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COMPARATIVE ANALYSIS BETWEEN FEM AND SLAB METHOD FOR FLAT ROLLING PROCESS

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ABSTRACT
Modelling of flat rolling processes has great interest not only from the point of view of process analysis but also for the industrial sectors because of the great amount of materials which are produced and consumed each year.
In this work, the flat rolling process is analyzed by using FEM and considering different process conditions such as: reduction, velocity of the strip and friction coefficient, among others. Plane strain conditions will be assumed, which is in fine agreement with actual results. In order to evaluate deformations and stresses within both the strip and the rolls a two-dimensional meshing has been considered. This will allow us to determine the deflection of the rolls for different strip thickness. Moreover, a comparison between numerical and analytical results obtained by using the slab method approach is presented. A four-high rolling mills configuration has been employed to carry out the FEM simulations.
Keywords: rolling processes, FEM, SLAB Method

1. INTRODUCTION
The rolling process is one of the most common industrial processes for manufacturing parts. This process consists in reducing the thickness or changing the cross section of a long workpiece by compressive forces applied through a set of rolls [1, 2]. In this work a comparison study between finite element analysis and the SLAB method [3, 4] is presented. A four-high rolling mills configuration has been considered as can be shown (seen) in Figure 1. This selected configuration is very common for cold forging, and presents the following advantages; lower power requirements and the rolls are cheaper to replace, among others.

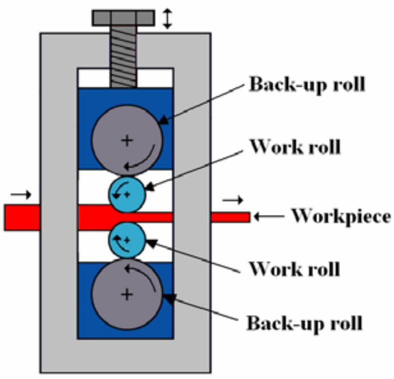


Figure 1. Four-high rolling mills configuration.

One of the most important things that need to be taken into account is to introduce good approximations of the boundary conditions, because this will help to obtain high accuracy in the

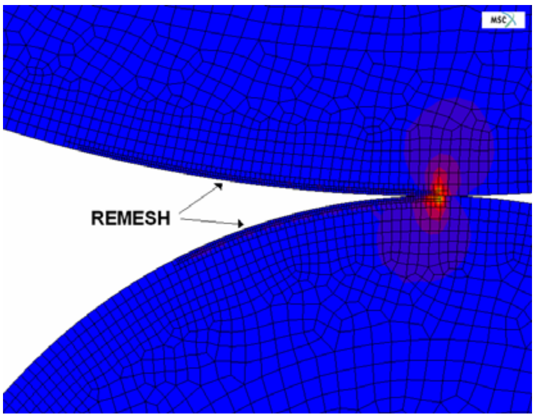
results and a good convergence. Another important point is the condition of contact between the different parts of the system, as will be shown later. Because of the symmetry of the process, it is only necessary to simulate half of the configuration, without losing any accuracy and decreasing the time of calculus. In the same direction, plane strain condition has been employed, because the width of the workpiece is much higher than the thickness (1000 mm >> 5 mm).
The main aim of this work is to obtain the location of the neutral point in the rolling processes by using the FEM. These results are compared with those obtained by using the SLAB analysis. In addition, different reductions of cross section in the rolling process have been simulated. These values are presented in Table 1.

