NUMERICAL MODEL FOR FLATNESS ANALYSIS OF THIN STEEL SHEET IN TENSION LEVELING PROCESS*

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Abstract. *This article deals with the study of a numerical model for a tension leveling process. This model is required in order to determine the influence of some parameters that play an important role in the actual process on the final flatness characteristics of a thin steel sheet. The numerical model was generated on a commercial finite element program. This model includes large displacements, large deformations and a complex contact condition, with an elasto – plastic constitutive material model. Furthermore, the analysis provides approximate information in regards of stresses, strains, and displacements across the tension leveller unit. A factorial design analysis has been employed in order to determine the influence of those parameters on the flatness index..*

Keywords: *tension leveling, factorial analysis, intermesh, finite element, steel sheet.*

1. Introduction

The tension leveling process is very useful for manufacturing tinplate material, that most of cases are thin steel sheet. According to Unwin (1999) and Park and Hwang (2002), tension leveling is the primary process applied after cold rolling and is used to correct mainly curl, gutter, edge wave and center buckle as shown in Fig. 1. These defects are consequence of length difference in inner fibers of the sheet; as a result, there is presence of residual stresses that could cause problem in future applications. Park and Hwang (2002) suggest that edge wave and center buckle are caused by difference in length between fibers at center and fibers at edge, whereas curl and gutter are caused by the distributions of normal stresses on plane section perpendicular to the longitudinal axis direction. In early analytical model, Kinnavy (1972) tried to explain how combined bending and tension could be a mean of extent plastically a sheet with a tension well below of the yield stress. He used in his analysis an elastic – perfectly plastic constitutive material model and did not study residual curvature, although he summarized that roll diameter has a strong influence on the tension change. Recently, Yoshida and Urabe (1999) have proposed a novel finite element model with a sophisticated constitutive model of cyclic plasticity. Besides, they suggested those principal factors that affect the residual curvature in tension leveling process are combination of roll – pitches, roll intermeshes and applied tension load.

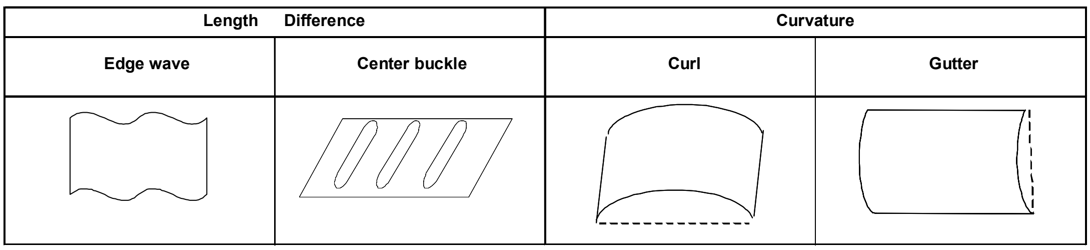

Figure 1. Shape defect of a sheet.

Morris *et al.* (1999) proposed an implicit finite element model for study residual curvature and residual stresses using a rate – independent isotropic hardening constitutive material model with spring – back analysis. Furthermore, they used thin shell element to simulate the strip. Huh *et al.* (2001) studied a tension bridles in the analysis of tension leveling with a two dimension quadrilateral continuum finite element and reduced integration with hourglass control. They carried out, specialty, an analysis to investigate the effect of the mesh size in the non – steady state finite element analysis on the amount and distribution of strain. Morris, Hardy and Thomas (2002) used the model developed in Morris *et al.* (1999) and did a designed fractional factorial analysis in order to study the effect that tension leveling process parameter have on the shape characteristics of the leveled product. They analyzed five factors: roll wrap angles,

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lines speed, elongation and yield stress. As a result, they concluded that the process is influenced by many second order interactions.

This paper deals with the analysis of a tension leveling unit, specialty in regard with his layout. The numerical analysis was carried out considering an elasto – plastic hardening behavior and contact conditions without friction force between strip and rolls. The analysis is based on the model presented by Morris, Hardy and Thomas (2002) and the layout was taken of a roll tension unit presented by Yoshida and Urabe (1999). The model is assembled and solved with the commercial code Ansys® Multiphysics (2002). The present paper describes the tension leveling unit used in the numerical analysis, constitutive material model, and factorial design analysis.

