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Finite element analysis of deflection of rolls and its correction by providing camber on rolls

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Abstract

Rolling process is a key step in the production of flat steel products. Because of automation commonly implemented in flat product rolling mills, the products should meet the requirements of tight tolerances. one of the major defects observed in the rolling process is flatness and lack of attainment of the desired surface profile due to deflection of the rolls. The spatial shape and dimensions of the roll gap are influenced by the elastic deformation of all parts of the rolling stand equipment affected by the roll pressure. The current study aims to determine the variation of the deflection in rolls in a two high mill with varying percentage reduction of the sheet i.e, 20%, 25% and 30% on annealed and non-annealed IF steel sheet and analyzing possible solutions to reduce the elastic deflection of rolls with special emphasis on cambering and modelling of the same in Abaqus CAE.

Keywords: cold rolling; recrystallization-temperature; elastic deflection; percentage reduction.

1. INTRODUCTION

Rolling is a metal forming process in which the metal ingot or sheet is pressed between two rotating rolls. Besides the compression by rolls, the friction between the work metal and surfaces of rolls also gives rise to compressive forces in the longitudinal and lateral directions. The demand for producing strips with narrow dimension tolerances is imposing a necessity to construct the stand with respective mill modulus and working rolls of optimum diameter (Janusz Po´spiech, 2005).

Yu Hai-Liang et al., 2007 presented an extensive situation review of deflection of rolls in a four high mill and analysed deflection of Sendzimir mill using 3D FEM under different rolling forces, strip widths and rolls assignments. Problem of deflection of rolls was treated by many authors and the literatures are relatively rich, both from theoretical and measuring point of view.

The problem on how to improve its shape and flatness, and the dimensional accuracy has always been of major interest to the steel manufacturers. Researchers have found solutions to these problems by introducing new types of mills, such as continuous variable crown (CVC) and pair cross (PC) mills equipped with roll shifting, roll crossing and work roll bending (B. Paolo et al. 1999, V. B. Ginzberg et al., 1997). A 3D Finite Element Method (FEM) has been used in the analysis of strip rolling by Kobayashi et al., 1989; Chenot et al. 1991 in the past. In his studies Z. Y. Jiang et al.,2003 showed that the specific force such as rolling force, intermediate force and the profile of the rolled strip for rolling is significantly different with the traditional strip cold rolling process. When the entry thickness of strip increases, the edge contact force increases, the edge contact of work rolls becomes more significant, which has a significant effect on the intermediate force, and the shape of exit strip becomes poor. The flatness defects in rolling were studied and a numerical approach for prediction of defects were coined by S. Abdelkhalek et al., 2011.

2. Objective

This work is focused on the simplest rolling mill having two deforming rolls and the mill known as two-high mill. The rolls have to support the Roll Separating Force (R.S.F.), which has a shearing effect on the necks. Thus, the roll diameter should be large. However, since bigger rolls have greater R.S.F., the two-high is used in only cases of very narrow strip (for example, flattened wire) and a very light reduction (skinpass operation).

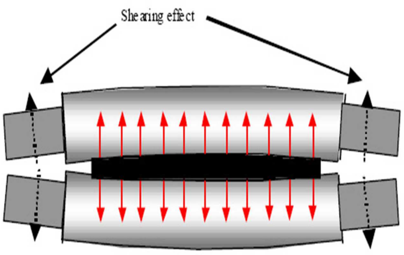
A two high mill with work roll diameter of 0.95m and 3.6m in length is selected to cold roll a strip of width 900mm with length of 0.5m and a thickness of 0.002m in a single pass. The dimensions of the roll shoulder are: Diameter 0.475m and length 0.2375m.

The percentage reductions taken to study the variation in the roll deflection are 20%, 25%, and 30%. The material chosen for the reduction by rolling is interstitial free (IF) steel which is widely used in automobile body panels and is deep drawable. The material received was in annealed and non-annealed condition to determine the effect of strain hardening on roll deflection.

The roller is made of D2 (Chromium Alloy) steel with Young’s modulus 210GPa and 0.3 Poisson’s ratio and the sheet is low carbon steel with Young’s modulus of 202GPa and Poisson’s ratio 0.3. The co-efficient of friction between the roll and sheet 0.147 to 0.176 and the roll rotating at a speed of 60 rpm were used in FEA simulations.

