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Defect Analysis of Angle Bar in Hot Rolling

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Abstract

In this work, the study of existing process was done to find the root cause of the problem. Three dimensional model of rolls and steel angle bar were developed in SOLIDWORKS. The models were imported in to LS-DYNA software for simulation of the rolling process with the different combination of mill speeds and friction coefficient. Physical and mechanical properties of raw material and temperature of ingots was specified. Meshing of model was done for accurate representation of effective stresses, effective plastic strain and displacement during rolling.

The analysis of the rolling process was done and results obtained in terms of equivalent stress and effective plastic strain. At suggested process parameters viz. mill speed of 90 rpm and friction coefficient of 0.25, the value of effective plastic strain & effective stress on the edges of steel angle bar are 0.57761 and 533.379 MPa respectively, which are within safe limits. It has been found that mill speed and friction coefficient are the two major factors that significantly affect the quality of rolling products. Lower value of friction coefficient requires that number of mill passes be increased. Higher value of friction coefficient increases the sticking between rollers and the incoming metal leading to defects in steel angle bar

Keywords: Hot Rolling, Cold Rolling, cracks, coefficient of friction, Stress

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1. Introduction

The investigating the mechanism of thermal crack growth while taking into account the complex thermal and mechanical interactions during the rolling process. They utilized the concepts of FEM for the estimation of rolls life, from the perspective of thermal fatigue. Their work described the methodology of predicting thermal fatigue crack growth using innovative modelling techniques and they highlights the importance to the operating conditions [1].

The accuracy of the FE model was analyzed through a dual comparison by geometrical and by physical aspects. The effectiveness of a new numerical subroutine was tested by a comparison with experimental values acquired from an industrial plant tool wear, the author characterized the extent of the tool wear by wear depth. Twenty points were used to measure tool wear depth with different area reduction, forming angle, and stretching angle [2].There was good agreement between experimental results and the simulation in terms of wear and rolling friction under different operating conditions. The analysis of disc-disc interaction has been presented by using FEM technique. However this work gives rise to thoughts about possible applications in various fields [3].

The finite element model for the prediction of the steady-state thermo-mechanical behaviour of the roll-strip system and of roll life in hot strip rolling. The model was comprised of basic finite-element models, which are incorporated into an iterative-solution procedure to deal with the interdependence between the thermo-mechanical behaviour of the strip and that of the work roll. However, the model addressed only a part of roll wear–related problems, leaving the rest for future works [4].

They used finite element analysis technique to investigate behaviour of rolls related to bending, shifting and levelling. The effective utilization of these methods, leads improvisation of the flatness in the cold rolled sheet. Apart from the profile of sheet, the shape was also significantly affected by the vibrations developed in mill housing [5]. The developed procedure for the simulation of the hot rolling process. They stated that rolling is a 3D process but using the generalized plane strain method, the real 3D problem can be solved using a 2D Finite Element Model, saving an important computing time [6].

FEM software are able to describe the kinetics of recrystallization during the process, taking into consideration grain size refinement and grain growth. By incorporating such mathematical models, it is possible to predict the formation process as a whole, including the final microstructure obtained for the forged part, allowing process optimization that focuses on a higher-quality final product [7].

They developed a computer system to detect shape defects in the rolled product and determined the degree of deformation of metal at the design stage, which allows the initial plans to approximate the final design as closely as possible. So this system is very helpful for future researchers, would make it possible to avoid having to perform a large number of costly and time-consuming commercial trials and to predict the defects might be formed in the rolled product [8].The variation of the blade cross-section, the deformation stress and strain of the work-piece keep changing during the rolling process and the conventional rolling theory is no longer valid. The complexity and diversity of the blade cross-section determine it impossible to establish a universal theoretical model for the rolling process [9].Finite element method is reliable and versatile analytical method that avoids bold hypothesis, which are often involved in the classical methods such as the slab method or the energy method [10].

