Numerical Simulation of Roller Levelling using SIMULIA Abaqus

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Abstract. The finite element (FE) 2D-model of roller levelling process is developed in the SIMULIA Abaqus. The objective of this paper is development FE-model and investigation of adjustable parameters of roller leveller together with elastic-plastic material behaviour. Properties of the material were determined experimentally. After levelling, the strip had a residual stress distribution. The longbow after cutting is predicted too. Recommendation for practical use were proposed.

1. Introduction
Numerical prediction of residual stresses become of practical importance when the laser cutting of strips is applied [1]. High values of residual stresses lead to deformation of strips (longbow) during and after laser cutting.

There are many operations in metallurgy before cutting. It is slab heating, slab rolling until given thickness, cooling, coiling, uncoiling, levelling and strip cutting. After each operation, the material accumulates an internal (residual) stress that is distributed throughout the strip [2]. When laser cutting is applied, the balanced stress state of the material is disturbed and it leads to the longbow defect. Sheet metal often shows shape defects, which is not complying with the increasing requirements for the quality of products needed to satisfy high demands of customers [3].

In general, there are two ways to flatten sheet:
1) In roller levelling, the strip is bent through a series of rolls, moving from heavy penetration at the entry and at the end distance between the top and bottom contact rolls equals the strip thickness.
2) In tension levelling, large-diameter bridle rolls at the material exit rotate slightly faster than the work rolls behind it, pulling the strip from the source coil under very high tension.

The setting up of such machines is extremely complex and mainly depends on the operator’s experience.

Some research has been done to address the longbow problem. A few works [4, 5] describe general models for roller levelers but these models could not provide precision settings for each machine. For example, the authors of work [3] developed a precision mathematical model for setting up a roller leveler that allows making flat sheet in on-line mode.

A recent increase in computing power enabled simulation to be used for production processes to the best advantage. The problem of residual stress calculation could be solved by using FE analysis. Influence of residual stresses on shape defects of strips is examined in articles [6-11]. But the authors don’t analyze shape of the sheet having been cut into narrow blanks.
Works [12-14] describe simulation of laser cutting and prediction of thermal stresses in the cutting area.

This paper gives details on FE 2D-simulation of levelling in SIMILIA Abaqus and analysis of longbow defect after cutting.

2. FE-simulation description

For this analysis, leveler with 15 rolls, 8 over 7, is used. The simulation is carried out for 15 rolls (8 top, 7 bottom) leveler (Figure 1). Input data for simulation is:

- strip (width, thickness, material hardening law);
- position of work rolls.

The simulation is carried out for an incoming strip with a radius of curvature equal to the coil lap (500mm). The strip has 10 elements along thickness. Element type used for the strip is 4-node bilinear plain strain with reduced integration (CPE4R). The strip is assumed to be in a stress free state before uncoiling.

Rolls are simulated by discrete rigid elements.

The tangential contact between rolls and steel strip were simulated with a coefficient of static friction \( \mu_{\text{stat}} = 0.25 \) and a coefficient of kinetic friction \( \mu_{\text{kin}} = 0.12 \).

The material properties used for simulation are given in Table 1 and Figure 2. These properties were determined experimentally for steel grade S355MC, 3mm thickness.

![Initial strip curvature](image)

**Figure 1.** Assembly initial state.

| Steel grade | Elastic modulus, GPa | Yield Strength, MPa | Tensile Strength, MPa |
|-------------|----------------------|---------------------|-----------------------|
| S355MC      | 206,8                | 380                 | 450                   |

![Tensile test curve for steel grade S355MC (3mm)](image)

**Figure 2.** Tensile test curve for steel grade S355MC (3mm).
The analysis includes 6 steps:

- **Step 1 (Dynamic, Implicit):** Upper rolls move vertically and penetrate the strip. Bottom rolls remain in their position (Figures 3 and 4).

**Figure 3. Initial State at Step 1.**

- **Step 2 (Static, General):** is needed for reset velocity and acceleration vectors.
- **Step 3 (Dynamic, Implicit).** Strip levelling
- **Step 4 (Static, General):** is needed for reset velocity and acceleration vectors;
- **Step 5 (Dynamic, Implicit):** Cutting.

“Model change” function is used and part of elements are deactivated. After that, bend of the strip under the influence of residual stresses is analyzed.

### 3. Results and discussion

Residual stress distributions in the strip are modeled and longbow defect after cutting is simulated. Various settings of roller leveler are analyzed. This analysis is presented in Figure 5 and Table 2.

**Figure 5.** Longitudinal residual stress distribution through thickness before Step5 and longbow simulation after Step 5.
Table 2. Variants of various setting ups of work rolls.

| № | Upper roll penetration of strip | Gap between rolls | Stress difference between surfaces of sheet, MPa | Schematic longbow defect |
|---|-------------------------------|-------------------|-----------------------------------------------|--------------------------|
| 1 | 3                             | 3                 | 0                                             | 374                      |
| 2 | 1.5                           | 0                 | 1.5                                           | 118                      |
| 3 | 3                             | 1.5               | 1.5                                           | 304                      |
| 4 | 4                             | 2.5               | 1.5                                           | 311                      |
| 5 | 5                             | 3.5               | 1.5                                           | 344                      |
| 6 | 8                             | 5                 | 3                                             | 401                      |
| 7 | 5                             | 0.5               | 4.5                                           | 151                      |
| 8 | 6.5                           | 2                 | 4.5                                           | 303                      |
| 9 | 6.5                           | 0.3               | 6.2                                           | 113                      |

Results of computation and analysis:

1) Penetration of first upper roll shall have a maximum value (leveler with maximum gap value 4.5 mm is modelled) to provide plastification rate from 60 to 80%.

2) Penetration of last upper roll shall be as small as possible and equal to the thickness of the strip. These recommendations were proposed for validation in experimental levelling tests in PAO «Severstal».

The main objective of this work is to build a numerical simulation model of steel sheet levelling and analyze a longbow defect after cutting. The model allows for a virtual determination of leveler settings based on adjustable bending of the levelling rolls.

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