Journal of Materials Processing Technology 212 (2012) 776–785

Contents lists available at SciVerse ScienceDirect

Journal of Materials Processing Technology

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

Numerical study on the evolution of surface defects in wire drawing

Hyun Moo Baek[a], Young Gwan Jin[b], Sun Kwang Hwang[a], Yong-Taek Im[a,*], Il-Heon Son[c], Duk-Lak Lee[c]

[a] National Research Laboratory for Computer Aided Materials Processing, Department of Mechanical Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

[b] PIE & Radwaste Division, KAERI, 1045 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Republic of Korea

[c] Wire Rod Research Group, Technical Research Laboratories, POSCO, 1 Goedong-dong, Nam-gu, Pohang, Gyeongbuk 790-785, Republic of Korea

ARTICLE INFO

Article history:
Received 8 May 2011
Received in revised form 30 October 2011
Accepted 31 October 2011
Available online 6 November 2011

Keywords:
Wire drawing
Surface defect
Finite element analysis
Aspect ratio
Stress components
Evolution map

ABSTRACT

In this study, a three-dimensional finite element analysis for multi- or single-pass wire drawing was carried out in order to evaluate the deformation behavior of various surface defects, such as longitudinal, transverse, oblique, and round, introduced during the manufacturing processes. For numerical simulations, a free surface contact treatment algorithm was employed to suppress node penetration by applying a penalty method. Simulation results were compared with the experimental data obtained by optical microscopy for multi-pass drawing samples of the medium carbon steel wire with a longitudinal round-type defect in terms of variation of the load requirement and evolution of the cross-sectional shape of the surface defect. Additional numerical studies were carried out to investigate changes of cross-sectional shapes of various surface defects depending on stress distributions in the single-pass wire drawing. It was found that the radial and circumferential stress components determined the final shape and aspect ratio of the defect. The current numerical approach can be helpful in determining a guideline to assess the acceptability of the surface quality of the drawn wire for the secondary manufacturing process based on the available data in the literature.

1. Introduction

Surface quality assurance of hot rolled wires is important because surface defects can develop into an external burst in the forged products during a secondary process of manufacturing, accounting for roughly 50% of raw material rejections, as reported by Huang et al. (2004). It is widely known that the occurrence, propagation, and disappearance of surface defects involved with producing the wires are not yet fully understood because of the complexity of many production stages in casting, hot rolling, and transportation, as well as the difficulty of the measurements during the process. Sychkov et al. (2006) attempted to classify various types of surface defects in the wires transformed from the steel-making process. They pointed out that an accurate classification of surface defects on the rolled products was not easy.

In the forging industry, single- or multi-pass wire drawing might be applied to reduce the diameter of the material in addition to improving its surface and mechanical quality. Owing to such complexities involved with the wire productions, the acceptable standard for surface defects is described in the ASTM Standard (F2282-03, 2009).

In order to better understand the forming mechanism of a surface defect, the hot bar rolling process was studied by Kwon et al. (2009) by applying the finite element (FE) analysis in conjunction with a conventional plastic work approach. According to their results, the surface defect was identified as a wrinkle defect occurring at an earlier stage of a roughing mill, and recrystallization further affected the instability of the deformation in the wire during the manufacturing process. They also reported that temperature and specific deformation energy levels governed the occurrence of the wrinkle defect, although the specific deformation level was dependent on the roll geometry. Based on the measured compression data, Kim et al. (2008) derived processing maps and applied them to the prediction of the surface defect formation observed in industry. Lee et al. (2007, 2008) and Awais et al. (2008) found that less flow instability was observed by increasing the initial rolling temperature whereas it was less sensitive to the change of the roll geometry introduced at each pass. On the other hand, Son et al. (2008) investigated the deformation behavior of surface defects with a notched shape on the billet in the multi-pass hot rolling process using the FE code, CAMP*roll*, developed by Kim et al. (2005). They focused on numerical study in which intentionally introduced notches on the billet can either diminish or grow depending on their initial sizes and locations. In spite of these efforts, the phenomenon

* Corresponding author. Tel.: +82 42 350 3227; fax: +82 42 350 3210.
E-mail address: ytim@kaist.ac.kr (Y.-T. Im).

0924-0136/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2011.10.028

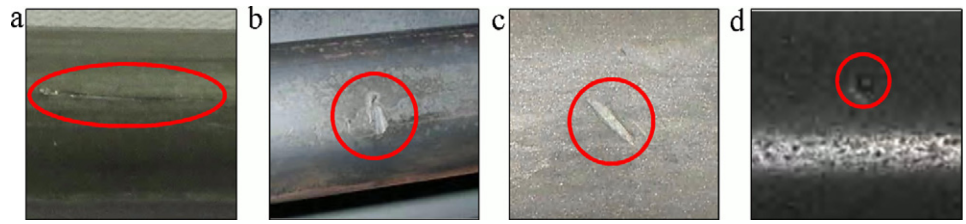

Fig. 1. Various types of surface defects observed in production: (a) longitudinal, (b) transverse, (c) oblique, and (d) round defect.

is not quite well understood yet, and it is almost impossible to perfectly prevent or remove the surface defect involved with various processing conditions due to a number of unknown sources.

