(ICERD 08084) Simulation of Load during Rod Rolling Of HC SS316 at Low Strain Rate

P. O. Aiyedun(1), O. S. Igbudu(2), B.O. Bolaji(3)
(1, 3) Department of Mechanical Engineering, University of Agriculture, P.M.B. 2240, Abeokuta, Nigeria.
e-mail: laiyedun_494@yahoo.com

(2) Department of Mechanical Engineering, Ambrose Alli University, Ekpoma

Abstract: *In this work, rolling loads of HCSS316 for seventeen sequential passes for the reduction of a 125 x 125 mm^2 billet to a 16 mm diameter rod at four different starting mean temperatures of 988^{0}C, 1094^{0}C, 1095^{0}C and 1191^{0}C and at different strain rates of 0.4s^{-1}, 0.8s^{-1}, 1.2 s^{-1} and 1.6 s^{-1} respectively, were simulated using the "Phantom Roll" method for Carbon-Manganese steel. In general, it was observed that load value increased as starting temperature decreases and for each set of starting temperatures, the load value increases with temperature. In all cases, the load values for grooved rolls were higher than those for flat rolls.*

Keywords: Rod rolling, Load, Strain rate, Temperature.

1 Introduction

Rolling is one of the most important metal working processes [1] whereby metals are plastically deformed. It is a direct compressive type of deformation in which applied compressive stress induces two compressive stresses, which are on mutually perpendicular planes. Forging and extrusion also fall under this type of deformation process. Rolling is used to reduce the thickness of the work-piece [2]. It could be carried out either cold or hot. Cold rolling is carried out at temperature below the recrystallisation temperature of the metal, while hot rolling is carried out at temperature above the recrystallision temperature.

Cold rolling increases the dislocation density and alters the shape, but not the average size of the metal grain. The process generally increases the strength and decreases the ductility of the metal. On the other hand, hot rolling significantly alters the microstructure of the metal such as homogeneity of texture, the size and shape of grains and the concentration of point and line defects (dislocations).

Two methods of rolling are distinguished-flat rolling and form rolling. Flat rolling is a process in which a work-piece of constant thickness enters a set of rolls and exit as a product with different constant thickness using flat rolls. Form rolling or shape rolling is a rolling method for products such as **I**-beam, channels, railroad tracts and large diameter pipes and rods using grooved rolls [2]. For rod rolling, which is the focus of this work, grooved rolls are used.

Warm working is deformation carried out at any temperature and strain rate that some amount of strain hardening is always evident [3, 4] or the simultaneous occurrence of deformation and recovery process whereby metals are deformed in their plastic condition by successive passes carried out at temperature above recrystallisation using a rolling mill [5]. The simultaneous deformation and recrystallisation, apart from saving of energy, also results in considerable speeding-up of the process. Rod rolling as a hot working process is the basis of this work using HC SS316 at low strain rates. In general, rolling is a more economical method of deformation than forging if metal is required in long lengths of uniform cross-section [1].

Computer simulation models which predict temperature, load, torque and micro structural changes are very powerful tools as it would be difficult, if not impossible, to obtain these parameters from a few surface measurements. The knowledge of accurate temperature makes it possible to evaluate load during rolling and micro structural changes. A lot of computer simulation models have been reported in the past in flat rolling, mainly for load calculations to design mills at the maximum energy consumption [6]. Different assumptions were made for simplicity and the finite difference method was most commonly employed.

Kawai [6] developed a computer simulation model, which predicts temperature and micro structural changes for rod rolling of mild steel and medium carbon steel. Assumptions made were:

- Sections of the material are round;
- One dimensional heat flow within the material. Heat flows from the center to the surface;
- Heat gain due to deformation is equally distributed to each element and for every time interval during rolling;
- Heat loss is caused by radiation and convection during air-cooling and by conduction during rolling;
- A 'phantom roll' method was used.

