Analysis of the Deformation Behaviour of Cold Flat Rolling for Aluminum Alloy

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Abstract: *In today's scenario, finite element simulation has become an important tool in the manufacturing industry. Cold rolling process plays an important role in the manufacturing of aluminum plate and sheet with a long-range variety of dimensions. In this paper, the plastic strain and stress distributions within the work piece, together with the normal pressure along the arc of contact are calculated. Analyses are conducted with different levels of friction, material properties, and reductions. This FEM simulation was carried out by using ABAQUS software. The goal of this research is to determine and compare the grid distortion, the normal stress and normal pressure through the aluminum alloy sheet during cold flat rolling. The usefulness of this numerical analyses for the investigation of parameters relevant to local industrial rolling practice is demonstrated.*

Key Words: *Cold Rolling, Normal Stress, Normal Pressure, friction, FEM.*

1. INTRODUCTION:

The rolling process is a popular process in metal forming industries where about 80% of metallic parts have been produced by rolling. Among all kinds of the metal rolling processes, the flat rolling is the most useful process. In industrial countries, about 40-60% of rolling products are produced with this type of rolling process. Therefore, many scientists have tried to enhance the quality of products by optimizing this process to satisfy their customers [1]. Cold rolling produces sheet, strip, and foil with the good surface finish and increased mechanical strength, at the same time maintaining close control over the dimensions of the product [2].

Numerical simulations and finite element methods have been found to be an effective tool for prediction in rolling problems. Liang Hao, Zhengyi Jiang and Xiawei Chen (2013) discussed contact pressure distribution and roll contour in roll bite by using finite element method [3]. K. Devarajan, K. Prakash Marimuthu and Dr. Ajith Ramesh (2012) studied the residual stresses and contact pressure by changing the roll diameters and roll speeds [4].

In this study, a three-dimensional finite element method for cold rolling of aluminum plate has been analyzed to study the behaviour of the material under different coefficients of friction and various percent reductions for obtaining a desired height of the rolled plate. The commercially available finite element software ABAQUS 6.13 has been used in this simulation.

2. PROBLEM STATEMENT:

The main objective of this study is to observe the deformation behaviour of the locally produced aluminum alloy by cold flat rolling varying with percent reduction, friction and materials condition (the same composition with different treatment processes, as cast, homogenize) by using finite element simulation. The secondary objective is to simulate the aluminum cold rolling process that could be a widely used process in the local industrial zone by applying ABAQUS simulation software. In this research work, the required aluminum alloy was commercially produced at Shwe Pauk Kan industrial zone, Yangon, Myanmar. These aluminum plates of an original cross section of 10.8 mm by 200 mm and 260 mm in length is reduced up to 4.32 mm in thickness by five passes rolling through the one roll stand. This paper describes and analyzes the three-dimensional rolling of the flat plate.

This simulation was carried out in five cases, as the data shown in the Table 2.1. A three-dimensional FEM study carried with friction coefficient varied from 0.1 to 0.5 and the reduction increased from 20% to 60%. In addition, all over the cases, the roll diameter (240 mm) is kept constant.

Table 2.1. FRICTION COEFFICIENTAND PERCENT REDUCTION

Case No.	Friction Coefficient	Percent Reduction (%)	Final Height (mm)
1	0.1	20	8.64
2	0.2	30	7.56
3	0.3	40	6.48
4	0.4	50	5.4
5	0.5	60	4.32

2.1. Materials Selection and Chemical Composition

Cold working can increase the strength of this aluminium alloy being medium strength, hardenable and not heat treatable. It also has good weldability, formability and corrosion resistance [5]. The chemical composition of this aluminum alloy contain Si 0.588%, Fe 1.118%, Cu 0.506%, Mn 0.313%, Mg 0.436% and Al 97.039%. This composition was measured by optical emission spectrometer, Bruker Q4.