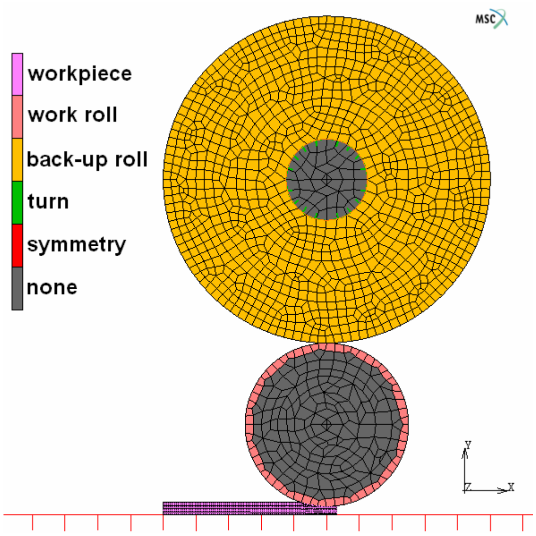
Table 1. Different reductions simulated.

Initial thickness (mm)	5	4.5	4	3.5	3	2.5
Final thickness (mm)	2					
Reduction (%)	60	55.5	50	43	33.3	20

2. FEM AND SLAB ANALYSIS

In this section, the FEM model characteristics are explained [5]. The measures of the rolls have been chosen from actual machines used in the industry. The diameter of the back-up rolls is 500 mm, and for the work rolls is 200 mm. The thickness of each model is shown in Table 1. There are two different ways of meshing the rolls. One of them consists in meshing the two rolls with small size of element from the beginning of the simulation, and the other consists in creating a bigger size of element length than the previous one and, while the model is being calculated, remeshing the zones where contact exists. The second option has been employed in order to reduce the number of elements, which also reduces the time of calculus. The remesh option occurs between the back-up and the work rolls and between the work roll and the workpiece. Figure 2a shows a detail of the remesh during the calculus between the rolls.





(a) Remesh in contact zones. *(b) Contact definition.*

Figure 2.Boundary conditions.

The boundary conditions introduced to carry out the simulations are four. The first condition fixes the displacement in x axis (parallel to the rolling axis) for the center of rotation of the back-up roll. The second condition fixes the displacement in both directions for the center of rotation of the work roll. The third condition is a pressure between the back-up roll and the work roll, which introduces the force necessary to move the work roll. The last boundary condition is the turn of the back-up roll. The last two conditions are introduced through a rigid contact between the back-up roll and a rigid circle inside this roll.
One of the most important complexities of this simulation is the introduction of the contacts. For this work, five contacts have been selected. Three of them are deformable contact, which makes it more

difficult to solve the problem, but provides us with much more information than rigid contacts. The motion of the back-up roll and the symmetry have been defined as rigid contact. These different contacts can be seen in Figure 2b.

The material properties used for the rolls are: Young's Module equal to 210 GPa and Poisson's Module equal to 0,3, which corresponds to a typical steel. For the workpiece, an aluminium alloy with yield strength of 94,2 MPa and without strain hardening, has been used.

It is necessary to emphasize the importance of finding out the right time step of the calculus, because it depends on a lot of factors such as: element size of each part of the system, velocity of rotation, nonlinearities, among others.

The results obtained with FEM are compared with the analytical method SLAB [2, 3]. The neutral point can be calculated by the SLAB method using Equation 1.

$$\frac{h_e}{h_s} = e^{\mu(He - 2H)} \tag{1}$$

Where μ is the Coulomb friction coefficient and:

$$He = 2\sqrt{\frac{R}{h_s}}\tan^{-1}\left(\sqrt{\frac{R}{h_e}}\theta_e\right) \tag{2}$$

$$H = 2\sqrt{\frac{R}{h_s}}\tan^{-1}\left(\sqrt{\frac{R}{h}}\theta\right) \tag{3}$$

The last equation necessary to be used is the geometrical relationship between the position of the neutral point h and the angle of this point referenced to the centre of the rolling mill θ. This Equation 4 can be obtained from Figure 3, where all the parameters introduced are indicated.

