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ScienceDirect

Procedia Engineering 184 (2017) 306 – 312

Procedia Engineering

www.elsevier.com/locate/procedia

Advances in Material & Processing Technologies Conference

Finite Element Analysis of Plastic Instability Phenomenon in Cold Rolling of Clad Sheets

Tetsuyuki Imai[a], Hiroshi Utsunomiya[a]* and Ryo Matsumoto[a]

[a]*Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University, Japan*

Abstract

Clad sheets with stacked dissimilar metal layers are used in various industries. Layers often deform non-uniformly during cold rolling in manufacturing processes. Criteria for onset of this plastic instability has not been fully understood. In this study, one-pass cold rolling of three-layered sheet having hard inner layer and soft outer layers has been analyzed by the elastic-plastic finite element method. As a result, periodical necking of the inner layer is reproduced successfully. It is found that higher difference in flow stresses between layers and lower work hardening result in the periodical necking.

Peer-review under responsibility of the organizing committee of the Urban Transitions Conference

Keywords: clad sheets, plastic instability, necking, cold rolling, finite element analysis;

1. Introduction

Clad sheets with structure of stacked dissimilar metal sheets, are widely used in various industries [1], for example, bimetals for temperature control, battery electrodes and electronic devices [2]. This is because they have unique combined functions and properties which are different from those of monolithic sheets. Many kinds of clad sheets with different combinations of materials, number of layers and thicknesses are available commercially. They are mostly manufactured through (a) stacking, (b) roll-bonding, (c) diffusion annealing and (d) cold rolling processes [3]. Layers of the clad sheet often do not deform uniformly in the cold rolling process. Layers may show periodical necking, meandering toward thickness direction, or fracture. These are problems due to the plastic instability. It limits manufacturing and applications of clad sheets [4, 5]. However, general criteria of the plastic instability has not been reported. Therefore, it is hard to avoid the problem in industries.

Peer-review under responsibility of the organizing committee of the Urban Transitions Conference
doi:10.1016/j.proeng.2017.04.099

In case of three-layered sandwich sheets, the hard inner layer shows necking and fracture [6, 7], while soft inner layer shows meandering toward the thickness direction [8, 9]. It was reported that various factors affect the plastic instability. They can be divided into (a) rolling conditions, (b) materials conditions and (c) lubrication conditions. For the rolling conditions, roll diameter, reduction in thickness, speed, and temperature, affect the phenomenon. For materials conditions, number of layers, combination of materials, thicknesses of layers [10], affect the phenomenon. For the material properties, yield stresses and work hardening rates of layers have strong effect. Onodera et al. [6] proposed that (a) higher difference in flow stresses and (b) lower work hardening rate of the hard layer, are the major factors to cause periodical necking. However, it is difficult to elucidate a general criteria, because many factors influence and interactions among these are not negligible. However, theoretical approach for the plastic instability has been limited [11].

In this study, a two-dimensional finite element analysis has been conducted. Cold rolling of three-layered sheet having a hard inner layer and soft outer layers is modeled. The periodical necking has been successfully reproduced by the numerical analysis. In order to investigate influence of material properties, analyses were performed with several combinations of flow stress and work hardening rate.

2. Finite Element Analysis

A non-steady-state analysis was performed, using a commercial finite element software ABAQUS Standard version 6.14. Fig. 1 shows FE model of this rolling analysis. Plane-strain condition without lateral spreading was assumed. Neither effects of temperature change nor strain rate were considered. The rolls of 130mm in diameter were assumed to be rigid and rotated at 2m/min. Friction coefficient between the sheet and the rolls was 0.1. One-pass rolling operation with thickness reduction of 20% was analyzed. The clad sheet 180mm in length had three-layer structure 0.6mm in total thickness (0.2mm in layer thickness) was divided into single mesh of 4-node quadrilateral elements with 20μm in side length. The three-layered structure was represented by giving different material properties to elements in layer by layer. In other words, there was no relative sliding on the two interfaces between the layers. Both the inner and the outer layers are elastic-perfectly plastic body with Young's modulus of 200GPa, Poisson's ratio of 0.3. Yield stress Y_h = 1GPa, were prescribed to the inner hard layer, while yield stress Y_s = 0.25GPa, was prescribed to the outer soft layers. These were the standard conditions of this finite element analysis.

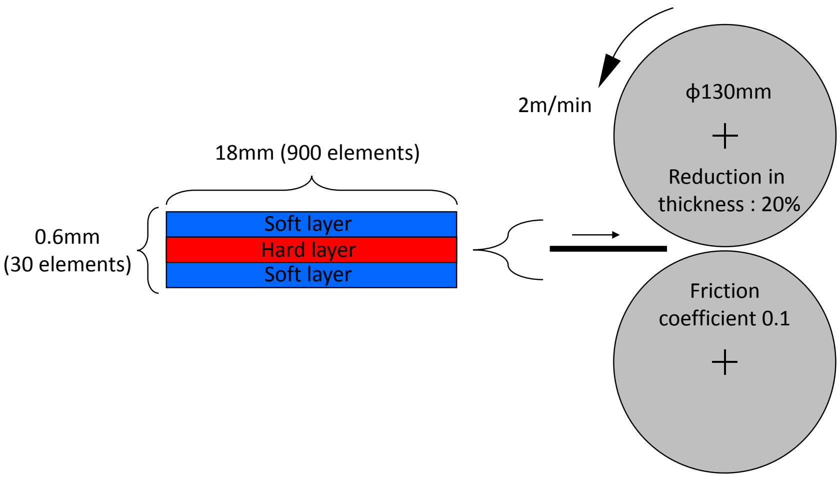

Fig. 1. Finite Element model for the cold rolling of clad sheet.