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Roll levelling semi-analytical model for process optimization

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Roll levelling semi-analytical model for process optimization

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Abstract. Roll levelling is a primary manufacturing process used to remove residual stresses and imperfections of metal strips in order to make them suitable for subsequent forming operations. In the last years the importance of this process has been evidenced with the apparition of Ultra High Strength Steels with strength > 900 MPa. The optimal setting of the machine as well as a robust machine design has become critical for the correct processing of these materials. Finite Element Method (FEM) analysis is the widely used technique for both aspects. However, in this case, the FEM simulation times are above the admissible ones in both machine development and process optimization. In the present work, a semi-analytical model based on a discrete bending theory is presented. This model is able to calculate the critical levelling parameters i.e. force, plastification rate, residual stresses in a few seconds. First the semi-analytical model is presented. Next, some experimental industrial cases are analyzed by both the semi-analytical model and the conventional FEM model. Finally, results and computation times of both methods are compared.

1. Introduction

The tightening of the CO2 emissions policies, together with the increase of safety requirement, is challenging the automotive sector to be competitive in car weight and price. In order to the challenge, new high strength materials are been incorporated to the market such as third generation steels i.e. Fortiform1050, Nippon1180, or the high strength aluminium alloys. However, these new materials lead to important manufacturing issues such as early fractures, high forming forces and high springback. One of the key processes to assure stability of the manufacturing line is the roll levelling process [1]. After the rolling process, the sheet usually has shape defects [2] and internal residual stresses that could lead to manufacturing quality issues down the line. In order to get rid of those defects and aiming at homogenising the through thickness stress profile the sheet is subjected to an iterative bending-unbending process.

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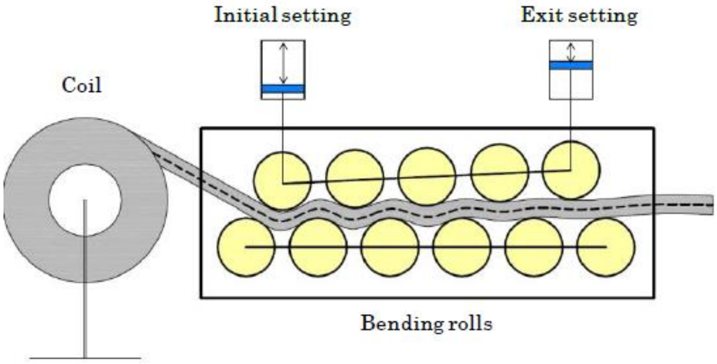

Figure 1. Roll levelling process, where the sheet is subjected to an iterative bending-unbending process.

Multiple works have been conducted on the analysis of the levelling process and on the correct set up of the rolls for an optimal process development. In this regard, previous researchers developed numerical finite element method (FEM) models to predict the evolution of the material properties during the levelling process [1-7]. The main advantage of this models is the capability of prediction prior process that allows the correct set-up of the machine or even close loop control systems.

The main disadvantage of the FEM models is the high computational time required that exceeds the admissible ones in both machine development and process optimization. In the present work, a semi-analytical model based on a discrete bending theory is presented. This model is able to calculate the critical levelling parameters i.e. force, plastification rate, residual stresses in a few seconds. First the semi-analytical model is presented. Then, the performance of model compared to the FEM one is evaluated in terms of accuracy in torque and computational time.

2. Roll levelling semi-analytical model

The developed semi-analytical model is based on a model proposed by Mendiguren et al. [8] in the framework of bending and springback modelling. As in Figure 2 it can be shown, first the thickness of the sheet is discretizated in a finite number of points (N = 2000 in this case). Then, once that the curvature that will take the sheet is known, a perfect bending under plane strain conditions is assumed and an elasto-plastic formulation [9] is applied to each discrete point. It has to be noted the necessity of anisotropic hardening models to be able to correctly represent the behaviour of the material during the bending-unbending process [10]. Finally if the section value is needed the integral through the thickness is numerically performed.

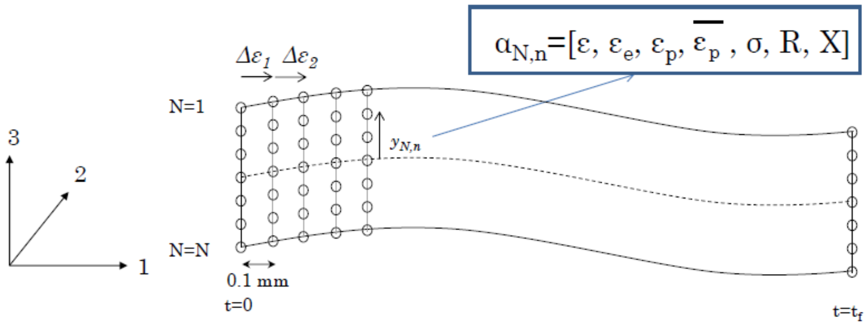

Figure 2. Semi analytical model definition inspired in [2].

