Investigation the Effect of Roller's Speed and Diameter on Coefficient of Friction During Rolling Process

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Abstract— The cold rolling of a flat plate is a deformation process in which the metal plate is passed through two opposite rotating rollers by compressive forces exerted by them. In the present study, the effect of rolling process parameters such as friction coefficient between roller-plate surfaces, roller's speed and diameter has been investigated. An FE simulation was carried out using ABAQUS 6.12 software (Explicit) to investigate the influence of these parameters on roller's force, equivalent plastic strain (PEEQ) and vonMises stresses. The results show the roller diameter has a significant effect on the effective friction coefficient (EFC) than roller speed, meanwhile, the increasing of roller diameter leads to decrease the rolling process time. Moreover, the vonMises stresses increase throughout the rolling process until reach a certain value then slightly decrease and remain almost in the extent of this value even the finished of the process. Also the equivalent plastic strain (PEEQ) has inverse relation with the roller speed.

Index Term— Effective friction Coefficient (EFC), roller's speed, diameter, force and moment, vonMises stresses, equivalent plastic strain (PEEQ), compressive force.

I. INTRODUCTION
Rolling is a fabrication process in which the thickness of the rolled metal is reduced by compression forces exerted by two rollers rotating in opposite direction. Among other kinds of rolling processes, flat rolling is one of the most practical and popular processes in manufacturing industries, therefore in industrial countries, about 40%-60% of rolling products are produced by this type of rolling [1,2]. Relative to the temperature of the rolling process, the rolling is classified to cold and hot rolling. There are interesting features of the hot rolling process which are derived from its properties such as free of residual stresses and its properties are isotropic but its products are suffered from; they cannot achieve close dimension tolerances which is considered as the main market requirements especially for flat rolling. In addition to, the surfaces of the products have a characteristic oxide scales. While, by contrast, a cold rolling permits a tighter dimension tolerances, there are no oxide scales on the products' surfaces and meanwhile, it strengthens the rolled metal [1,2,3,4]. Consequently, these characteristics lead to make cold rolling process ideal for producing and provide a lot of industries' products such as electronics, automobiles, transportation, office furniture, and appliances [3,5].

P.L. Srinivasa et al. [2], using AFDEX software, to analyze the influence of roller parameters on vonMises, effective stresses, effective strain and shear stress for AISI-1055 steel alloys. They concluded, the effective stress and strain can be reduced by using larger roller's diameter over lower speed. A. Pesin et al. [6] utilized 3D-DEFORM software to simulate then study the strain distribution on the thickness of pure aluminum plate through the cold rolled process with a flat and grooved roller. They found the effective strain increases by using a grooved roller. Furthermore, there is irregular strain distribution throughout the cross-section of the plate and the increasing of indentation's depth of grooved roller affected by increases of effective strain values. Raji A. Nurudeen et al. [7] by adopting on the stress-strain relationship of tensile and Izod impact experiments test, evaluated the effect of degree of cold drawing on the mechanical properties of low carbon steel. They reported that both toughness and ductility values were reduced by increasing the degree of cold drawing whilst there is an increases trend in hardness as the degree of cold drawing increases.

Syed Reza Motallebi [1] used the 2D rolling model to study rolling process for aluminum alloys using FEM software, DEFORM-2D. He concluded that temperature distribution and rolling force were depended on friction coefficient, thickness
reduction, roller's speed and diameter. B. Mahdi and B. Hosein [4] analyzed the stability or roller's force and torque during the rolling process. The results showed that both of rolling force and torque values are not stable and fluctuate around an average value. Moreover, the average roller separating force and torque are increased with increasing thickness reduction. By using Orowan's theory, J. Yanagimoto et al. [8] suggested a mathematical model to investigate the rolling force and microstructure evolution during the hot rolling process. Furthermore, X. Shangwu et al. [9] developed 3D FE model to study rolling process for both rigid and flexible roller cases. K. Devarajan et al. [10], studied the effect of rolls' speed and diameter on the contact pressure, vonMises and residual stresses in cold rolling process by using FEM software, ABAQUS. They revealed, the contact pressure gradually increases until reaches a maximum value at the neutral point and the rolling force decreases with increasing the roller speed. Also, J.C Lin. [11] investigated the influence of changing the plate dimensions and roller diameter on the rolling process. H. Abdullahi and K. Dehghani [12] determined the pressure distribution and the irregularity of friction coefficient during cold rolling by using the Matroll software. They reported, there are some of the irregularities which occur when the coefficient of friction is too low.