$$h = h_s + 2R(1 - \cos\theta) \tag{4}$$

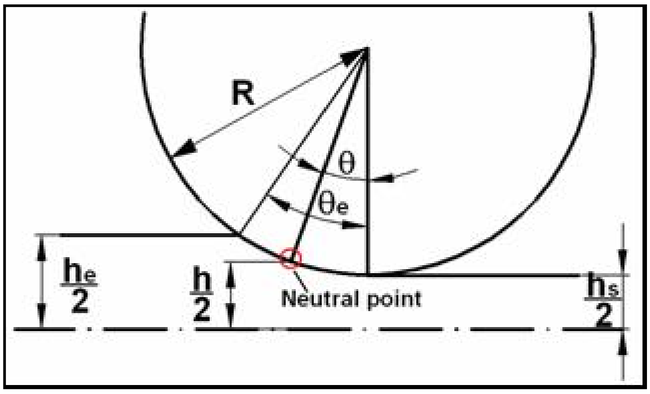


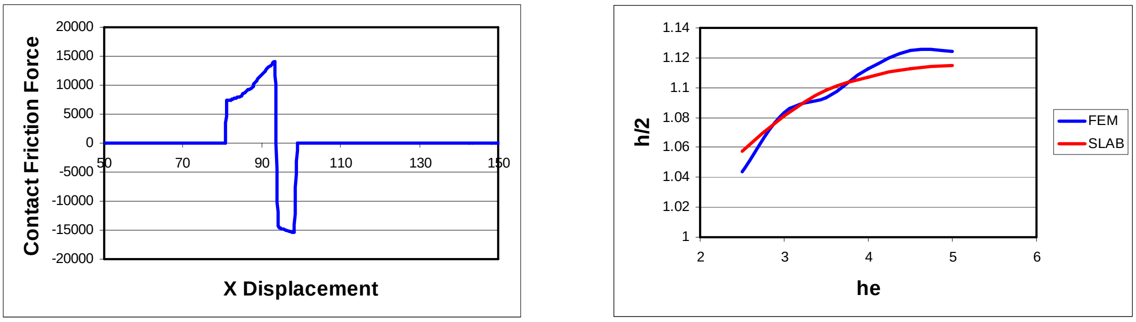
Figure 3.Parameters for the SLAB method.

3. RESULTS

In this work the location of the neutral point from FEM and SLAB method has been compared. From Equations 1 to 4 it is easy to obtain the value of h for each reduction of the rolling shown in Table 1. The curve obtained using these equations can be observed in Figure 4b in red color.

To obtain the results from FEM simulations there are different possibilities. One of them is to draw the velocity of a node of the external part of the workpiece and to compare it with the rolling mill velocity. The intersection point of these curves decides the location of the neutral point. For this work, a different consideration has been taken into account. As we know, the neutral point is the point where the velocity of the workpiece is higher than the rotation velocity of the rolling mills, so there will be a change in the direction of the contact friction force in this point. This change can be observed in

Figure 4a. In Figure 4a the evolution of the friction force during the rolling process can also be seen. Until the node reach the rolling mill there is no contact, so the friction force is nil. Then the friction force increases while the compression is increasing. Then, the velocity of a point in the workpiece exceeds the rolling mill velocity and a change in the direction of the friction force takes place. Finally this force increases until the contact between them disappears.



(a) Longitudinal displacement vs. Contact Friction Force for the case of h_e=5 mm.

(b) Comparison of neutral point location vs. .entrance thickness.

Figure 4.Results.

The comparison between both methods of the neutral point location is shown in Figure 4b. The same tendency exists in the curves with small differences. There is more accuracy for low reductions. The value of *h* has been shown from the symmetry line to the upper rolling mill, so *h/2* has been introduced in *y* axis for Figure 4b.

4. CONCLUSIONS

A comparative study between FEM and SLAB method has been made in this work in order to the neutral point in rolling processes. Different reductions have been employed. A four high rolling mills configuration has been employed to carry out the FEM models.

The location of the neutral point from the FEM results has been determined by finding out the point where the change in the direction of the contact friction force occurs.

It has been shown that the neutral point is close to the exit of the rolling process and that a fine agreement exists between both, FEM and the SLAB method.

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