The sizing press followed by horizontal rolling is more efficient in width reduction than deformation by a heavy edger mill followed by horizontal rolling. The finite-element analysis results for the deformation of a slab also show reasonable agreement with measurements from an actual mill test, and from physical modelling experiments [11]. The effects of process parameters such as the cooling condition of the work-rolls, the rolling speed, and the roll metal interfacial heat-transfer coefficient on the temperature distributions in the work-rolls as well as in the rolling metal. The comparison between the model predictions and experimental results shows the validity of the proposed model [12]. The rapid development of computer technology and the improvement of general finite element analysis software, especially with the development of parallel computing technique, it has become possible to analyze cold strip rolling process and calculate the strip deformation with 3-D finite element contact model of rolls and strip [13]. The temperature of H-beam was a downward trend in the hot rolling process, however, local temperature display rising trend, uneven deformation of flange lead to more complex temperature distribution, there is certain correlation between equivalent plastic stress and temperature distributions, increasing of equivalent plastic stress as the temperature increases, research results can provide theoretical basis for rolling regulations and reference of the production of hot rolling for H-beam [14]. The vertical roller mill 3-D model established in Pro/E is imported into ADAMS through the data interactive software Mech/pro to analyze its stress, and then carry out the FEA of the model loaded in ANSYS. After Comparing with the material yield limit, the both stresses are reasonable which will meet the demand of design. This co-simulation method provides a reliable basis for vertical roller mill design and can also be applied to other mechanical system design process [17].

A coupled thermo-mechanical finite element method computation on steel pipe rolling process, gets the residual stress and strain change rule in the rolling process. They analyzed the influence of roller spacing and velocity parameters on residual stress and strain, which provides a reliable theory basis for improving the performance of hot rolling seamless steel pipe and the optimization of rolling technological parameters [18].

The roll cross angle, rolling press quantity, intersection position and rolling speed can change the size of the axial force, axial forces may float small by the pressing ratio increases, lager by rolling speed increases, bigger by adding more far intersection point position, This conclusions have realistic significance in cross rolling schedule making, and provide basis theory reducing rolling axial force [19].

The ring can approximately maintain its round shape at the initial rolling period, when the process is entering the medium period, the roundness of the ring becomes worse, and it tends to be improved at the final rolling period. A series of ring rolling experiments were conducted. So the reliability of the finite element model of the vertical hot ring rolling process with measurement and control was validated [20].

The formation of edge defects in hot strips, resulting from slab corner cracks generated in continuous casting. They developed a model-based concepts for the identification of such initial slab cracks. To accomplish this task a systematic finite element tool Deform-3D was utilized. The numerical results clearly pointed out the significant morphological changes of the cracks during rolling and afford valuable indications for a deeper understanding of the underlying process details [21].

A two dimensional elastic plastic model was used to simulate the cold rolling of thick strip. They found the speed and diameter of rolls have influence on the quality of rolling products [24].

The mechanical properties of high strength steel and mild steel at elevated temperatures. They found that yield strength, tensile strength and elastic modulus of steels at elevated temperatures decreases [25].

2. Problem Description

The company, Shamli Steels Private Limited situated in Muzaffarnagar (U.P.), is a manufacturer of steel angle bars which are used as structural members. Therefore strength and surface quality of hot rolled steel angle bar are key quality parameters.

The company is facing the problem of edge cracks in steel angle bar during the hot rolling operation as shown in Figure 1.These cracks reduce strength of the angle bar due to which such components are rejected. This results loss in productivity and increase financial burden on company.

3. Objectives of the Present Work

The aim of present work is to carry out the investigation of edge cracks of steel angle bar during hot rolling operation. The objectives of current work are as follows:

- Modeling of the rollers and ingot assembly for transient analysis.
- Analysis of effective stress and effective plastic strain produced in the angle bar using finite element approach.
- To determine optimum process parameters for prevention of edge cracks in angle bar.
- To reduce scrap and quality problem.