Previous works have stated that that the contact position between the rolls and the sheet are not at the Summit of the rolls, but there is a contact angle regarding the summit of the roll, as shown in Figure 3. Previous research has shown that this contact angle is strength material and thickness dependent [2, 11].

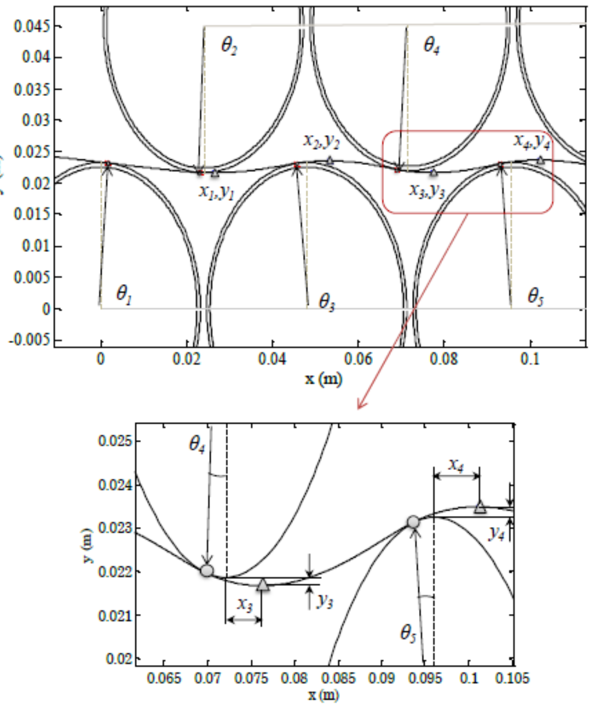

Figure 3. Offset of the maximum and minimum points of the sheet.

A neuronal network has been developed to predict the bending line based on the thickness and material strength. This neuronal network has been trained with more than 300 FEM simulations in a wide range of thicknesses and material strengths.

The process of the semi-analytical model works as follow:

- First, using the neuronal network, based on the material strength and the thickness the bending line is obtained
- Next, the sheet is discretizated in sections (one each 0.1 mm) and the sections are discretizated in 2000 points
- Then, knowing the strain increment of each point, from section to section, a plane strain elastic predictor-plastic correct algorithm is conducted
- Finally, the desired values of residual stress profile, levelling forces, torques or plastification rate are calculated

Figure 4 shows the through thickness stress gradient evolution calculated using the semi-analytical model from de coil to the exit of the leveller. During this process, it is taken into account the coil radius reduction, the springback after uncoiling and the springback when the sheet leaves the leveller.

3. Model results

In table 1 the average error on the calculated total torque between the FEM model [1, 7] and the semi-analytical model are shown. In the same way, the calculated times are shown as a reference.

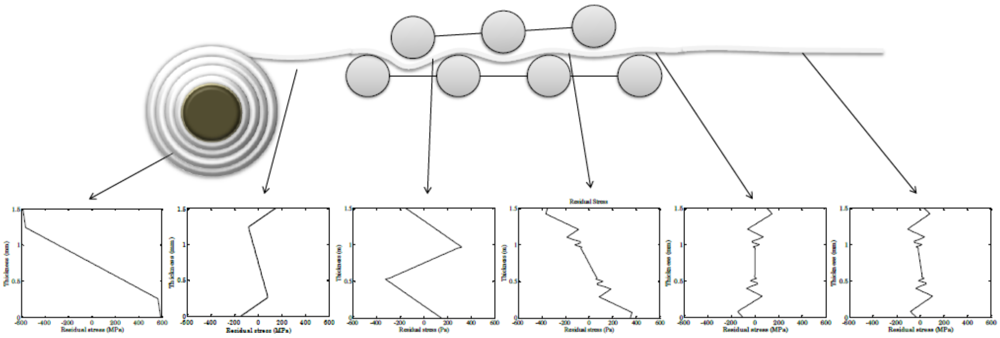

Figure 4. Uncoiling process simulation where the residual stresses profile can be monitored.

Table 1. Performance of the numerical models.

Model	Average error of total torque	Computational time
FEM	29.2 %	5 h
Semi-analytical	16.7 %	18 s

4. Conclusions

In this work a semi-analytical model of levelling has been developed. This model is able to predict the basic levelling variables in less than 30 s with a similar accuracy compared to a 3h FEM model. The correct performance of this model will allow the close loop control process implementation on future levelling machines.

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