For the first above, a geometric factor was introduced to modify the round sections to the real sections.
The 'phantom roll' method makes it possible to ignore the temperature calculation in the roll while reasonable accuracy is maintained. Also, it makes it possible to save the computer calculation in the roll by assuming a parabolic temperature distribution. This method saves more of computer time and memory [7].
Oseghale [7] in his work expanded the 'phantom roll' method to take care of load and torque calculations by neglecting the effect of roll flattening or deformation in the near surface region of the rolls. He also, in addition to the assumptions made by Kawai, assumed that a two dimensional deformation of metal (carbon manganese steel) during reduction.

Aiyedun [8] in his work made a comparism between the theoretical load and torque to that obtained experimentally using HC SS316 steel slab at low reduction and low strain rate (0.08-1.5s^{-1}) by hot rolling the steel at different temperature using the modified Leduc's programme which uses the Sim's sticking friction approach. He observed that there was excessive load and torque in comparism with values obtained by normal rolling practice at low strain rates and low reduction for flat rolling. The difference was observed to be influenced by temperature, micro structural changes, precipitation strengthening and composition. The precipitation strengthening was more pronounced at low strain rates [9].

In this work, attempt has been made to roll-up all above three discussed models into one ball so as to simplify and integrate the various features linking them together for the evaluation of load during rod rolling of HC SS316 at low strain rates. Accordingly, an assumption similar, to that of Oseghale [7], was adapted. Also, a continuous rolling mill was used in view of the shortcomings of a two-high mill.

2. Mathematical Model

2.1 Rolling Load

In the evaluation of load, Ekelund's method used as input data temperature, reduction and velocity. It is as given below [7]. The rolling load, in kg is

$$P = A_p K_w \quad (1)$$

where, A_p, is the projected area, mm^2

K_w, is the mean roll pressure, calculated under actual rolling conditions, kg/mm^2

$$A_p = b_m L \quad (2)$$

$$b_m = (b_o + b_1)/2 \quad (3)$$

where L = projected contact length

b_m = average stock width

b_o = breadth before entry

b_1 = breadth after exit

2.2 Evaluation of Contact Area (A_p) Between the Rolled Material and the Rolls

The mean width of the rolled strip over zone of deformation (b_m) is determined using equation 3. However, if the edge of the rolled strip over the zone of deformation is approximated not by a circle but by an arc of a parabola then, equation 4 is used.

$$b_m = b_o + \tfrac{2}{3}(b_1 + b_o) \qquad (4)$$

$b_m = b_o + 2/3(b_1 + b_o)$

The quantity L in equation 2 is found from the relation given below if the angle of contact is known.

$$L = AC = \sqrt{r\Delta h} \qquad (5)$$

For rolling in non-rectangular section rolls, and taking Δh equal to the mean linear reduction over the width of the section, that is,

$$\Delta h = \frac{Q_o}{b_o} - \frac{Q_1}{b_1} \qquad (6)$$

- for a Rhombus Rolled from Rhombus,

  $\Delta h = (0.55 \text{ to } 0.56)(h_o - h_1)$ (7)

- for Oval Rolled from a Square,

  $\Delta h = h_o - 0.7h_1$ (for shallow oval) (8)

  $\Delta h = h_o - 0.85h_1$ (for round oval) (9)

- for a Square Rolled from an Oval,

  $\Delta h = (0.65 \text{ to } 0.7)h_o - (0.55 \text{ to } 0.6)h_1$ (10)

- for a Circle Rolled from an Oval,

  $\Delta h = 0.85h_o - 0.79h_1$ (11)

where,

h_o – dept of cross-section of strip before the pass

h_1 – dept of cross-section of strip after the pass.