In a steel bar and wire production, the drawing process is normally introduced after rolling to reduce the diameter of the wire by pulling it through a single or series of drawing dies. During wire drawing, the surface defects transformed from the rolling process could survive or diminish depending on the processing condition. In industry-related applications, cutting or grinding might be necessary to remove such surface defects before wire drawing because the drawn wire can be used as both a final product and a source material for subsequent manufacturing like forging.

A study on the deformation behavior of the surface defect during the wire drawing process was carried out by Yoshida and Shinohara (2004). They found that a deep transverse crack on the wire surface may develop into a defect known as a check-mark during repeated drawing passes. Shinohara and Yoshida (2005a) also studied the wire drawing of a bar containing an initial longitudinal defect with a rectangular cross-section by using the FE analysis. The results indicated that the defect was closed at the bar surface after the second pass, but an internal overlap with the shape of an "inverted Y" remained in the workpiece. In addition, Shinohara and Yoshida (2005b) analyzed the evolution of the V-notched longitudinal defect introduced in stainless steel during the wire drawing. They showed that larger notch angles, a larger semi-die angle, and a reduction of area (RA) per pass led to a larger decrease in the depth of the defect. However, the final product almost displayed defects with an overlap in its root and an opening at the bar surface.

As mentioned earlier, there are various types of surface defects on the wire in terms of their cross-sectional shape and direction, as shown in Fig. 1. In the steel mill, it is necessary to set up a guideline to determine the acceptability of the hot rolled wire depending on the evolution of the various surface defects as given in the ASTM Standard (F2282-03, 2009). In this regard, limited research have been undertaken to predict the evolution of surface defects due to the difficulties of the contact treatment algorithm of the free surfaces in the FE analysis and measurement of surface defects during the process.

In this study, arbitrary surface defects were introduced in the initial workpiece and the evolution of deformation behavior of such defects was numerically simulated during the multi-pass wire drawing. The wire drawing experiments were carried out to verify numerical simulations for the longitudinal round-type surface defect model for the medium carbon steel specimen. Numerical simulations were further extended to investigate various directional and cross-sectional changes of surface defects for a single-pass drawing depending on the radial and circumferential stress distributions. Finally, the deformed geometry was assessed based on the final depth and aspect ratio of the surface defects to determine the available guideline that can be employed to check the applicability of the present approach for assessing the acceptability of the produced wires for a secondary process.

2. Experimental

The cross-section of the surface defect on the wire, as shown in Fig. 1(a), was assumed to be a round shape, according to the work by Kwon et al. (2009), and artificially introduced on the steel wire in the longitudinal direction, as shown in Fig. 2. In this figure the width w and the depth d of the surface defect are defined, and the aspect ratio φ is introduced as w/d for determining geometrical changes of various surface defects investigated in the present study. The dimension of the initial width and depth of the longitudinal round-type defect introduced for the multi-pass drawing

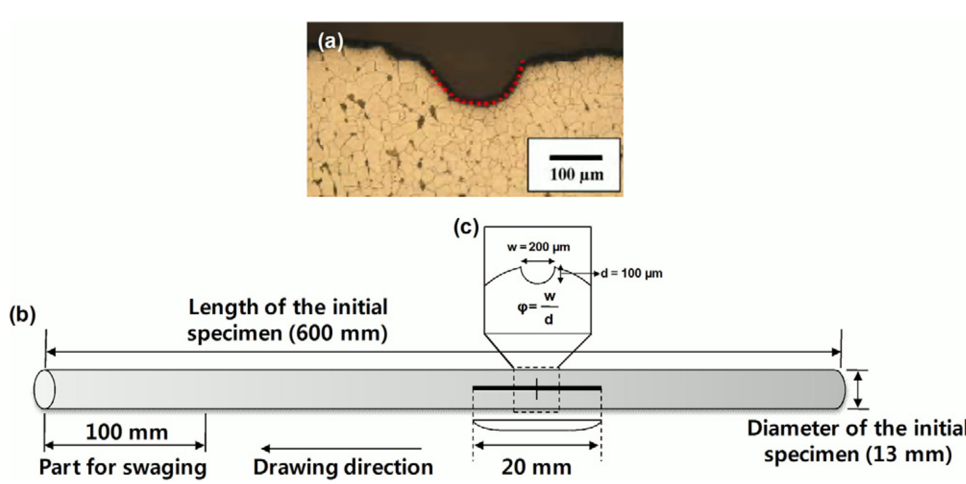

Fig. 2. Schematic diagram of the initial surface defect and specimen: (a) surface defect represented in the literature (Kwon et al., 2009), (b) the specimen with an artificially introduced longitudinal round-type defect, and (c) a cross-sectional view of the round-type defect.