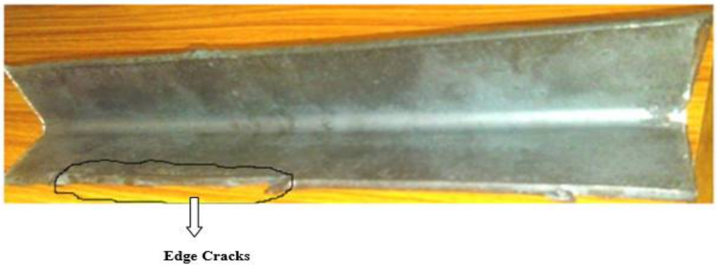


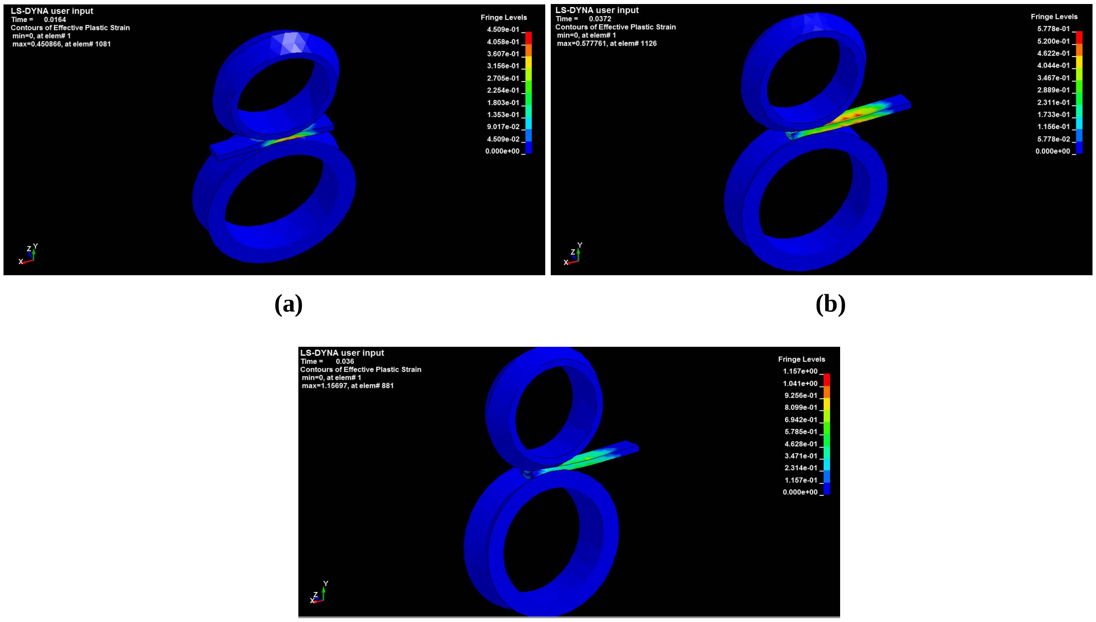
Figure 1: Edge Crack

4. Results and Discussion

The analysis of edge cracks in steel angle bar was carried out by varying the mill speed and the friction coefficient. The diameter of the rollers and temperature of the material were not changed as per industry requirement. Also limit of mill speed was taken 110 rpm.

The simulation results were obtained in the terms of effective plastic strain and effective stress distribution. The acceptance criteria of plastic strain is 0.5 in hot rolling [26]. So the plastic strain value exceeds this limit then it will lead edge cracks in steel angle bar.

