International Journal of Mechanical Sciences 53 (2011) 661–675

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

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

Coupled approach for flatness prediction in cold rolling of thin strip

S. Abdelkhalek [a,*], P. Montmitonnet [b], N. Legrand [a], P. Buessler [a]

[a] ArcelorMittal Research Maizières, R&D Industrial Operations, Voie Romaine, B.P. 30320, F-57283 Maizières-Lès-Metz, Cedex, France
[b] CEMEF, Ecole des Mines de Paris-ParisTech. 1, rue Claude Daunesse, B.P. 207, F-06904 Sophia-Antipolis, Cedex, France

ARTICLE INFO

Article history:
Received 12 November 2010
Received in revised form
14 February 2011
Accepted 3 April 2011
Available online 14 April 2011

Keywords:
Sheet metal
Rolling
Flatness defects
Residual stress
Buckling
Numerical and asymptotic method

ABSTRACT

The paper presents a predictive model of the flatness defects, which appear during rolling of thin plates, the origin of which is the roll stack thermo-elastic deformation. The combination of the elastic deflection, the thermal crown and the roll grinding crown results in a non-parallel bite, and if the deformed roll transverse profile is not an affinity of the incoming strip profile, differential elongation results and induces high stresses in the outgoing strip. The latter, combined with the imposed strip tension force, result in a net post-bite stress field which may be sufficiently compressive locally to promote buckling. A variety of non-developable shapes may result, generally occurring as waviness (centre waves, wavy edges, quarter-buckles, etc.). This problem is most of the time addressed in a decoupled way, i.e. as a post-processing of the residual stresses computed by a strip rolling model; the present paper on the contrary describes a fully coupled approach of in-bite plastic deformation and post-bite buckling. For this purpose, a simple buckling criterion has been introduced in a FEM model of strip and roll deformation, Lam3/Tec3; its implementation is documented in details. The capabilities and limits of the present approach are described and discussed. Characterised by its coupled approach, it is primarily devoted to cases where on-line (under tension) manifested defects occur. It is shown that the impact of the post-bite, post-buckled stress field on the in-bite stress and strain fields is quite small in the cases investigated; however, subtle changes appear in the velocity field at bite exit, and this is sufficient to transform completely the post-bite stress field, which is found in much better agreement with measurements if such a coupled treatment is used.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Flatness defects are among the major problems encountered in strip rolling. Their direct origin is out-of-bite stress gradients resulting in buckling in the compressive stress areas. Depending on the stress component involved and the location of compressive areas, waves in the longitudinal, transverse or oblique directions can be found at diverse locations [1–4] (see Fig. 1: long edge/centre, quarter-buckles, herringbone buckles, etc.). In turn, these pre- and post-bite stress gradients have their origin in the differential elongation due to the combination of incoming strip crown and work roll (WR) active profile. The latter is a combination of grinding crown, thermal crown, and elastic roll stack and stand deformation (see Fig. 2).

During the rolling process, the strip is under tension from coilers or neighbouring stands. Hence, defects can be more or less hidden (latent defects); yet heterogeneous stress distributions may be measured by tensiometer rolls (Fig. 3a and b). Such a latent defect may become apparent (manifested defect) when the strip tension is released (Fig. 3c). The decoupled strip rolling/buckling approach used in most of the literature should be adequate in such cases.

In some cases however, in particular for thin strips, the stress field may be sufficient to create a manifested defect on the mill, under tension. In this situation, a feed back of the stress relief (due to post-bite buckling) on in bite stress is possible, which calls for a coupled approach. The present paper is devoted to the development and application of such a coupled model, to start analysing in which cases this coupling effect is significant. Studying a few representative cases of on-line manifested flatness defects in thin strip rolling is the main topic of the present paper.

2. Literature survey

Modelling flatness defects requires four elementary "bricks":

1. A model giving the contact stresses at the strip–roll interface, either in the form $f(y)$ (rolling force distribution) or $\sigma_n(x, y)$ (stress distribution).

* Corresponding author. Tel.: +33 3 87 70 42 93; fax: +33 3 87 70 41 01.
E-mail addresses: sami.abdelkhalek@arcelormittal.com (S. Abdelkhalek), pierre.montmitonnet@mines-paristech.fr (P. Montmitonnet), nicolas.legrand@arcelormittal.com (N. Legrand), pascal.buessler@arcelormittal.com (P. Buessler).

0020-7403/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmecsci.2011.04.001