FEM software, DEFORM, have been used to study the influence of friction coefficient and percentage reduction on roller force during the hot rolling process by R. Sushan [13]. The authors referred, the percentage reduction has a more significant effect on roller force than that of friction coefficient does. T. Anikesh and M. Amit [14] used 2D finite element model to discuss the behavior of aluminum alloy under several values of friction coefficient, roller diameter and the initial thickness of rolled plate on a rolling process. The researchers evaluated the effect of these parameters on the maximum stress, equivalent plastic strain, reaction force. Their results showed, the initial thickness of the plate has a greater effect on reaction force than that of roller diameter, while the increases of friction coefficient have less effect on roller force than roller diameter does. Shailendra Dwivedi et al. [15] were investigated the effect of several rolling parameters on integrity and mechanical properties of the 2024-aluminum alloy during hot rolling using ABAQUS 6.10 software. The results of the study confirmed and enhanced the positive influences of rolling process's parameters on the rolled products' properties such as strain rate and roller force.

The main objective of this study is to analyze and investigate the influence of rolling process parameters such as friction coefficient along the contact arc at the roller-plate interface, roller's speed and diameter on roller's force (RF), equivalent plastic strain (PEEQ). Furthermore, to see whether the roller's speed and diameter have any effect on effective friction coefficient (EFC) which is necessary for accomplishing the rolling process.

II. MATERIALS AND FINITE ELEMENT MODELLING

The initial dimensions of steel plate that used in the study are of; length of 100 mm, the width of 20 mm and the thickness of 15 mm which is reduced to 10 mm during the cold rolling process. The roller's width is 30 mm with a radius of 40, 60 and 80 mm. it rotates with different rotation speed ranging from 5 rad/sec to 30 rad/sec with six cases. The draft; d, is 5 mm ( where \( d = t_o - t_f \), \( t_o = \) starting thickness, and \( t_f = \) final thickness).

To achieve a precision analysis, there are some assumptions have to be taken into account. The plate material is assumed isotropic and homogenous with density of \((7.8 \times 10^3) \text{ ton/m}^3\), Young's modulus of \((150 \text{ GPa})\), Poisson's ratio of \((0.33)\), and the strain hardening properties are shown in table [10]. The roller was modeled as rigid and a Coulomb friction model is considered between the roll and the metal plate. On the entry point, the initial feed velocity of the plate in the X-axis direction is equal to the horizontal component of the roller's surface velocity throughout all values of rotating speed have been used in the study.

A 3D rolling model has been adopted to simulate a cold rolling process of steel by using ABAQUS ver. 6.12 software (Explicit) [16]. Due to symmetry, it is only a quarter of the plate was modeled as illustrated in Figure 1. The investigation’s problem is considered as a plain-stress problem and the meshing was done with C3D8R elements which are an 8-nodes linear brick element with hourglass control and explicit dynamic analysis.
III. RESULTS AND DISCUSSION

3.1. Effect of Roller’s Speed and Diameter on Coefficient of Friction

It is evident from the figure (2) that the effective friction coefficient (EFC) that is needed to start the rolling process decreases with increasing the roller diameter. This is related to when the roller diameter increases, the contact area between the roller and rolled plate increases too, so less friction coefficient needs to attain (achieve) the friction force which is necessary for rolling process. Meanwhile, the rolling process starts with a large value of friction coefficient at low roller's speed (ω = 5 rad/sec) then decreases until reaches the steady state case at about (ω = 15 rad/sec) for all study's cases of roller diameter. It is equal about (µ= 0.35) at roller speed of (ω = 10 rad/sec) when the roller diameter; R = 40 mm,

while it is equal to (µ = 0.168) when (R = 80 mm). It means, by using larger roller diameter, the rolling process happens at a lower value of friction coefficient. Also, it is clear that the roller diameter has a greater effect on effective friction coefficient (EFC) than that of roller speed. Where it is found the reduction in EFC is about (52%) when the roller diameter increases from (R = 40 mm) to (R = 80 mm) whilst it is equal about (30%) when the roller speed increases from (ω = 10 rad/sec) to (ω = 20 rad/sec) for roller diameter (R = 40 mm) and it is equal to (17%) for (R = 80 mm).

