
[1] Presently at Department of Mechanical Engineering, University of New Hampshire, USA.

0020-7403/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmecsci.2010.11.003