2. Finite element model

A one five roll units is modeled for finite element analysis of tension leveling of sheet steel. Figure 2 shows the leveling layout with the important dimension and the three dimensional model. The dimensions of the modeled sheet are 1800 mm of length, 50 mm of width, and 0.7 mm of thickness. Finite element is carried out, as illustrated in Fig. 2 (b), first by applied desired tension (constant through the analysis), and then pushing down the rolls for the desired amount of intermesh and finally moving the set of rolls to desired amount. The type of analysis is large displacement, large rotations, and large strains with updated lagrangian formulation, according to Bathe (1996).

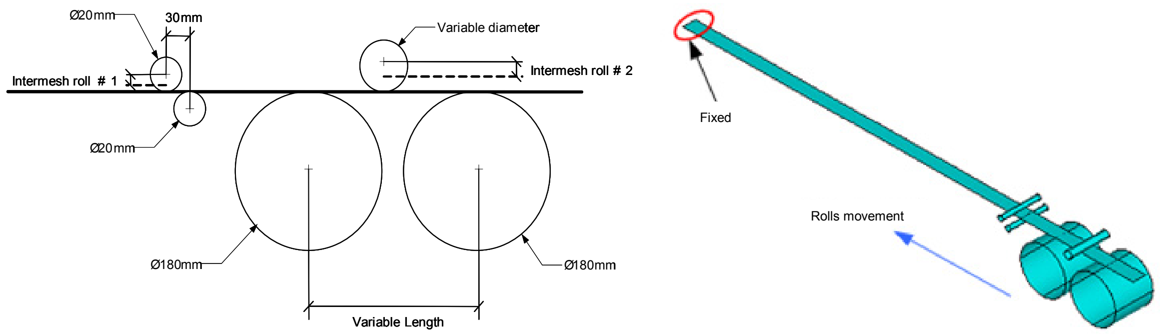

Figure 2. Leveling layout using in finite element analysis. (a) Description of the unit and (b) three dimensional model.

Contact between rollers and strip is modeled with surface to surface contact elements. Therefore, rigid surface (at rollers) are modeled by 3-D target segment element using pilot node as a way to assign boundary conditions. Deformable surface (at strip) is modeled by 3-D four node surface to surface contact element. Moreover, sheet is modeled by the finite strain layered shell element with and elasto – plastic material and reduced integration with hourglass control. Besides changes in shell thickness and traverse shear deformation is accounted for. Shell thickness effect is include in the analysis for incorporating the fact that contact only occurs on the physical boundary of the shell, not on its mid plane. Numerical integration is carried out at five integrations points along the thickness direction. At the end of the leveling process, all the external force are excluded and a spring – back analysis taken place.

2.1. Constitutive modelling

When analyzing manufacturing processes is very important to define the type of constitutive model used in the analysis for represents the actual behavior of materials. In this paper, the authors use an isotropic hardening constitutive model for represent the material of the sheet, despite this model does not predict the Bauschinger effect (Dowling, 1999). Figure 3 (Ansys® Multiphysics, 2002) shows the stress – strain behavior and hardening rule according to isotropic hardening; and Tab. 1 shown the isotropic hardening constitutive model according to Malvern (1969), and Simo and Hughes (1998). Where $\boldsymbol{\varepsilon}$ is total strain tensor, $\boldsymbol{\varepsilon}^e$ is elastic strain tensor, $\boldsymbol{\varepsilon}^p$ is plastic strain tensor, $\boldsymbol{\sigma}$ is the Cauchy stress tensor, γ is a plastic multiplier, σ_Y is initial yield stress, and α is the equivalent plastic strain.

3. Factorial analysis

A factorial design analysis has been employed in order to determine the influence of those parameters on the sheet curvature. The insight is gain confidence about the proper setting parameters of the tension leveling process and finds the influence that the configuration has over the residual sheet curvature. The variable response is sheet curvature, Eq. (1), taken as the inverse of the radius of curvature presented in Morris *et al.* (1999).

Where k is sheet curvature, ρ is radius of curvature, a is the longitudinal distance of deformed sheet, and h is the maximum height of deformed strip, like in figure 4.

$$k = \frac{1}{\rho} = \frac{2h}{a^2 + h^2} \tag{1}$$

We have been developed a factorial design 2^4 without replicate according to Montgomery (2002). Table 2 shows the factor definition for this analysis. Afterwards to run the experiments and collect the data, we used a normal probability plot to analyze the estimated effect and find the principal effect. In Tab. 3 we shown the run order of the experiment, where the lower – case letters means high factor level, likewise the plus sign.

