International Journal of Mechanical Sciences 53 (2011) 827–838

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

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

An airy function to rapidly predict stresses in wound metal strip having asymmetric thickness profile

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ARTICLE INFO

Article history:
Received 6 October 2010
Received in revised form
8 July 2011
Accepted 8 July 2011
Available online 23 July 2011

Keywords:
Sheet rolling
Winding stress
Wedge
Asymmetric thickness profile
Flatness control
Airy function

ABSTRACT

With increased demand for thin gage flat metals, control of strip flatness or shape in cold rolling processes has become very important. To improve the flatness quality of cold rolled metal strip and sheet, this work provides a rapid method to predict the transient strains (or stresses) occurring during the rewinding of flat-rolled steels having problematic asymmetric strip thickness profile (or wedge). Flatness control systems, used to monitor and correct the distribution of stress across the width of rolled sheet, are unable to distinguish between stresses induced during rolling, and those caused when rewinding strip containing asymmetric thickness profile. The winding stresses, unless large enough to plastically deform the strip, vanish upon unwinding during subsequent operations such as stamping. Therefore, to help avoid strip flatness defects in thin strip containing wedge, a method is developed to separate the winding stress contribution from the overall stresses that are measured indirectly by flatness control systems. A fourth-order polynomial Airy function is developed to rapidly predict the in-plane stresses based on mandrel wrap number and spatial location on the strip. The Airy function is obtained by applying two-dimensional finite element analysis to study the transient in-plane stresses during rewinding at various numbers of mandrel wraps for a strip containing wedge profile. Three-dimensional finite element analysis is first employed, however, to show justification to a simplified two-dimensional problem described by the plane-stress Airy function. The two-dimensional finite element analysis provides insight as to how the in-plane stresses evolve, and allows determination of coefficients for the Airy function based upon model geometry and displacement boundary conditions. This approach differs from other methods that employ Fourier series to solve the biharmonic equations for an assumed two-dimensional problem. Finally, filtering of the winding stresses from flatness control system input signals is also discussed based on data taken from a rolling mill different to that used for model development.

1. Introduction

1.1. Strip flatness

As products derived from metal sheet become smaller and more precise, the demand for higher quality raw materials also increases. When cold rolling thin metal strip or sheet containing asymmetric thickness profile, quality problems such as poor final flatness are difficult to address. This is particularly true because the rolling and winding of strip with asymmetric thickness profile can cause localized buckling (strain defects) due to high in-plane stress gradients. The resulting poor strip flatness also decreases rolling productivity, and may render the products unusable in downstream manufacturing processes such as annealing, slitting, or stamping. An overview of the cold rolling and subsequent winding process for strip with less-problematic, symmetric thickness profile has been discussed by Edwards and Boulton [1]. In contrast, the focus of this work is an analytical method to rapidly assess in-plane stress (or strain) and related flatness for strips with asymmetric thickness profile (or wedge). Parameters for the study are based on the reversing cold rolling mill operated by Mid America Stainless Corp (Fig. 1a and b).

Almost all of the type 301 and 304 stainless steels rolled on the narrow Mid America Stainless mill contain up to three percent wedge [2]. This is because the narrow coils rolled are obtained from wider coils containing up to 3% parabolic thickness profile. Parabolic and wedge-type strip thickness profiles, corresponding to those before and after slitting, are depicted in Fig. 2.

1.2. Flatness implications when winding strip with asymmetric thickness profile

Flatness or shape defects in rolling occur mostly where localized regions of the strip contain excess longitudinal strain (elongation in the rolling direction) as compared to surrounding

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doi:10.1016/j.ijmecsci.2011.07.003