3. Methodology

The sheet samples of interstitial free steel were collected at entry and exit of the two high 4-stand rolling mills, rated 4000HP with soluble oil used as lubricant with a speed of 150m/min in the first stage reduction. Were tensile tested as per ASTM-E8M standard to characterize the tensile properties affecting the deflection of rolls in a two high mill. The sheet samples collected before and after a given reduction were tensile tested as per ASTM-E8M standard and mechanical properties are shown in table 1. The annealed tensile properties were used in FE-simulations to determine the roll deflection.



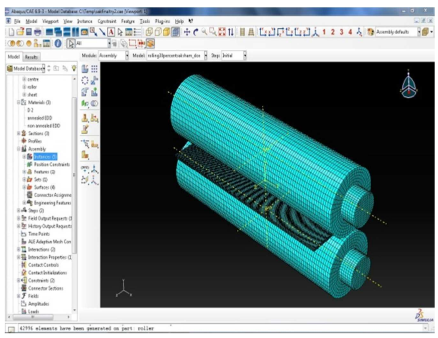


Figure 1: Figure shows two high mill with higher central deflection and as modelled in FEA

Table 1. *Showing Properties of IF steel for both Annealed and Non-Annealed after reduction*

IF-steel	0.2%-offset yield(MPa)	UTS (MPa)	Strain hardening exponent 'n'	Strength coefficient 'K'(MPa)	% Elongation
Annealed(CRCA)	123	205	0.33	428	51
Non -annealed (after deformation)	219	415	0.17	690	11

The following parameters are calculated prior to the rolling analysis:

- $\tan \alpha = \sqrt{(R*\Delta h)/(R-(\Delta h/2))} \approx \sqrt{\Delta h / R}$ (1)
  Where, R = Radius of Roll and α = Angle of Bite, and Δ h is Draft= $(h_i - h_o)$
- $L_p = \sqrt{R * \Delta h}$, (2)
  Where L_p = Projected Length
- $\mu \geq \tan \beta$ (3)
  μ = Friction Coefficient and β = varies from 0 to α

Table 2. *Various Rolling parameters used in simulations*

Percentage Reduction / Material	Angle of Bite (degrees)	Projected Length of Contact (m)	Minimum Value of μ for unaided entry
20% reduction	8.255	0.0689	0.145
25% reduction	9.214	0.077	0.162
30% reduction	10.076	0.0844	0.176

4. Results of 3D-fea model for cold rolling of a strip in a 2-high mill.

The numerical model developed in this study considers a percentage reduction of 20%, 25% and 30% on two types of material – annealed and non- annealed to establish the relationship between the camber of the sheet and the stress developed in the rolls. The subsequent pages of this chapter show the stress developed in the roll and the respective sheet profile.

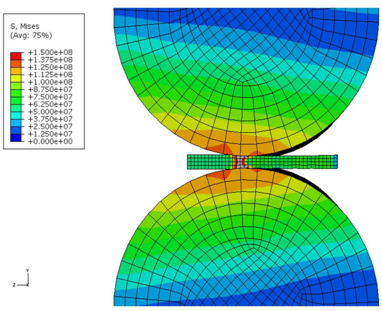


Fig. 2a: *Stress developed in the rolls.*

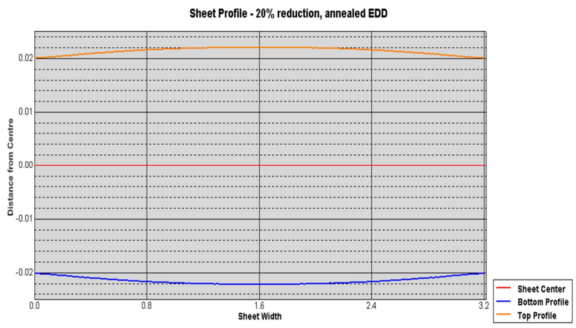
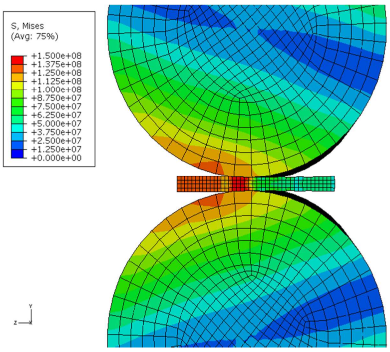


