ARTICLE IN PRESS

CRAS2B:3603

C. R. Mecanique ••• (••••) •••–•••

Contents lists available at ScienceDirect

Comptes Rendus Mecanique

www.sciencedirect.com

Computational modeling of material forming processes / Simulation numérique des procédés de mise en forme

Finite element modelling of cold drawing for high-precision tubes

Florian Boutenel [a,*], Myriam Delhomme [b], Vincent Velay [a], Romain Boman [c]

[a] ICA (Institut Clément-Ader), Université de Toulouse, CNRS, IMT Mines Albi, INSA, UPS, ISAE–SUPAERO, Campus Jarlard, 81013 Albi CT cedex 09, France

[b] Minitubes ZAC Technisud, 21, rue Jean-Vaujany, BP 2529, 38035 Grenoble cedex 02, France

[c] Department of Aerospace and Mechanical Engineering, University of Liège, 9, allée de la Découverte, B-4000 Liège, Belgium

ARTICLE INFO

Article history:
Received 29 August 2017
Accepted 9 January 2018
Available online xxxx

Keywords:
Precision metal forming
Cold tube drawing
Tube sinking
Mandrel drawing
Finite element method
Large deformation

ABSTRACT

Cold tube drawing is a metal forming process that allows manufacturers to produce high-precision tubes. The dimensions of the tube are reduced by pulling it through a conical converging die with or without inner tool. In this study, finite element modelling has been used to give a better understanding of the process.

This paper presents a model that predicts the final dimensions of the tube with very high accuracy. It is validated thanks to experimental tests. Moreover, five studies are performed with this model, such as investigating the influence of the die angle on the drawing force or the influence of relative thickness on tube deformation.

1. Introduction

Medical devices, like stents, cardiac valves, and implants, are manufactured with thin-walled tubes of small diameters [1]. As applications in the biomedical field, these tubes require a very high precision in dimensions and surface finish. Also, these properties are strongly linked to the quality of the metal forming process.

Cold tube drawing enables manufacturers to produce tubes with controlled dimensions, good surface finish, and high mechanical properties [2]. This metal forming process gives a better tube quality compared to hot forming. Tube drawing consists in reducing the tube dimensions by pulling it through a conical converging die with or without inner tool. Different drawing methods exist [3]. In this paper, two techniques are studied: tube sinking and mandrel drawing (Fig. 1).

For both of them, the die calibrates the tube's outer diameter. Tube sinking is the only method that does not use an inner tool. The inner diameter is reduced because of the free deformation inside the tube. In consequence, the inner surface finish is degraded. In mandrel drawing, the inner tool, named mandrel, moves with the tube and calibrates its inner diameter. The main drawback of this technique is related to the end of the drawing operation where the tube is clamped around the mandrel. Thus, a reeling operation is required to remove the tool.

The metal forming industry wants to perpetually improve productivity and product quality. In order to reach this purpose, a better understanding of the processes is necessary. On the one hand, a large series of experimental tests can be done.

* Corresponding author.
E-mail addresses: florian.boutenel@mines-albi.fr (F. Boutenel), m.delhomme@minitubes.com (M. Delhomme), vincent.velay@mines-albi.fr (V. Velay), r.boman@ulg.ac.be (R. Boman).
URLs: http://www.institut-clement-ader.org/ (F. Boutenel and V. Velay), http://www.minitubes.com/ (M. Delhomme), http://www.ltas-mnl.ulg.ac.be/ (R. Boman).

