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Computational simulation of manufacturing processes

Lagrangian and arbitrary Lagrangian Eulerian simulations of complex roll-forming processes

Yanick Crutzen, Romain Boman, Luc Papeleux, Jean-Philippe Ponthot *

LTAS – Computational Mechanics, University of Liège, 9 allée de la Découverte, B-4000 Liège, Belgium

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A B S T R A C T

The Arbitrary Lagrangian Eulerian (ALE) formalism is a breakthrough technique in the numerical simulation of the continuous-type roll-forming process. In contrast to the classical Lagrangian approach, the ALE formalism can compute the hopefully stationary state for the entire mill length with definitely effortless set-up tasks thanks to a nearly-stationary mesh. In this paper, advantages of ALE and Lagrangian formalisms are extensively discussed for simulating such continuous-type processes. Through a highly complex industrial application, the ease of use of ALE modelling is illustrated with the in-house code METAFOR. ALE and Lagrangian results are in good agreement with each other.

1. Introduction

In the manufacturing industry, cold roll forming has achieved a renewed interest since high-yield-strength metals have been brought to the market. According to recent expectations, roll-formed sections will be even very common in the near future for automotive industry [1]. The primary reason is that it is a convenient way for forming materials with high mechanical strength circumventing limitations of the classical deep drawing process for such materials (e.g., limited press power, sheet tearing, large springback, limited formability, etc.). Besides, roll forming provides a high productivity and complex shaped cross-sections.

In cold roll forming, the material is fed into the mill as a flat pre-cut or continuous strip and is incrementally formed through successive roll stands until the desired cross-sectional shape is obtained. In a continuous forming method (also named post-cut method), the material is typically coiled and cut to length after roll forming. In most cases, the continuous forming method is adopted in the industry [2,3] since the pre-cut method exhibits a certain number of drawbacks. Contrary to the post-cut method, the pre-cut forming method requires a minimum product length: the product length should be at least equal to twice the inter-stand distance to ensure that the strip is engaged in a minimum of two stands at any time of the forming process (see Fig. 1). In addition, the end-flare defect is usually larger when pre-cut sheets are roll formed. Moreover, the forming tools are more prone to wear or even damage, especially due to the leading and trailing ends of the pre-cut strip that can hit the tooling. Designing a pre-cut mill requires thus extra care, resulting usually in a higher number

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* Corresponding author. Tel.: +32 04 3669310.
E-mail addresses: Y.Crutzen@ulg.ac.be (Y. Crutzen), R.Boman@ulg.ac.be (R. Boman), L.Papeleux@ulg.ac.be (L. Papeleux), JP.Ponthot@ulg.ac.be (J.-P. Ponthot).
URL: http://www.ltas-mnl.ulg.ac.be (J.-P. Ponthot).

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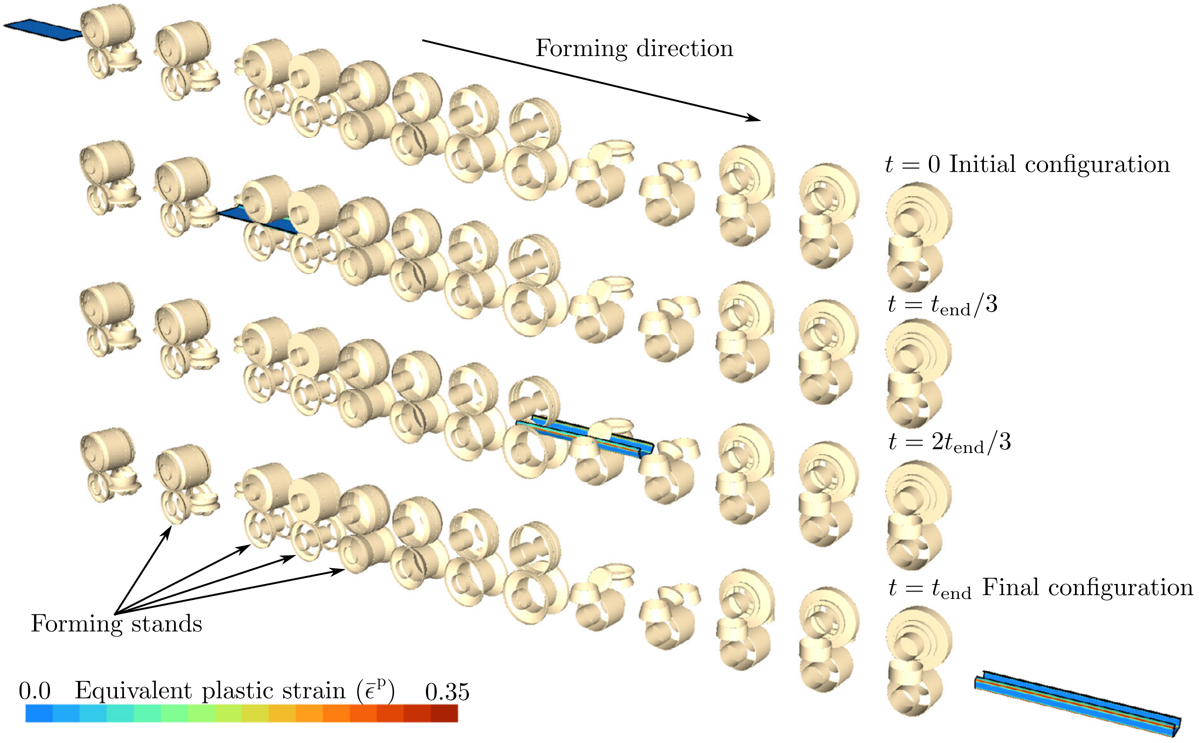