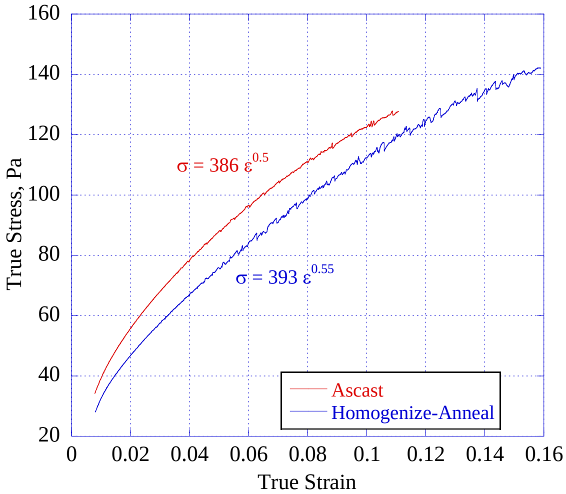

Figure2.1 True stress-strain curves for the plastic range of as cast and homogenize-anneal aluminum alloy

The mechanical properties of the work piece used in this simulation have been obtained from tensile testing. The true stress-true strain graph of as cast and homogenize-anneal treatment materials are described in Fig. 2.1.

The stress-strain relation used for as cast aluminum was:

$$\sigma = 386\ \varepsilon^{0.5}$$

and for homogenize-anneal aluminum was:

$$\sigma = 393\ \varepsilon^{0.55}$$

where σ and ε are true stress and true strain, respectively.

Young's Modulus (E), 6.433 GPa and 5.604 GPa, strength coefficient (K), 386 MPa and 393 MPa, and strain hardening exponent (n), 0.5 and 0.55, for as cast and homogenize-anneal aluminum alloy were determined from experimental tensile testing which was done by universal testing machine, SHIMADZU UH-1000kNX.

3. SIMULATION CONDITION:

The roller was modelled as rigid [4]. The strip was modelled as elastic-plastic and assumed flat plate was isotropic with the density of 2730 kg/m^3 and Poisson ratio of 0.33, the plate was given initial velocity of 243.4 mm/s before entering the roll gap and the angular velocity of the rollers 2.042 rad/s.

3.1 FE Mesh

The symmetrical deformation about x, y, z planes were studies [6]. Isoperimetric hexahedral elements with eight Gauss points were used throughout the plate, including the entry side to the roll gap [6]. A global mesh size is two for rollers and plate. The adaptive mesh control manager of ABAQUS reduces the amount of mesh distortion and maintains a high-quality mesh throughout the analysis [6].

3.2 Boundary Conditions

The boundary conditions for the rollers and plate are shown in Table 3.1. U_1, U_2, U_3, U_{R1}, U_{R2} and U_{R3} are the displacement of the plate and rotation of the rollers in directions x, y and z. V_{R1}, V_{R2} and V_{R3} are the velocity of the rollers in x, y, z directions [6].

Table 3.1 VELOCITY BOUNDARY CONDITION

Position	Conditions	BoundaryConditions
Roller centre	Displacement/ rotation	U_1=U_2=U_3=0 U_{R1}=U_{R2}=0
Roller centre	Velocity/angular velocity	V_{R3}= 2.04203 rad/s
Plate side surface	Symmetry	U_3=U_{R1}=U_{R2}=0
Plate bottom surface	Displacement/ rotation	U_2=0

3.3 *Finite Element Simulation*

Finite element simulation has three stages in pre-processing, analysis and post-processing. Pre-processing and post-processing include Abaqus/CAE and Abaqus/Viewer. Abaqus/CAE is an interactive pre-processor that can be used to create finite element models and the associated input file for ABAQUS. Abaqus/Viewer is a menu-driven interactive post-processor for viewing the results obtained from ABAQUS/Standard and ABAQUS/Explicit [7]. This job was analyzed by using Abaqus/Explicit method.

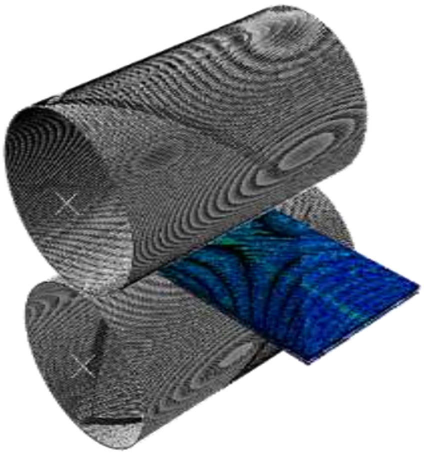

Figure 3.1 Three-dimensional rolling of flat plate

4. RESULTS AND DISCUSSION:

The main interests of this study are contact pressure and normal stress for variation of coefficient of friction and percent reduction in cold rolling process. Thus, the finite element simulation of cold rolling of an aluminum plate will be done at the coefficient of friction 0.1, 0.2, 0.3, 0.4 and 0.5, with the different percent of reduction 20%, 30%, 40%, 50% and 60%. And pressure distribution in rolling of as cast aluminum plate compared that of homogenize-anneal aluminum.