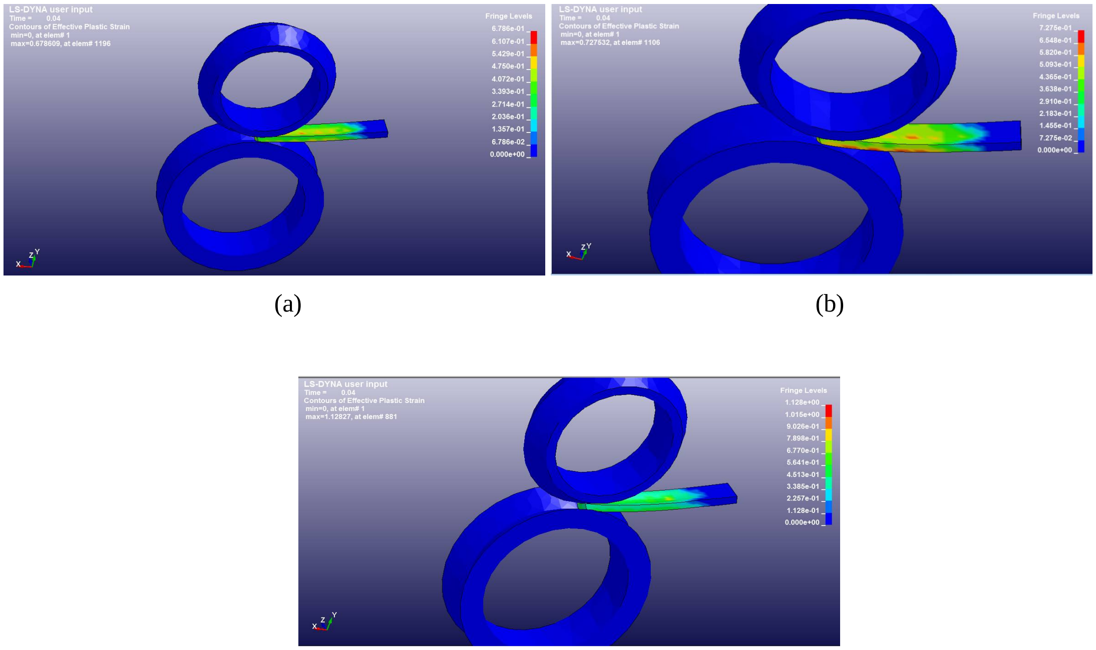
In this work the ingot and rollers assembly was subjected to mill speed of 90 rpm, 95 rpm and 100 rpm with friction coefficient 0.20, 0.25 and 0.30. The maximum effective plastic strain was produced 1.15 at N=90 rpm with friction coefficient 0.30 and minimum effective plastic strain was produced 0.450866 at N=90 rpm (μ=0.20)



(a) **(b)**

(c)

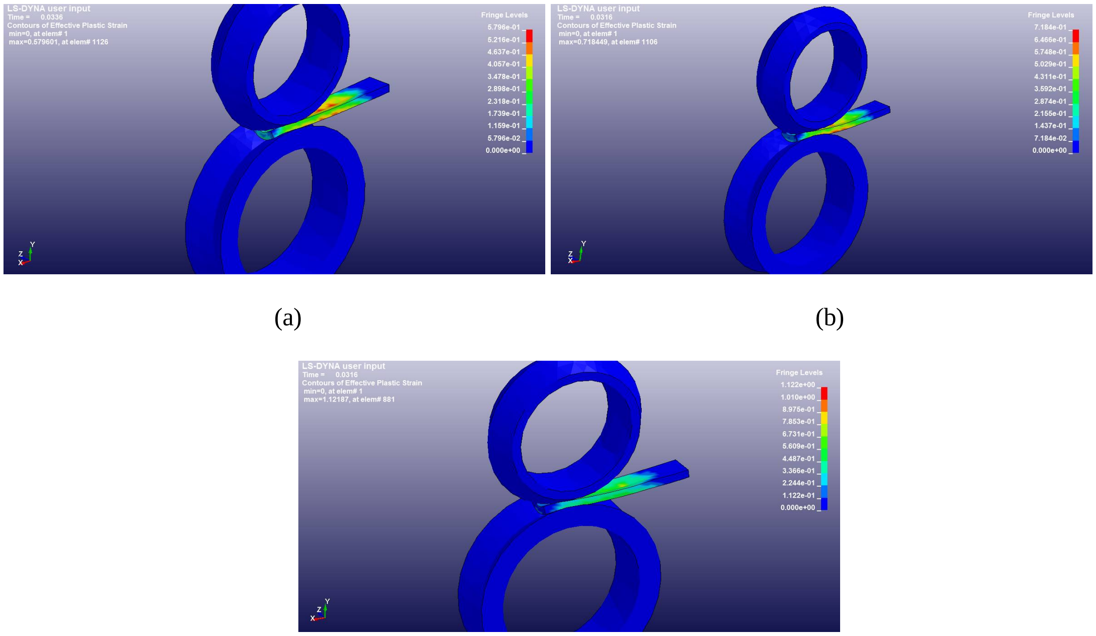
Figure 2: Effective Plastic Strain Distribution in Angle Bar at N=90 rpm
(a) µ=0.20 (b) µ=0.25 (c) µ=0.30