Fig. 1. Illustration of the progress of a Lagrangian roll forming simulation of a C-channel as proposed in [4] with the pre-cut method using METAFOR [5,6] (sheet length = 710 mm — inter-stand distance = 300 mm).

of forming stands and, in turn, in a possible higher investment cost. Finally, a distinct advantage of a post-cut mill is that several auxiliary operations such as punching, sweeping, welding, longitudinal bending, etc. can be gathered in-line to form a single complete unit, removing the need for handling cost.

Finite element analysis (FEA) is regarded in industry as an essential tool for the early design and optimization stages of a roll-forming mill. Complex deformations occur during the roll-forming process, involving possible shape defects on the final product such as longitudinal bow, oil canning, end-flare, etc. Hence, the designers' know-how based on empiricism or some simplified formulae [3] cannot be sufficient for ensuring the demanding quality of the product. In addition, the introduction of new high-strength materials into a relatively ancient forming process is a challenging task for the designers. In particular, mastering the larger springback experienced with the higher strength materials is by far not a straightforward operation, regarding the tight dimensional tolerances required for the roll-formed product. As a result, attempts to simulate the roll forming process by the finite element method are multiplying in the literature [7–23].

However, for such a problem, FEA generally remains incredibly time-consuming, thus limited, in the scientific literature, to some simple cases (exceptions can be found in [8–11,14]) and to the pre-cut forming method (exceptions can be found in [12,14]) and thereby does not fit very well in today's competitive industry. These numerical models rely on a Lagrangian kinematical description where the mesh follows the material's motion. In such Lagrangian models, an initially-flat pre-cut strip is formed in the successive forming stands (the progress of such a Lagrangian simulation can be seen in Fig. 1). This kind of formalism is not very well suited for simulating the continuous roll-forming process. Indeed, the modelled strip should be ideally longer than twice the length of the mill, resulting in costly and certainly not affordable numerical models. Consequently, in industrial practice, these difficulties hinder the intensive use of FEA in the design of roll-forming mills.

The application of the Arbitrary Lagrangian Eulerian (ALE) formalism to continuous roll-forming simulations as presented here is an effective alternative to the classical Lagrangian one (see Fig. 2). This approach definitely represents an original proposition on a market dominated by the Lagrangian kinematics. It does not follow the technology standards established especially by COPRA, the leader in software technology for roll-formed sections simulation, with its dedicated module COPRA FEA RF [24]. In contrast to the conventional Lagrangian approach, the ALE formalism, which consists in decoupling the motion of the material and the mesh, has the capability to compute the hopefully stationary state of the continuous process for the entire roll forming line at an acceptable response time by using a nearly-stationary mesh. In the particular case of roll forming, the mesh nodes are globally fixed in the forming direction but are free to move in transverse directions. Taking advantage from this approach, the mesh is only refined in the close neighbourhoods of the forming tools for accurate modelling of contact and bending. Since the pioneering work performed by Boman et al. [12,14] in the area of modelling, the continuous roll-forming process in ALE formalism, relentless breakthroughs have been made. First, Boman et al. investigated a specific strategy for the case of a U-channel: the initially-flat strip is bent between the rolls of the mill like in a

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