4.1 Effect of Percent Reduction on Normal Pressure

Fig. 4.1 and Fig. 4.2, show the effect of reduction on the distribution of contact pressure. Apex shows neutral point for each reduction as seen in Fig. 4.1 and Fig. 4.2. It can be seen that contact arc lengths become longer and pressure distribution hills are higher by increasing the reduction rate, and the neutral point shifts toward the exit side of the work piece as percent reduction is increased. The pressure curves shown here line very similar to these two different treatment conditions for same material composition. It should be these two material properties that (strength coefficient, K and strain hardening exponent, n) are not of so much difference according to their true-stress true-strain curves. In Fig. 4.1 and Fig. 4.2, the maximum normal pressure was increased nearly equal spacing ($1{\sim}2 \times 10^8$) at each higher percent reduction.

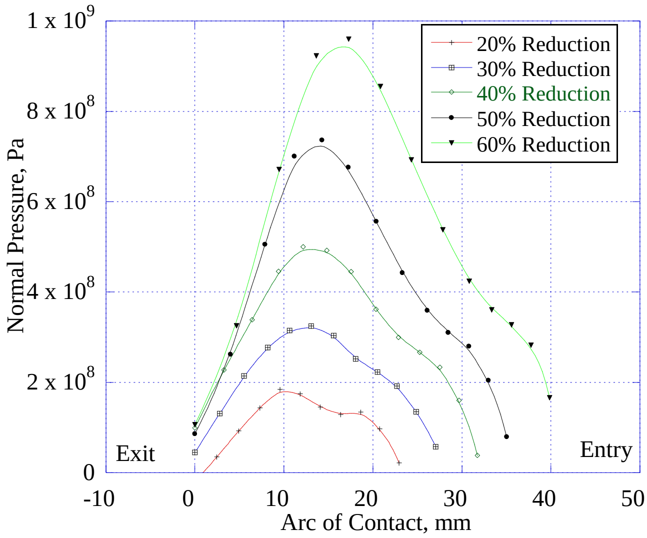

Figure 4.1 Pressure distributions in rolling of the as cast aluminum alloy plate for various percent reduction (friction factor, μ =0.3)

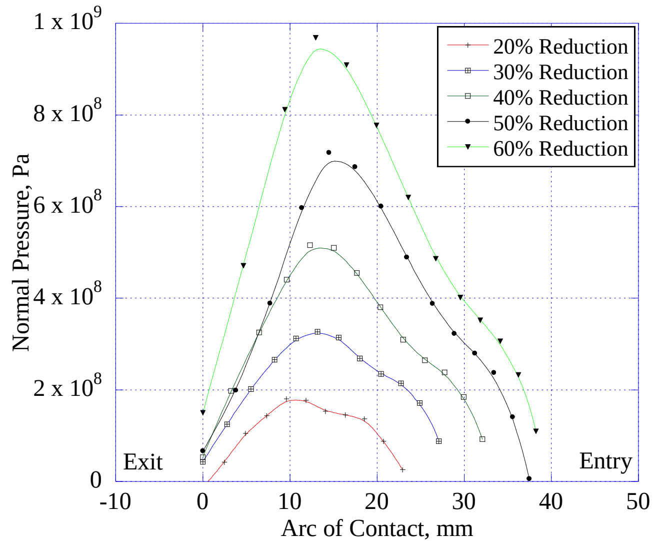

Figure 4.2 Pressure distribution in rolling of the homogenize-anneal aluminum alloy plate for various percent reduction(friction factor, μ =0.3)