Fig. 2b: *Sheet surface profile during rolling*

Figure 2: *Stress analysis for 20% reduction of annealed IF-steel Sheet*



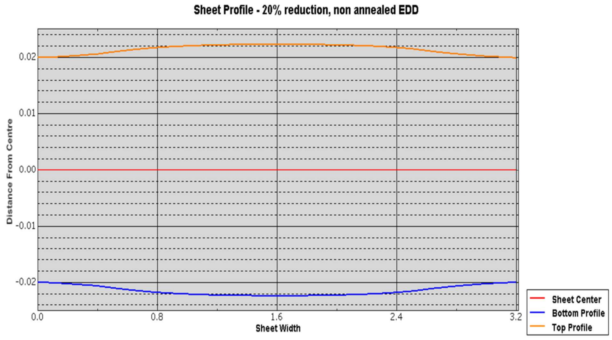
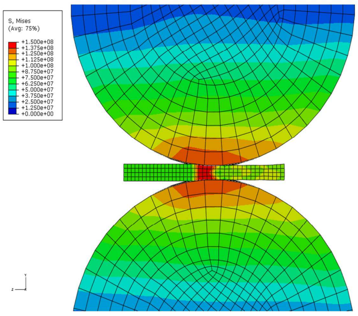


Fig. 3a: *Stress developed in rolls*

Fig. 3b: *Sheet surface profile during rolling*

Figure 3. *Stress analysis for 20% reduction with Non-Annealed IF-steel Sheet*



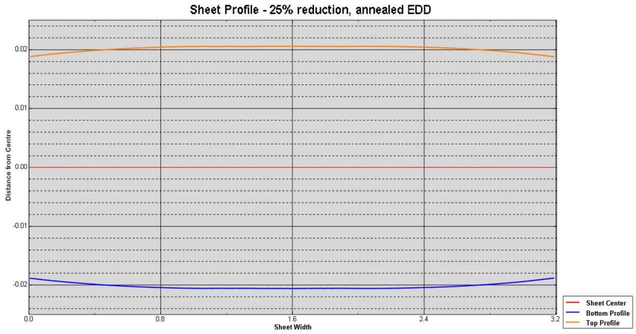
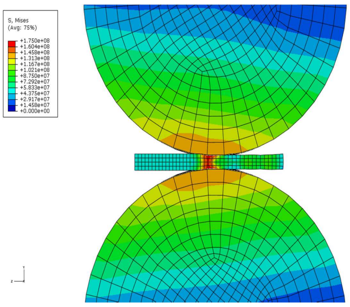


Fig. 4a: *Stress developed in the rolls*

Fig.4b: *Sheet surface profile during rolling*

Figure 4. *Stress analysis for 25% reduction with annealed IF-steel Sheet*



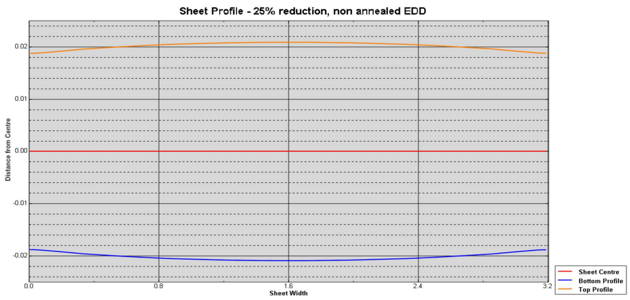
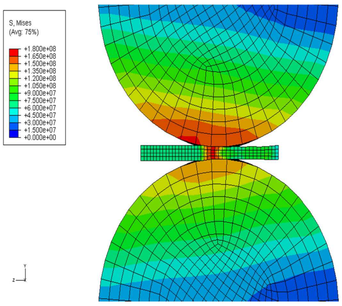