2.3 Evaluation of Zener-Hollomon Parameter (Z)

The Zener-Hollomon parameter is given as [10],

$Z = \varepsilon \exp(Q/RT)$ (12)

The strain rate is obtained using equation 13

$$\bar{\varepsilon} = \ln \varepsilon = \frac{1}{E}\left[\int_0^L \ln \varepsilon d\varepsilon\right] \qquad (13)$$

the approximate mean rolling strain rate $\bar{\varepsilon}$ is given by

$\bar{\varepsilon} = [1.08V/(R\Delta h)^{1/2}]\,[(\Delta h)^{1/2}/h_1h_2]^{0.25}\,[\ln(h_1/h_2)]^{0.45}$ (14)

3.5 Simulation of the Model

In the simulation of the model, conditions and input data similar to those Oseghale [7] were assumed for this work. A $125\times125mm^2$ stainless steel (HCSS 316) square billet was used as the starting material for rolling to a 16mm diameter rod using 17 sequential passes.

Assumptions made were:

- Water cooling to the material such as de-scalar and roll cooling system was neglected;
- The air cooling condition was taken to be the same as the laboratory, although, a lower cooling rate is because of the obstruction of radiation by the trough between mill stands;
- The roll radii for flat and grooved roll were taken to be 140mm and 254mm respectively;
- The value of the activation energy of deformation for HC SS 316 was taken to be 460KJ/mol, [11];
- The fiction factor or coefficient of friction between roll and stock was assumed to be 0.25 based on the experimental result of El-Kalay and Sparling who concluded that coefficient of friction varied between 0.23 and 0.38 [11]

3. Results Discussion

The simulation was carried out starting with four different mean temperatures of 988 ^{0}C, 1094 ^{0}C, 1095 ^{0}C and 1191 ^{0}C and starting strain rates of 0.4 s^{-1}, 0.8 s^{-1}, 1.2 s^{-1} and 1.6 s^{-1}, respectively for seventeen sequential passes in a continuous rolling mill. The input data were based on those of Oseghale [7]. Figures (1 to 8) show the plots of load against temperature. For both flat rolls and grooved rolls, the points were fitted with curves for all starting temperatures. As shown in these figures, it was observed that for grooved rolls, load values were larger than for flat rolls; this translates into more power dissipation with grooved rolls. The higher values encountered could probably be due to:

- Higher value of projected contact area between roll and stock for grooved rolls;
- Friction effect due to the side wall of grooved rolls as a result of higher value of the projected area of contact.

The plot of load against $\log_{10}(Z)$ is shown in figures (9). The points were fitted with straight lines for both grooved and flat rolls. An inverse relationship exists between $\log_{10}(Z)$ and load.

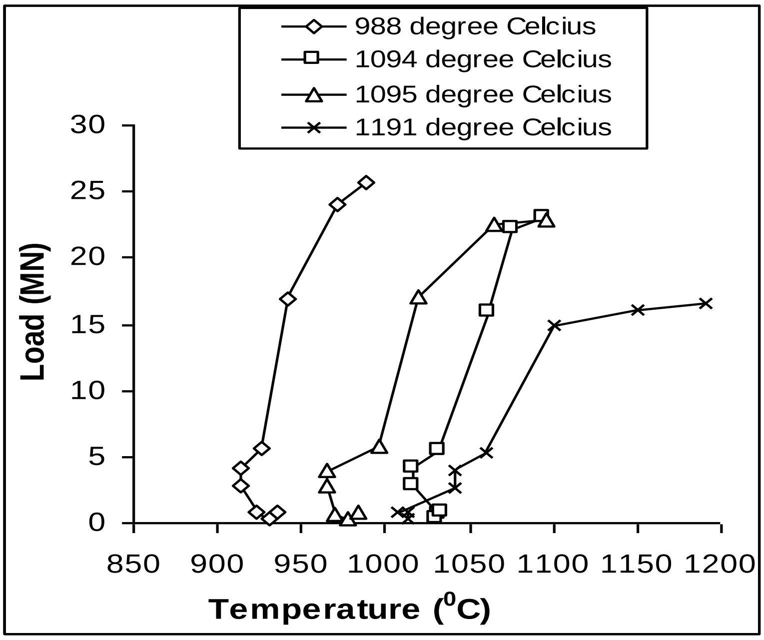

Fig. 1: Plot of load versus temperature for rolling using flat rolls at initial starting strain of $0.4s^{-1}$ for four mean temperatures