https://doi.org/10.1016/j.crme.2018.06.005

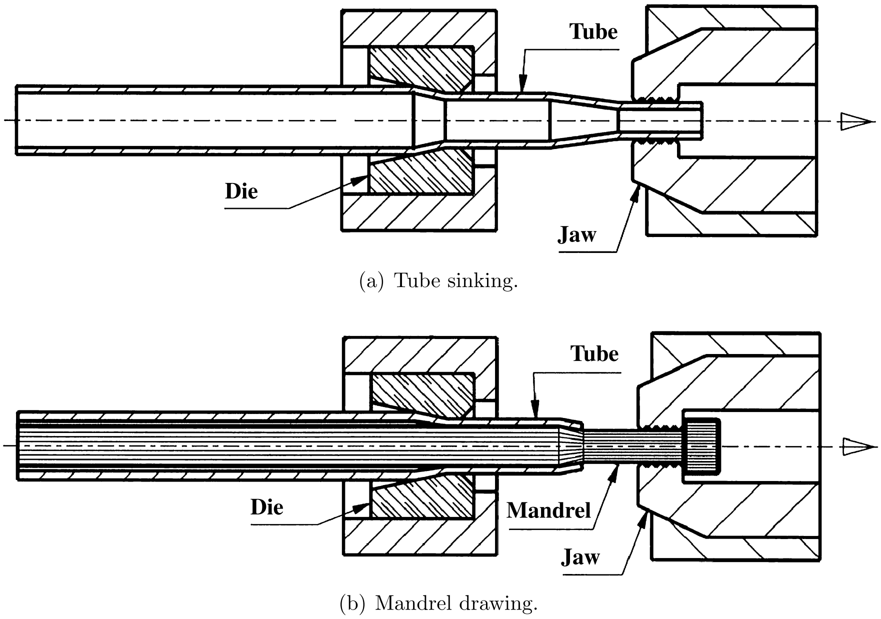

Fig. 1. Sketch of the two drawing methods studied in this paper (adapted from [4]).

However, this type of approach may be time and money consuming. On the other hand, lots of tests can be performed virtually thanks to finite element (FE) modelling. It also gives access to physical values, such as stresses and strains, which are not measurable during the process. Thus, FE modelling seems to be a helpful tool.

Analytical solutions have been developed by several authors to study the effects of process parameters. Um et al. [5] obtained an upper bound solution to fixed plug drawing that can be simplified in the case of tube sinking. This method has been adapted to mandrel drawing by Alexandrova [6] in the case of mandrel drawing. Later, the Hill's general method of analysis for metalworking processes and a fracture criterion have been added to this analytical model to study the workability of mandrel drawing [7]. Zhao et al. [8] have proposed an analytical solution to tube sinking using an integration method of strain rate vector inner product.

Numerical studies of tube drawing using FE can also be found in the literature. A finite element analysis has been conducted by Sawamiphakdi et al. [9] to determine the initial tube sizes that give the appropriate mechanical properties after drawing. Linardon et al. [10] combined a conical mandrel tube drawing test with a FE modelling to select a failure criterion. The potential making of high-quality thin tubes with shape-memory alloys thanks to mandrel drawing has been studied by Yoshida et al. [3]. Karnezis et al. [11] used a FE model to investigate the possibility of reducing the number of drawing passes. Palengat et al. [12] underlined the importance of the properties of the interface (tube with tools) on the drawing limits. Several studies dealing with tools design have been achieved in order to improve the process. Sheu et al. [13], Lee et al. [14] and Béland et al. [15] focused on the die geometry, while Kim et al. [16] had an interest for the mandrel one.

In this paper, a FE model is designed to precisely predict the final dimensions of the tube. This axisymmetric steady-state model takes into account different issues, including tool geometry, tube elastoviscoplastic behaviour, tool elastic behaviour, contacts and friction. Moreover, the numerical convergence is built to reach a 1-micron accuracy. In consequence, this model can be used to analyse the tube drawing process, and thus, permits a better understanding.

This modelling was performed on Metafor [17–19], an in-house nonlinear finite element code of the Department of Aerospace and Mechanical Engineering of the University of Liège, Belgium.

This paper is organised as follows. A detailed model formulation is given in Section 2. Then, Section 3 compares the numerical results with drawing experiments in order to validate the model. Furthermore, a numerical analysis of the process is presented in Section 4. Finally, Section 5 reports on the conclusions of this work.

2. Formulation of the finite element model

This section describes precisely the FE modelling. Tube sinking and mandrel drawing are treated together because of their many similarities. For mandrel drawing, the reeling operation is not modelled. It implies that, at the end of the simulation, the tube remains clamped around the mandrel.

Please cite this article in press as: F. Boutenel et al., Finite element modelling of cold drawing for high-precision tubes, C. R. Mecanique (2018), https://doi.org/10.1016/j.crme.2018.06.005