Fig. 5a : *Stress developed in the rolls*

Fig.5b: *Sheet surface profile during rolling*

Figure 5. *Stress analysis for 25% reduction with non-annealed IF-steel Sheet*



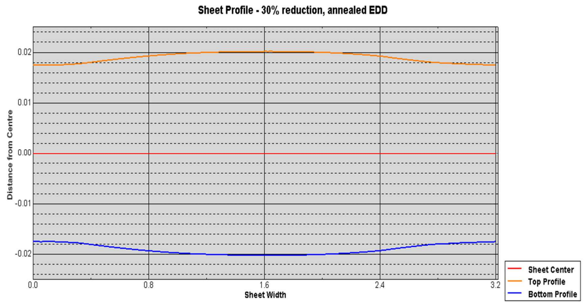
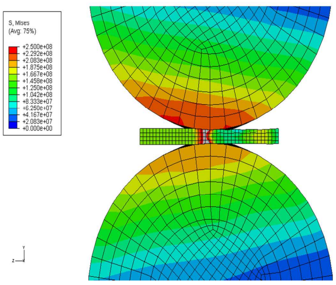


Fig. 6a: *Stress developed in the rolls* Fig. 6b: *Sheet surface profile during rolling*

Figure 6. *Stress analysis for 30% reduction with annealed IF-steel Sheet*



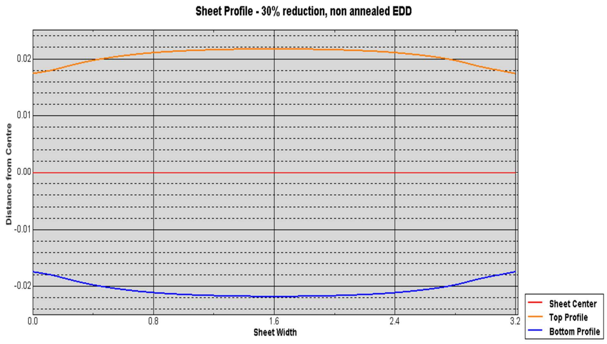


Fig. 7a: *Stress developed in the rolls* Fig.7b: *Sheet surface profile during rolling*

Figure 7. ***S****tress analysis for 30% reduction with Non-Annealed IF-steel Sheet*

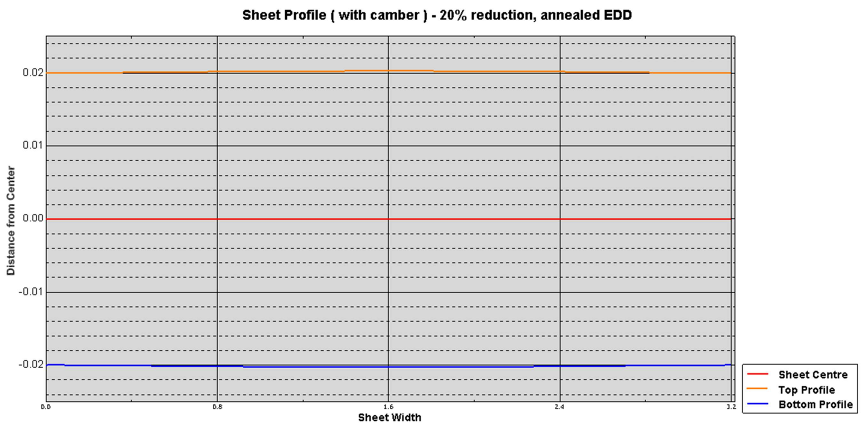


Figure 8. *Sheet surface profile after providing camber in rolls*

It is quite evident from the figure8, that when the camber was introduced in the diameter of rolls, the sheet cross sectional profile was straight and uniform with slight convexity at the middle of the sheet.

5. CONCLUSION

The roll deflection has been studied under the effect of roll separating force and its effect on the roll gap has been analysed using Abaqus CAE. The numerical model confers to the theoretical concepts of rolling and the results obtained are in agreement.

Further, the parametric study undertaken to reduce the roll deflection has been successful by employing camber in the rolls. Providing camber, it is found that the sheet profile improves, though complete removal of the convex deformation in sheet cross section is difficult.

The effect of annealing and strain hardening of the sample in rolling indicates that the strain hardening of the sheet produces higher stresses in the respective rolls than the stress developed when the annealed sheet is rolled necessitating the intermediate annealing.

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A Brief Author Biography

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