(a) (b)

(c)

Figure 3: Effective Plastic Strain Distribution in Angle Bar at N=95 rpm
(a) μ=0.20 (b) μ=0.25 (c) μ=0.30

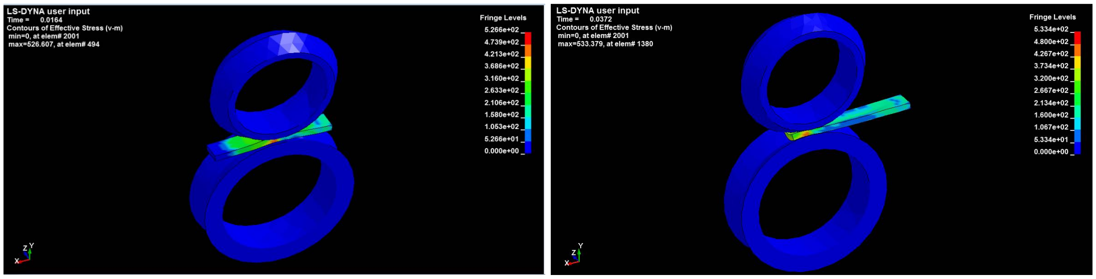


(a) (b)

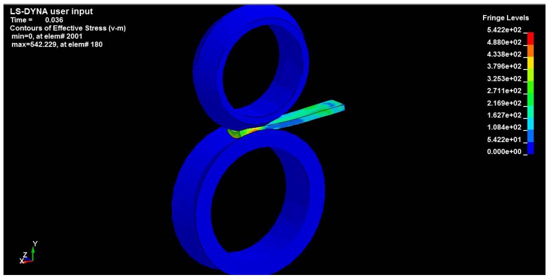
(c)

Figure 4: Effective Plastic Strain Distribution in Angle Bar at N=100 rpm
(a) μ=0.20 (b) μ=0.25 (c) μ=0.30

In this work the ingot and rollers assembly was subjected to mill speed of 90 rpm, 95 rpm and 100 rpm with friction coefficient 0.20, 0.25 and 0.30 the maximum effective stress was produced 582 MPa at N=100 rpm with friction coefficient 0.30 and minimum effective plastic strain was produced 417.7 MPa at N=95 rpm (μ=0.20)