4.2 Effect of Normal Stress on Distorted Layer

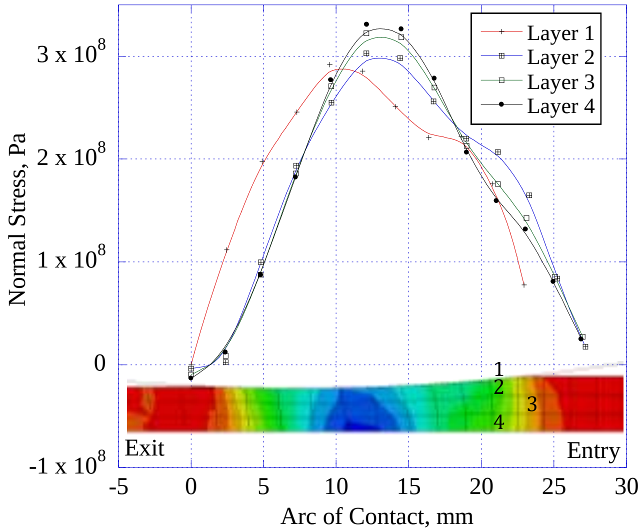

Figure 4.3 Normal stress distribution of the as cast aluminum plate at reduction = 20% and friction coefficient = 0.3

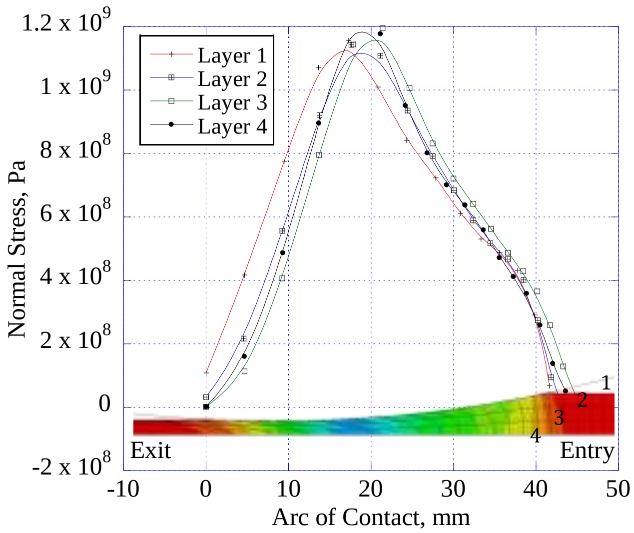

Figure 4.4 Normal stress distribution of the as cast aluminum plate at reduction = 60% and friction coefficient = 0.3

The distribution of stress components on various layers for 20% and 60% reduction are shown in Fig. 4.3 and Fig. 4.4. The stresses are compressive over most of the deformation zone and show a small tensile value ahead of the entry point. At the exit side, normal stress in layer-1 is higher than the other layers. However, at the entry side, its value is lower than the others.

4.3 Effect of Various Frictions on the Pressure Distribution

Fig. 4.5 shows the effect of friction influenced on normal pressure by increasing deformation. In this figure, the normal pressure rises when the coefficient of friction and percent reduction increases. In low friction coefficient, the pressure curve gradually rises from lower reduction to higher reduction. In higher friction coefficient, the pressure curves are steeper from lower reduction to higher reduction. In lower percent (20%) reduction, the magnitudes of normal pressure are not different so much for each friction coefficient. But the magnitudes of the normal pressure are significantly changed at higher percent reduction (60%).

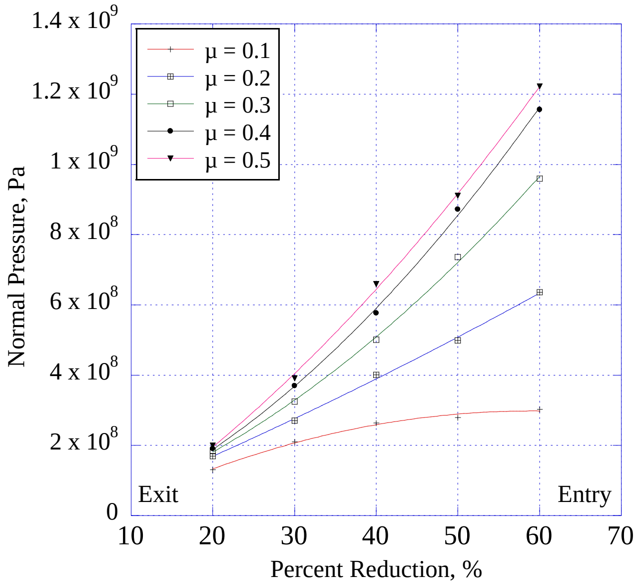

Figure 4.5 Effect of friction on the pressure distribution of as cast aluminium alloy plate