Table 1. Constitutive material model.

Kinematics:

$$\dot{\varepsilon} = \dot{\varepsilon}^e + \dot{\varepsilon}^p$$

Yield criterion: Von Mises

$$f(\sigma,\alpha) = \sqrt{\|\sigma\|^2 - \frac{1}{3}(tr[\sigma])^2} - \sqrt{\frac{2}{3}}K(\alpha)$$

Flow rule: Assosiative

$$\dot{\varepsilon}^p = \gamma \cdot \frac{\sigma - \frac{1}{3}(tr[\sigma])I}{\sqrt{\|\sigma\|^2 - \frac{1}{3}(tr[\sigma])^2}}$$

Hardening rule: Isotropic

$$K(\alpha) = \sigma_Y + \bar{K}\alpha$$

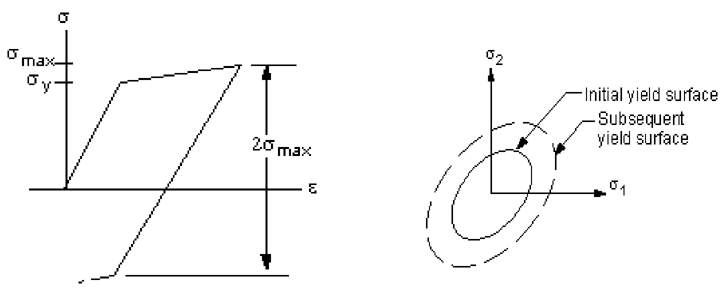

Figure 3. Graphic representation of the constitutive material model. (a) Bilinear isotropic stress – strain curve and (b) isotropic work hardening rule.

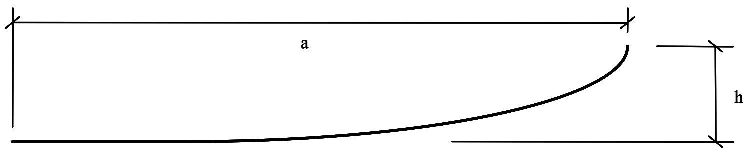

Figure 4. Layout of deformed sheet that shown important dimension to evaluate residual curvature.

Table 2. Factor definition

Factor	Definition	Factor level	
A	Roll intermesh #1	Low = 5 mm	High = 10 mm
B	Roll distance	Low = 140 mm	High = 200 mm
C	Roll Intermesh #2	Low = 5 mm	High = 10 mm
D	Roll diameter	Low = 30 mm	High = 60 mm

Table 3. Constants of contrast of the experiment according to Montgomery (2002).

	Factor			
Run	A	B	C	D
(1)	-	-	-	-
a	+	-	-	-
b	-	+	-	-
ab	+	+	-	-
c	-	-	+	-
ac	+	-	+	-
bc	-	+	+	-
abc	+	+	+	-
d	-	-	-	+
ad	+	-	-	+
bd	-	+	-	+
abd	+	+	-	+
cd	-	-	+	+
acd	+	-	+	+
bcd	-	+	+	+
abcd	+	+	+	+

4. Numerical result

The finite element analysis is carried out in order to investigate the factor effect it has over the sheet curvature. The estimated effects are shown in the normal probability plot of Fig. 5. The meanings of the capital letter are presented in Tab.2.

