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On the correlation of meso-scale local texture and roping profile in AA6xxx sheet alloys

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Abstract. Roping as a heterogeneous plastic deformation is generally attributed to the occurrence of the meso-scale clustering of grains with similar orientations. Large-scale electron backscattered diffraction (EBSD) orientation maps are customarily used to correlate the orientation topography with the roping profile. The most common way of investigating this phenomenon is to extract the predominant texture components and then to correlate them with the roping profile, since grains belong to different texture components lead to different plastic responses. Instead of using a microscopic representative volume element in the length scale of the grain size, the present work proposes a moving window mechanical model to use a representative volume element of the meso-scale, corresponding to a grain cluster, to simulate roping. For a tensile test in the transverse direction, a quantitative prediction of surface roping profile can be obtained. For an artificial EBSD orientation map, the proposed model can yield both roping wavelength and amplitude.

1. Introduction

Aluminium alloys for automobile body panel application often show a specific type of band-shaped surface roughening upon stretching, called “roping” or “ridging”. Roping, manifesting itself as a series of ridges and valleys along the rolling direction (RD), has attracted much attention within the communities of crystallographic texture and crystal plasticity. Thanks to the rapid development of automated EBSD technique, clustering of similarly orientated grains, i.e., orientation banding, has been found by several research groups [1–5]. Furthermore, much effort has been made to correlate the spatial distribution of grains, which belong to a specific texture component, with roping. Thus, the band-like distribution of grains with Cube orientation [3, 6] as well as Goss [7, 8], R [9], X [10] and combinations of Goss-Cube [11] and X-Cube-Goss orientations [10] was proposed as predominant cause of roping. All the aforementioned research has indicated that the evolving surface roughness profiles can be related to the surface texture patterning.

An earlier work by the present authors [12] showed that roping could not be understood simply by banding of grains belonging to only specific orientations. Therefore, the present work will simulate roping based on a representative volume element (RVE) of the meso-scale with contrasting texture. To understand roping, two aspects, namely the roping wavelength and amplitude, need to be analysed together. The wavelength has already been predicted by different authors through various methods [8, 13]. Further understanding of the amplitude formation can provide a deeper insight into the origin of roping. However, no satisfactory roping profile with

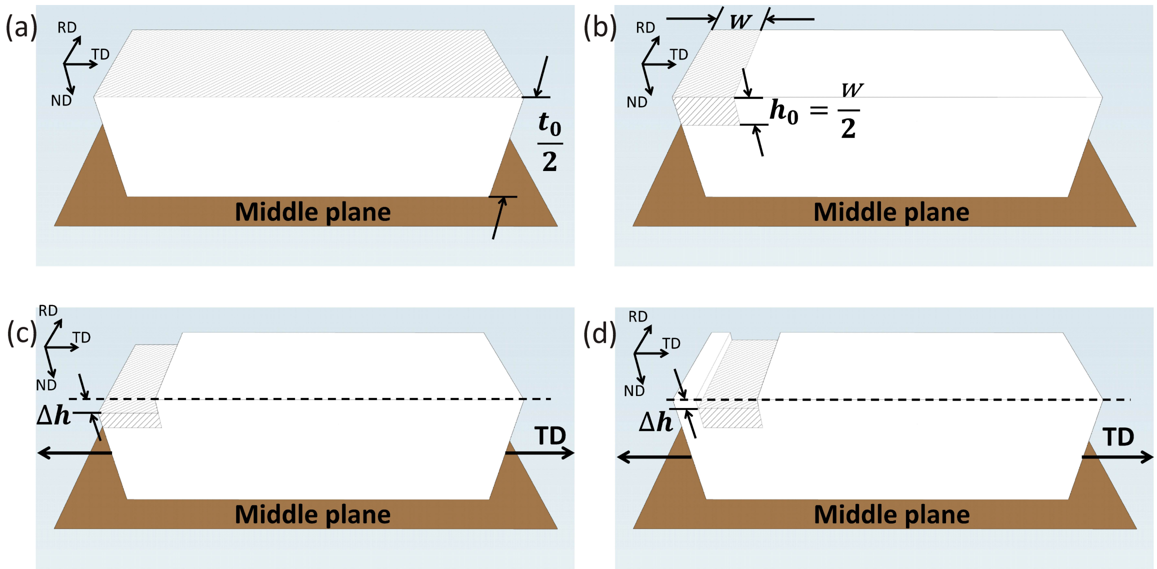

Figure 1. Schematic illustration of the meso-scale moving window mechanical model: (a) An EBSD map illustrated by the hatching lines is measured on the sheet surface; (b) A RVE of the meso-scale illustrated by the hatched volume is selected; (c) A plastic tensile strain is exerted to the selected RVE, resulting in its thickness change of Δh; (d) Scanning the RVE through the entire surface EBSD map yields a hypothetical surface profile under this plastic tensile strain.

substantial roping amplitude has been predicted based on the surface texture patterning for AA6xxx sheets to the knowledge of the authors.