3.2. Effect of Roller’s Speed and Diameter on Roller Force

Figure (3) shows the influence of roller diameter on roller force (RF) at the different coefficient of friction. It can clearly observe that the roller force increases with increasing the roller diameter. It can be explained due to the increasing of contact arc length then the contact area between the material and roller leading to increase the plastic strain hence results in strain hardening which affects on the material to be more resistant to deformation.
The increasing in roller force varies from (21.6%) to (26.8%) when the roller diameter increases from (R = 40 mm to R = 60 mm then to R = 80 mm) respectively at friction coefficient \( \mu = 0.25 \), while at \( \mu = 1.0 \) it is varying from (23%) to (29.8%). By contrast, the rate of roller's force rising is decreasing with increase the friction coefficient.

It is (2.5%) with increasing the friction coefficient from (\( \mu = 0.25 \) to \( \mu = 0.5 \)) for roller diameter (R = 40 mm), while it is about (0.46%) when (\( \mu = 1.5 \)). The same trend is found for roller diameter of (60 mm and 80 mm). Consequently, the roller diameter has a more significant effect on roller force than that of friction coefficient does. Therefore, to decrease the roller's force and power consumption during the rolling process, it is useful to propose using small roller diameter as it is possible.

As it is demonstrated in figure (4), the roller force increases rapidly to peak value after entry point then almost fluctuates about certain value during the rolling process until reaches to another peak value just before the existing point. The figure reveals that the roller diameter affects on the amplitude of roller force fluctuations for different values of friction coefficient. There is larger fluctuations occur with smaller roller diameter than that happen with large roller diameter. Meanwhile, the increasing of roller diameter leads to decrease the time of the process. This is attributed to increasing of the contact area of the roll bit.
Fig. 4. Effect of roller diameter and coefficient of friction on roller force (RF)
3.3. Effect of Roller's Speed and Diameter on Equivalent plastic strain (PEEQ)

It can be inferred from figure (5), the equivalent plastic strain; PEEQ increases linearly with increasing friction coefficient at different rolling speed. Moreover, the effect of rolling speed is reverse on PEEQ, where the increase of roller speed tends to decrease the equivalent plastic strain. This is due to increasing of roller bit that results in shorter contact time between rolled material and roller.

![Graph showing the effect of friction coefficient on equivalent plastic strain.]

3.4. Effect of Roller's Speed and Diameter on vonMises stress

The distribution and value of vonMises stress during rolling process are evident in figure (6). It can be seen, it is equal to (368.7 MP) just after the plate enters between the rollers and after some increment of rolling time, it increases gradually until reaches (396.9 MP) then slightly decreases and oscillates about a certain value of about (390 ± 3 MP).

This can be explained as; at beginning of the rolling process, the plastic deformation occurs until plastic strain reaches a certain value then when the material is hardening consequently the materials become more resistant to plastic deformation.
Fig. 6. Distribution of vonMises stress during rolling process for roller diameter; R = 40 mm, roller speed; \( \omega = 10 \text{ rad/sec} \) and friction coefficient; \( \mu = 0.7 \).
VI. CONCLUSION

According to the results and discussion of the present study, can be proposed the following conclusions:

1. The roller diameter has more significant effect on the effective friction coefficient (EFC) than that roller speed does. Meanwhile, the increasing of roller diameter leads to decrease the rolling process time.

2. The vonMises stress gradually increases during the rolling process until reaches a certain value then gradually decreases and remains to the extent of this value even the rolling process finishes.

3. The equivalent plastic strain (PEEQ) has inverse relation with roller speed, whereas roller speed increases the PEEQ decreases.

REFERENCES


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