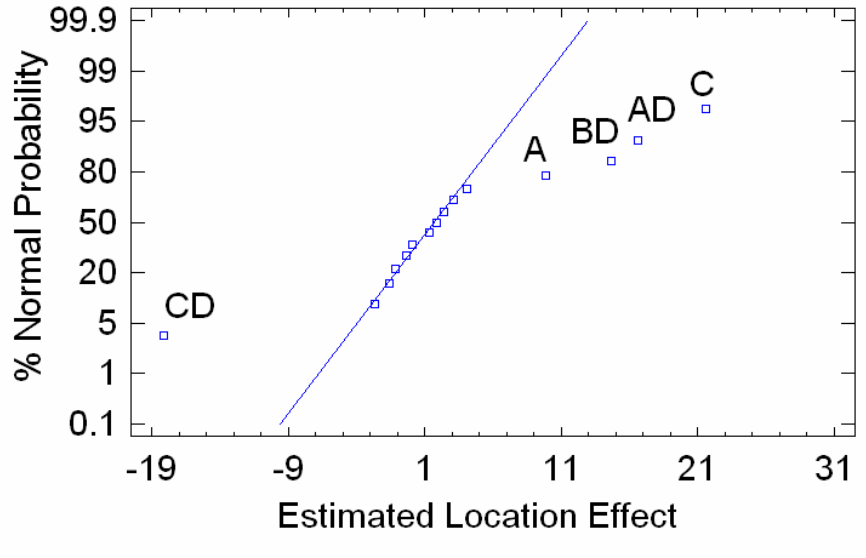

Figure 5. Probability plot of estimated location effect.

Note that there are two principal factors affecting the residual curvature and three interactions affecting, too. In this analysis only the interaction roll intermesh #2 / Roll diameter has a negative effect over the residual curvature. The most single influential factor is intermesh roll #2. The roll diameter in combination with other factor has a strong influence in the residual curvature. In Fig. 5 we observed a little difference in variance in the data, but they not alter the result. The residual curvature seen is affected by the leveler entrance and exit intermesh.

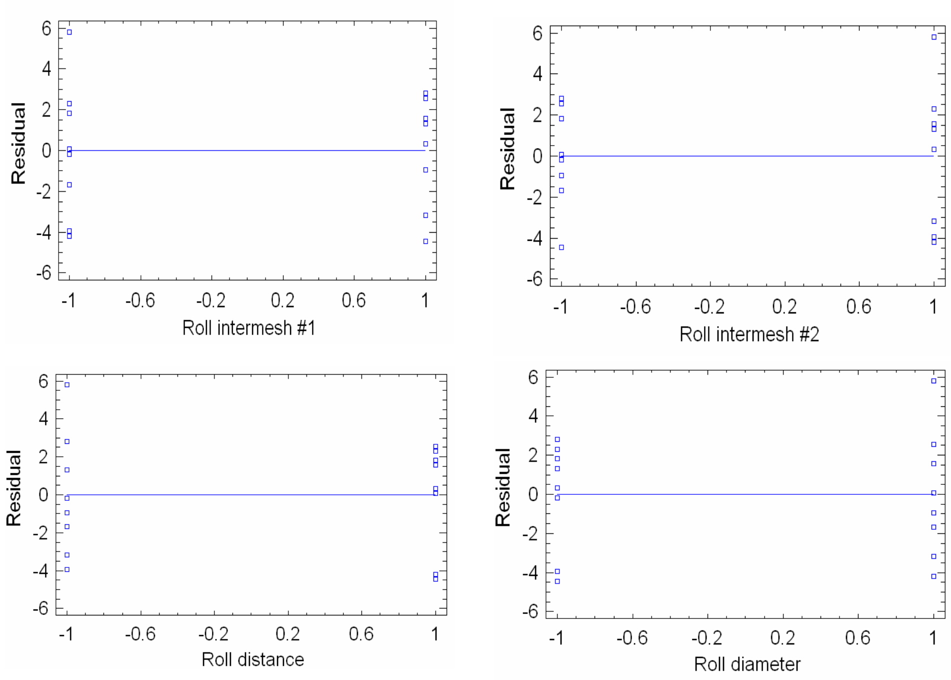

Figure 5. Plots of residuals versus each factor.

5. Conclusion

This paper combines the design factorial analysis with the finite element method for the study of a complex manufacturing process. Using an implicit time integration scheme for the finite element solution of those classes of problems has a lot implication in computational time consuming. Nevertheless it is a good method for study tension leveling. Using a linear isotropic hardening model is a gross simplification of the actual behavior of material. In order to obtain more accurate result a constitutive model that includes the Bauschinger effect should be used.

The statistical designed experiment used in this analysis shows that the tension leveling process analyzed has three second order interactions and two principal factors that influence sheet curvature. In an actual process is easier to control intermesh than roll distance or roll diameter. Hence, it is a good candidate for adjust in actual process for control residual curvature. The effect of change back tension did not be study in this analysis. The next stage of this work is to validate result with experimental data.

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5. Responsibility notice

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