4.4 Grid Distortion in Rolling of Aluminum

Level of inhomogeneity of deformation can be observed from the shape of the distorted grids by the variation of 20% to 60% deformation respectively, with a constant friction factor of 0.3 as shown in Fig. 4.6. In this figure, the elements for low percent reduction are less distorted than higher one. For both high and low reduction, the elements in the surface layer are more distorted than those in the lower layer. Moreover, the plastic strain (PE) is the highest value at the exit side of roller for larger percent reduction (60%).

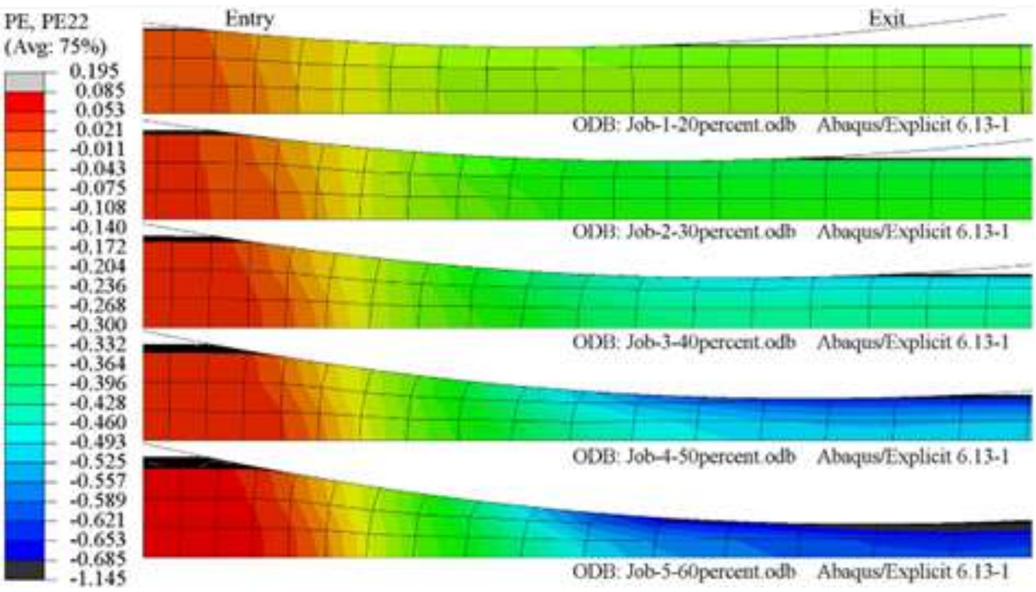

Figure 4.6 Grids distortion in rolled as cast aluminum with friction coefficient (0.3) and percent reduction (a) 20% (b) 30% (c) 40% (d) 50% (e) 60%.

5. CONCLUSIONS:

This three-dimensional finite element method was developed to simulate cold flat rolling process considering on the variation of friction, percent reduction and two different aluminum alloy which was produced at local industrial zone. Pressure distribution curves of simulated two alloys were observed as similar trends. These results may be nearly the same nature of two true stress-strain curves of unrolled aluminium alloy plate. Otherwise, the grid distortion of the surface layer was larger than the lower layer in as cast rolled aluminum plate. It has been demonstrated that the effects of friction and percent reduction influence on the grid distortion, stress and pressure distribution can be detected by using this simulation. This method is also applicable for complex geometry and can give a good agreement for the prediction of deformation behavior in cold flat rolling of aluminum shape forming.

6. RECOMMENDATIONS:

It is recommended that homogenize-quenched aluminum alloy should be used for further simulation according to its higher strength and ductility than as cast and homogenize-annealed aluminum alloys. Moreover, the finite element method should be used flat rolling process simulation prior to industrial rolling design because it can give a good agreement to estimate deformation behaviour in flat rolling process.

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