

Finite elements and discretization techniques for the prediction of flatness defects during sheet metal forming processes.

The prediction of buckling is a matter of primary concern to sheet metal producers and hence represents one of their major research topics. Indeed, the flatness defects, which manifest themselves in the form of waves of various orientations, represent one of the main criteria that allow the qualification of the product quality. Numerous attempts have been made to determine the origin of these defects for decades, which aim to eliminate or at least noticeably reduce them.

In sheet metal forming processes, such as rolling, complex loading conditions come into play, combining plasticity, contact, highly compressive stress state in the vicinity of tools, elastic tool deflection, significant stress variations consecutive to the contact zone, very flat geometry of the product... Under the extreme loading conditions characteristic of rolling, the deformation of the rolls (flattening, bending, and thermal dilatation) results in elongation heterogeneity subsequent to the contact zone in the rolling direction. This heterogeneity induces residual stresses that may lead to buckling.

The finite element simulation of this problem is underpinned by numerous difficulties. Three-dimensional finite elements, which are well suited for the simulation of the contact zone, are not appropriate for accurately predicting large rotation buckling. On the other hand, traditional shell elements commonly used for modeling flat products are not suited to carry the compressive loading induced by two-side contact with the tools.

The objective of this research is to investigate innovative discretization procedures that allow the proper analysis of the metal sheet both under contact zone and in the rest of the sheet. The numerical chaining of a rolling code, based on three-dimensional elements, and a buckling code using shell elements has been recently applied to this type of problem [1]. Other more or less strong coupling approaches may be tackled, exploiting e.g. the observation that stress field relaxation induced by buckling does not affect the rolling zone. Another promising research direction would be the accommodation of different finite elements within a single, unified simulation. The development of enhanced shells [2] or solid-shell elements [3,4] that are able to model the entire process would be a significant progress in this field. Indeed, the complex nature of the rolling stress state is one of the limitations of the current shell elements available in the literature [5-8]. Clearly, the simplest method would be to adopt the same discretization technique for all zones of the metal sheet. This common finite element would be either an enhanced shell or a solid-shell formulation, for which the LEM3-ENSAM team has a well acknowledged experience [9], and the investigation of this finite element technology represents the major objective of this PhD thesis. Let us mention another more complex alternative, which should be assessed, consisting of the coupling of two FE models (Arlequin technique or « bridging ») allowing thus shell and 3D finite elements to be connected.

Although this research work is of fundamental nature, its potential/prospective applications are important. This project would allow two research teams to interact combining their well recognized core competences, namely the modeling of rolling processes and the associated buckling and flatness defect predictions, and the development of enhanced, solid-shell finite elements that combine the advantages of both types of elements. In the two above-mentioned research fields, the LEM3 laboratory already has long term partnerships with well-known industrial corporations as well as existing collaborations with other laboratories (CEMEF, LaMCoS) through joint projects funded by the ANR research agency.

[1] H. Zahrouni, M. Potier-ferry, N. Legrand, P. Buessler. « Etude du flambage d'une bande métallique soumise à différents chargements mécaniques ». Rapport de contrat de recherche, 2007.

[2] N. Buechter, E. Ramm, D. Roehl. « Three dimensional extension of non-linear shell formulation based on the Enhanced Assumed Strain Concept ». International Journal for Numerical Methods in Engineering, vol. 37, 1994, pp. 2551–2568.

- [3] F. Abed-Meraim, A. Combescure. « SHB8PS – a new adaptive, assumed-strain continuum mechanics shell element for impact analysis ». *Computers & Structures*, vol. 80, 2002, pp. 791–803.
- [4] F. Abed-Meraim, A. Combescure. « A physically stabilized and locking-free formulation of the (SHB8PS) solid-shell element ». *European Journal of Computational Mechanics*, vol. 16, 2007, pp. 1037–1072.
- [5] Y. Tosawa. « Analysis of three-dimensional deformation in strip rolling taken deformation of rolls into consideration ». *Advanced Technology of Plasticity*, vol. 2, 1984, pp. 1151–1160.
- [6] F. G. Rammerstorfer, F. D. Fisher, N. Friedl. « Buckling of free infinite strips under residual stress and global tension ». *Journal of Applied Mechanics*, vol. 68, 2001, pp. 399–404.
- [7] F. D. Fisher, F. G. Rammerstorfer, N. Friedl, W. Wisser. « Buckling phenomena related to rolling and levelling of sheet metal ». *International Journal of Mechanical Sciences*, vol. 42, 2000, pp. 1887–1910.
- [8] C. D. Coman, A. P. Bassom. « An asymptotic description of the elastic instability of twisted thin elastic plates ». *Acta Mechanica*, vol. 200, 2008, pp. 59–68.
- [9] F. Abed-Meraim, A. Combescure. « An improved assumed strain solid-shell element formulation with physical stabilization for geometric nonlinear applications and elastic-plastic stability analysis ». *International Journal for Numerical Methods in Engineering*, vol. 80, 2009, pp. 1640–1686.
- [10] H. Ben Dhia, G. Rateau. « The arlequin method as a flexible engineering design tool ». *International Journal for Numerical Methods in Engineering*, vol. 62, 2005, pp. 1442–1462.

Scientific field: Solid Mechanics, Computational Mechanics, Mixed Finite Elements.

Key words: Buckling, plastic instabilities, residual stresses, thin sheets, rolling, flatness, enhanced shell elements, solid–shell elements.

Laboratory: LEM3 (Laboratoire d’Etude des Microstructures et de Mécanique des Matériaux), UMR CNRS 7239.

Web site: <http://www.lpmm.univ-metz.fr>

Team: Computational Mechanics.

Head of the team: Michel POTIER-FERRY.

Supervisor: Farid ABED-MERAİM.

Email: farid.abed-meraim@ensam.eu

Collaboration with other partners during the PhD:

In France: M. POTIER-FERRY, H. ZAHROUNI (LEM3, UDL); P. MONTMITONNET (CEMEF, Mines ParisTech).

Application:

Please send application form and materials to Mr. Yvon VELOT

→ yvon.velot@ensam.eu