2. Methodology

A large-scale EBSD orientation map is used as input to simulate surface roughening, in particular roping, with the help of the moving window method [12, 14]. Figure 1 schematically illustrates the simulation procedure of the meso-scale mechanical model. Firstly, the surface EBSD orientation map is measured and fed into this model. Secondly, a RVE of the meso-scale is selected by a window, of which the width is w and the length extends over the entire RD dimension of the EBSD map. Additionally, the height of this RVE of the meso-scale, h_0, is assumed to be $w/2$ (see Figure 1(b)). Due to lack of information on spatial distribution of texture through the thickness, the spatial distribution of the surface texture is used to represent that of the RVE. Then, the thickness change of the RVE of the meso-scale, Δh, is simulated by the Full Constraints (FC) Taylor model assuming that each RVE of the meso-scale behaviors like a standard free-standing tensile test sample [15–18]. Lastly, Δh is given as a function of the position of the window, when the window scans through the entire EBSD map in the transverse diection (TD).

In order to study the effect of window width, w, on the predicted roping profile, artificial EBSD orientation distribution maps are made using MTEX [19] and the MTM-FHM software system [20]. Figure 2(a) shows such an EBSD map with alternating equal bands of grains with Cube and R orientation. The banded pattern of Cube and R is chosen because Cube and R are typical texture components in AA6016-T4 [5, 10, 21]. Additionally, the development of the surface roping profile is attributed to the spatial distribution of grains with R orientation in the form of RD-elongated colonies embedded in the Cube orientation dominant matrix, according to Wittridge and Knutsen [9]. For the EBSD map shown in Figure 2, the band width is 504 μm and the step size is 8 μm.

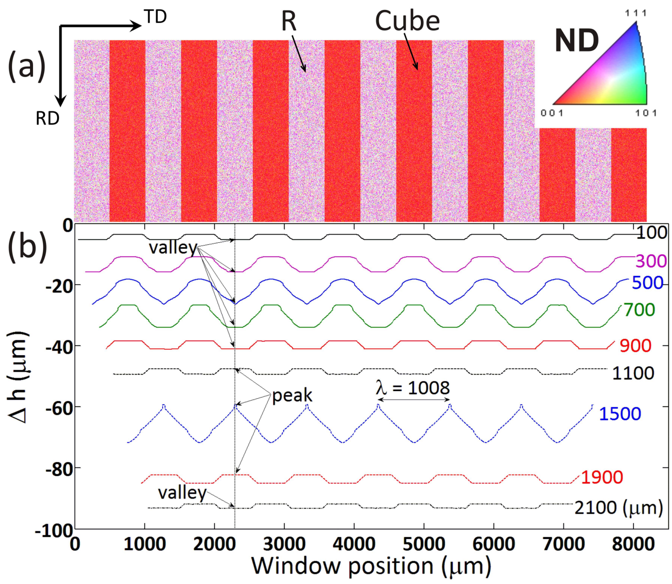

Figure 2. Effect of the window width on the hypothetical surface profiles simulated based on the artificial EBSD orientation map: (a) the EBSD IPF map of alternating equal bands with R and Cube orientation. The color coding scheme, which is illustrated by the unit triangle on the top right of the EBSD map, is defined according to the crystallographic direction along the sample's normal direction (ND) (b) the hypothetical surface profiles simulated by using different window widths which are indicated on the right of the profiles

3. Results and Discussions

Figure 2 shows the effect of the window width on the hypothetical surface profile simulated based on the banded R/Cube EBSD map. Since the period of a pair of R and Cube band along TD is 1008 μm, this value will be the wavelength of the roping profile upon deformation. Crystal plasticity simulations using the FC Taylor model give r-values of 0.35 and 1.0 for the ideal R and Cube orientation, respectively, if the tensile axis is parallel to TD. Therefore, the simulated profile is characterized as the positive tendency if the R and Cube bands form valleys and peaks, respectively. It is negative in case of the opposite. As shown in Figure 2, the positive and negative tendency profile will repeatedly alternate with increasing window width by the multiple of the wavelength. Consequently, the effect of the window width on the roping profile morphology can be summarized as:

$$\begin{array}{ll} positive\ tendency, & if\ 2n < \frac{w}{\lambda} < 2n+1; \\ negative\ tendency, & if\ 2n+1 < \frac{w}{\lambda} < 2n+2; \ , \\ & n = 0, 1, 2 \cdots, \end{array} \tag{1}$$

where, w is the window width and λ the wavelength.

No matter which window width is used, the wavelength can be identified as shown in Figure 2(b). Therefore, this meso-scale model is insensitive to the choice of the window width for the purpose of identifying the wavelength. The amplitude changes with the choice of the window width due to the correlation of the volume height with the window width as shown in Figure 1(b). When the window width satisfies $w = \left(n + \frac{1}{2}\right)\lambda$ with $n = 0, 1, 2 \cdots$, the amplitude approximately reaches the maximum. It is unfortunate that the study does not include simulation results on experimental EBSD maps. Nevertheless, the proposed meso-scale moving window model extends the scope of roping analysis towards the formation of roping amplitude.

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4. Conclusions

The proposed meso-scale moving window mechanical model can simulate the roping wavelength and amplitude in a objective way based on the selected the meso-scale local texture. This model developed based on the MTM-FHM software system interprets roping in terms of the existence of mesoscopic RVEs with contrasting local textures. A quantitative criterion for estimating the roping wavelength using the positive and negative tendency property (Eq. 1) is proposed. The prediction of roping wavelength is insensitive to the choice of window width. The results of the application of this meso-scale model to the experimental EBSD maps will be reported elsewhere.

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