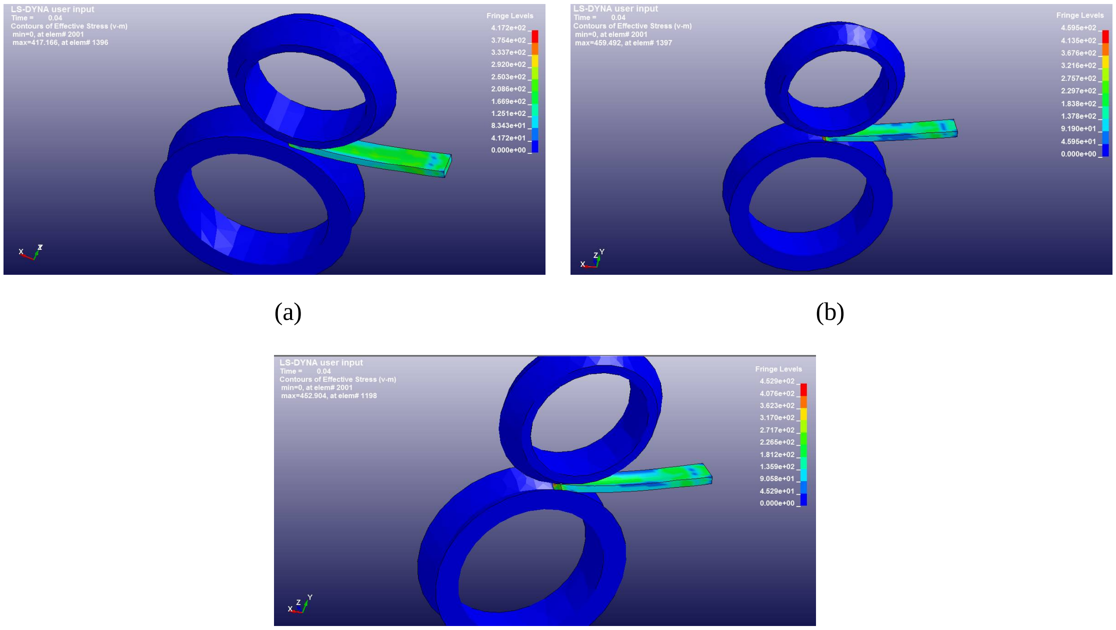


(a) **(b)**



(c)

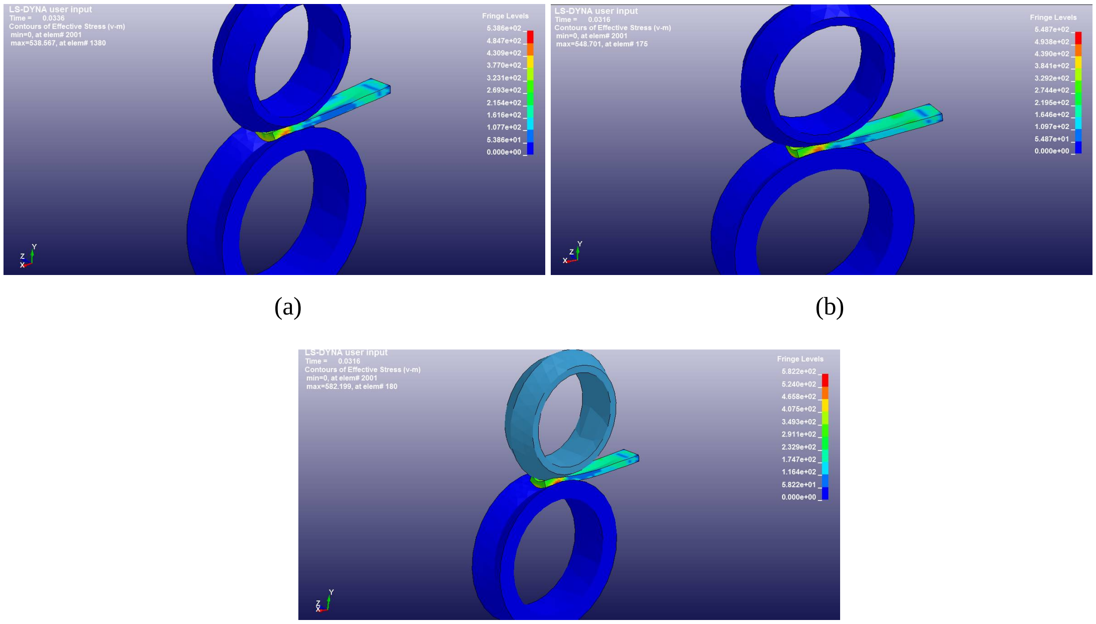
Figure 5: Effective Stress Distribution in Angle Bar at N=90 rpm
(a) µ=0.20, (b) µ=0.25, (c) µ=0.30



(a) (b)

(c)

Figure 6: Effective Stress Distribution in Angle Bar at N=95 rpm
(a) µ=0.20, (b) µ=0.25, (c) µ=0.30



