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Rubber Assisted Compression Beading of Tubes

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Abstract

This paper introduces a new process for producing compression beads that successfully extends the formability limits of conventional compression beading. The process named as 'rubber assisted compression beading' makes use of a preforming stage that involves placing a cylindrical rubber plug inside the tube and expanding it by compressing with a punch. The rubber plug is then removed and the bulged tube is subsequently subjected to axial loading between two opposed dies in order to produce the desired compression bead. The presentation discusses plastic flow and formability limits associated with each individual stage of the proposed process.

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Keywords: Tube forming; Compression beading; Preforming; Rubber forming; Formability

1. Introduction

Compression beading is a tube forming process that is accomplished by forcing one tube end towards the other (or the two tube ends towards one another) while leaving a gap opening l_{gap} in-between the dies that hold the tube. (Fig. 1).

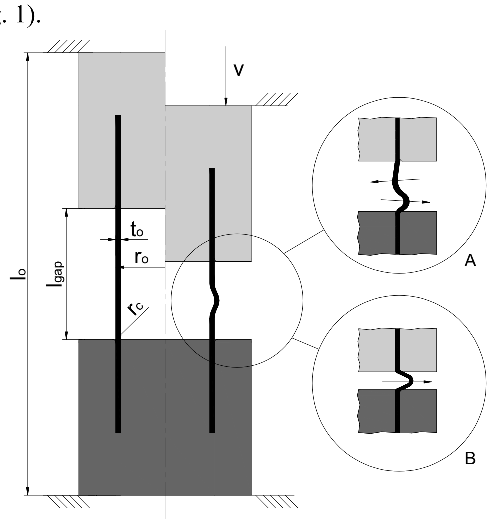

Fig. 1. Schematic representation of the compression beading of tubes.

As the tube is subjected to axial compression it collapses by local buckling under the resulting plastic axisymmetric instability wave and produces the required compression bead at the aforementioned gap opening.

Compression beading is utilized for creating sealing beads for pressure hose applications, for attaching tubes to sheets, for damping vibrations in air-pressure lines, liquid systems or exhaust tubes and for increasing the effectiveness of a sealing by means of O-rings, among other industrial applications.

The first investigation of local buckling in thin-walled tubes was performed by Shanley [1] who modified the elementary theory of columns due to Euler and suggested the concept of tangent modulus for calculating the critical instability load in plastically deformed cylindrical shells subjected to axial compression.

The past decades have seen major advances in this topic. Hutchinson [2], for example, studied the influence of geometric imperfections in the buckling behavior and critical instability loads of cylindrical shells. Tvergaard [3] analysed the influence of the ratio of the radius to the thickness of the tube r_0/t_0 (hereafter referred to as 'the radius-to-thickness ratio') in the development of axisymmetric and non-axisymmetric modes of deformation. Goto and Zhang [4] introduced the role

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played by boundary conditions and, more recently, Le Grognec and Le van [5] performed a comprehensive discussion on the utilization of finite elements to determine the critical instability loads, the bifurcation modes and the post-critical behavior of cylindrical shells in the elastoplastic range.

Fundamental studies in tube end forming by Alves et al. [6] prompted Gouveia et al. [7] to perform the first materials processing-oriented investigation in local buckling of thin-walled tubes. The work made use of varying gap opening conditions and identified (i) the tube slenderness ratio l_{gap}/r_0 and (ii) the radius-to-thickness ratio r_0/t_0, as the two main process operating parameters. The results showed that by varying r_0/t_0 it is possible to divide plastic flow into two different groups. For high values of r_0/t_0 compression beads are steadily formed both outward and inward (refer to 'A' in Fig. 1) whereas, for decreasing values of r_0/t_0, compression beads gradually changes to became outward dominant (refer to 'B' in Fig. 1).

The industrial application of compression beading for connecting tubes to sheets and tubes to tubes was recently investigated by Gonçalves et al. [8, 9] who concluded that the initial gap opening l_{gap} can significantly influence the overall process window. This is because the reduction of the unsupported tube length due to downward positioning of the upper die will always lead to the development of small width (and sometimes incomplete) compression beads that are generally unsuitable for industrial applications.

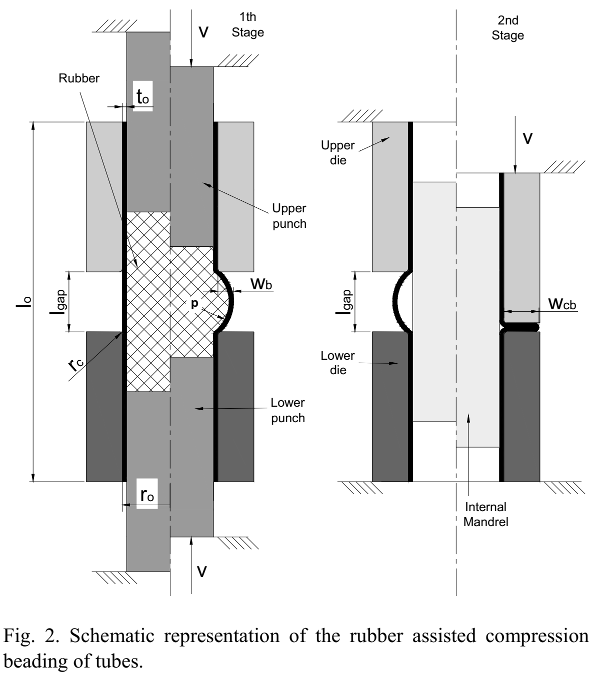

Fig. 2. Schematic representation of the rubber assisted compression beading of tubes.

Under these circumstances, the aims and objective of this paper is to introduce a 'rubber assisted compression beading' process that makes use of the original idea by Al-Qureshi [10] of using elastomers as pressure-transmitting medium for tube bulging, in order to meet the challenge of producing outward dominant, large width, compression beads in a broader range of process operating conditions. The new proposed process is schematically shown in Fig. 2 and makes use of a preforming stage that involves placing a cylindrical rubber plug inside the tube and expanding it by compressing with a punch. The punch is then retracted, the rubber plug is removed, and the bulged tube is subjected to axial loading between two opposed dies in order to produce the desired compression bead.

The organization of the paper is the following. Section 2 addresses the mechanical characterization of the material and the experimental work plan. Section 3 provides an overview of the analytical and finite element modeling conditions. Section 4 presents and discusses the results obtained for plastic flow and failure and compares the formability limits of the new proposed process with those of conventional compression beading. Section 5 presents the conclusions.

2. Experimental Background

2.1. Mechanical characterization

The tubular specimens utilized in the investigation were cut from commercial S460MC (carbon steel) welded tubes with an outside radius $r_0 = 16$ mm and a wall thickness $t_0 = 1.5$ mm. The stress-strain curve of the material was obtained by means of tensile and stack compression tests performed at room temperature on a hydraulic testing machine with a cross-head speed equal to 100 mm/min (1.7 mm/s). The relationship between true stress and true strain was approximated by means of the Ludwik-Hollomon's strain hardening model,

$$\sigma = 616.4\,\varepsilon^{0.06} \text{ (MPa)} \tag{1}$$

The critical instability load P_{cr} for the occurrence of local buckling was determined by compressing tubular specimens with 100 mm initial length between flat parallel platens. The average critical instability load P_{cr} was determined to be approximately equal to 100 kN.

2.2. Methods, procedures and work plan

As seen in Fig. 2 the rubber assisted compression beading process is accomplished by a sequence of two forming stages. In the first stage, a cylindrical rubber plug with 14.5 mm radius and 50 mm height, made from polyurethane with a Shore hardness of 90A, is placed