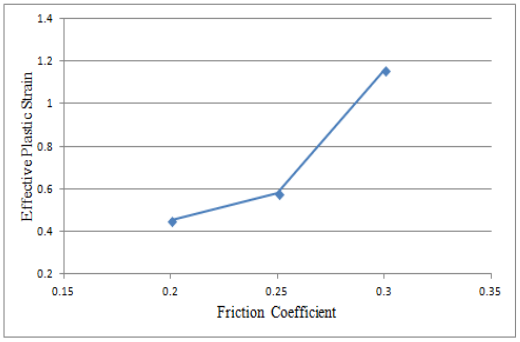
(a) (b)

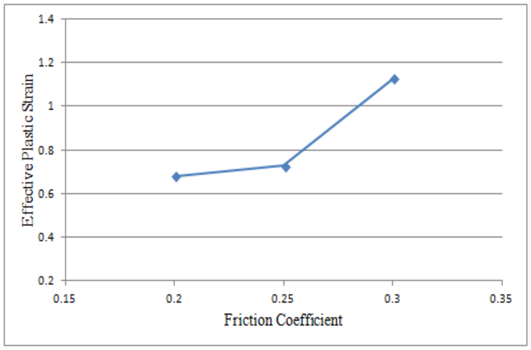
(c)

Figure 7: Effective Stress Distribution in Angle Bar at N=100 rpm
(a) μ=0.20, (b) μ=0.25, (c) μ=0.30

The figures 2-4 shows plastic strain development in the angle bar. Maximum plastic strain (1.15697) region is represented by red colour zone at the status bar. And the figures 5-7 shows effective stress development in the angle bar. Maximum effective stress (542.229 MPa) is represented by red colour zone at the status bar. The various colours at the status bars represents variation of plastic strain and stress values.

The effective plastic strain and effective stress results obtained for angle bar during rolling at mill speed 90, 95 and 100 rpm and different friction coefficient are plotted in the form of graphs as shown in Figures 8-9.





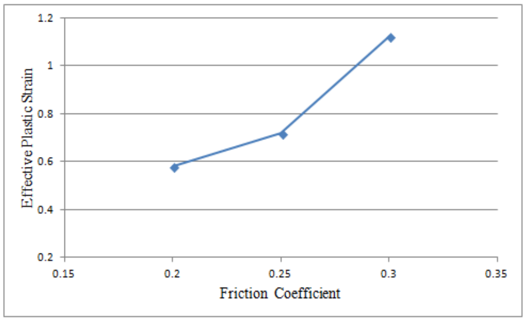


Figure 8: Effective Plastic Strain Variation with Friction Coefficient (0.20 To 0.30) (a) N=90 rpm, (b) 95 rpm, (c) 100 rpm

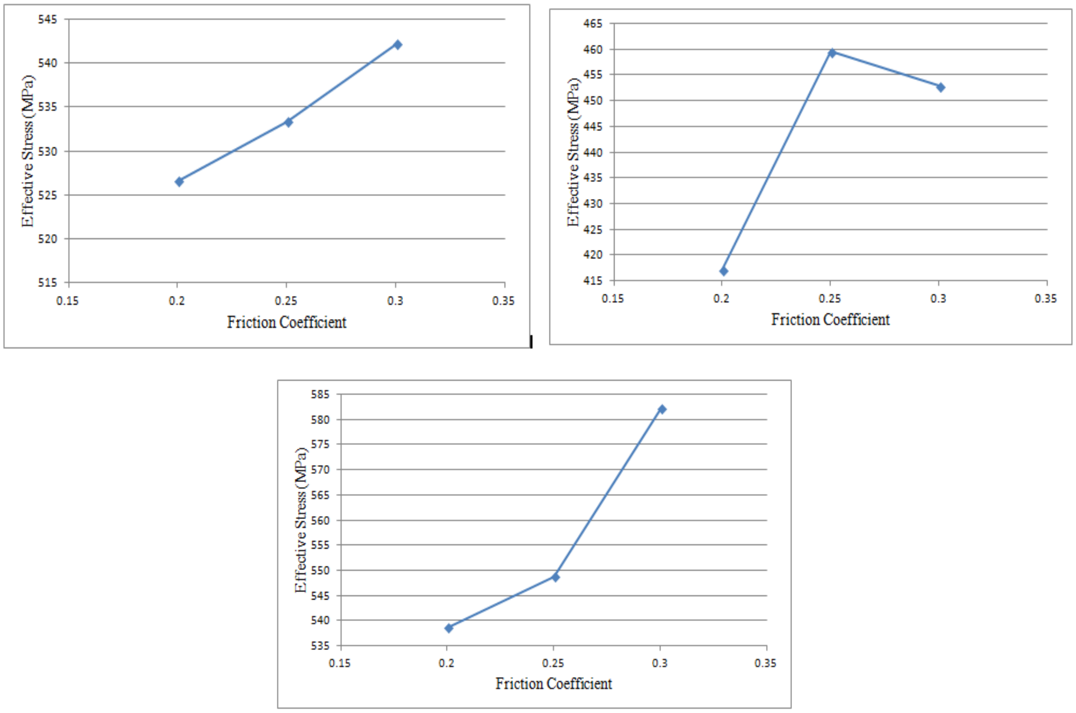


Figure 9: Effective Stress Variation with Friction Coefficient (0.20 To 0.30) At (a) N=90 rpm, (b) N=95 rpm, (c) N=100 rpm

The figure 8 shows variation of plastic strain with increased friction coefficient value at mill speed 90 rpm, 95 and 100 rpm. The plastic strain increases with increasing friction coefficient. And the figure 9 shows variation of effective stress with increased friction coefficient at mill speed 90, 95 and 100 rpm. The effective stress increases with increasing friction coefficient.

5. Recommendations

The process parameters used by company for production of steel angle bar at 9th mill pass were mill speed of 100 rpm and friction coefficient of 0.30.

The optimum process parameters obtained by modelling and simulation of the process followed by data analysis was shown in Table 1.

Table 1: Optimum Process Parameters

S.No.	Mill Speed (rpm)	Friction Coefficient	Effective plastic Strain	Effective stress (Von-mises), MPa
1	90	0.25	0.57761	533.379

So it is suggested that mill speed of 90 rpm and friction coefficient of 0.25 be used for the rolling of steel angle bars as the effective plastic strain and effective stress are observed to be within permissible limit under these conditions. It is also observed that effective plastic strain and effective stress remain in permissible limit for mill speed of 90 rpm and friction coefficient of 0.20 as well. But the lower value of friction coefficient requires that number of mill passes be increased. Higher value of friction coefficient increases the sticking between rollers and the incoming metal. This leads to defect in angle bar. Therefore it is also suggested that the rollers be cooled at 9th mill pass where a large reduction in height of incoming metal occurs.

6. Conclusions

The following conclusions are drawn on the basis of analysis of rollers and ingot assembly.

- The three dimensional model of rolls and steel angle bar were developed to simulate the hot rolling of C20 carbon steel using finite element analysis software LS- DYNA 2015. The analysis of the rolling process was done and results obtained in terms of equivalent stress and effective plastic strain.
- The effects of the friction on the rolling of steel angle bar were studied for friction coefficient values of 0.20 to 0.30. The simulation results indicate that the value of friction coefficient affects the effective stress and effective plastic strain during rolling of incoming metal.
- It is observed that the plastic strain distribution in steel angle bar after 9th mill pass, is not homogeneous on edges and it is more than design value of 0.5 for C20 carbon steels at original process parameters.
- Simulation results indicate that high plastic strain contours are generated in steel angle bar with increased value of friction coefficient at constant mill speed.
- The effects of mill speed on the deformation during rolling were examined. It is observed that mill speed has an effect on the effective stress and effective plastic strain distribution during rolling.
- The effective plastic strain and effective stress on the edge of steel angle bar were obtained. At suggested process parameters viz. mill speed of 90 rpm and friction coefficient of 0.25, the value of effective plastic strain & effective stress on the edges of steel angle bar are 0.57761 and 533.379 MPa respectively, which are within safe limits.

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