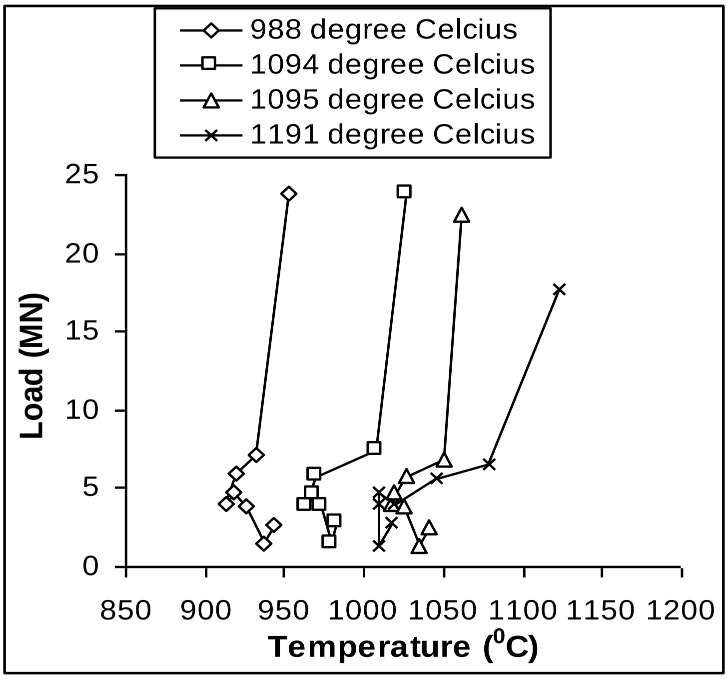

Fig. 2: Plot of load versus temperature for rolling using grooved rolls at initial starting strain of $0.4s^{-1}$ for four mean temperatures

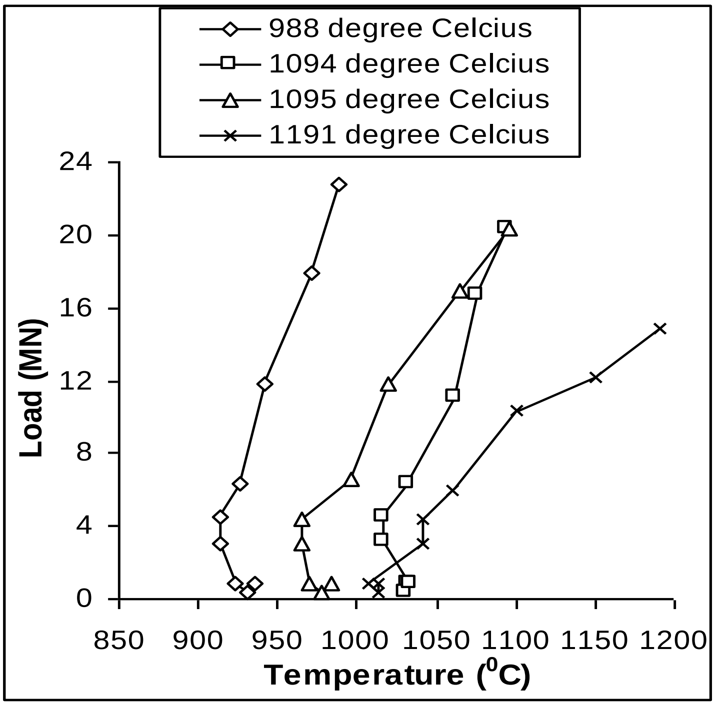

Fig. 3: Plot of load versus temperature for rolling using flat rolls at initial starting strain of $0.8s^{-1}$ for four mean temperatures

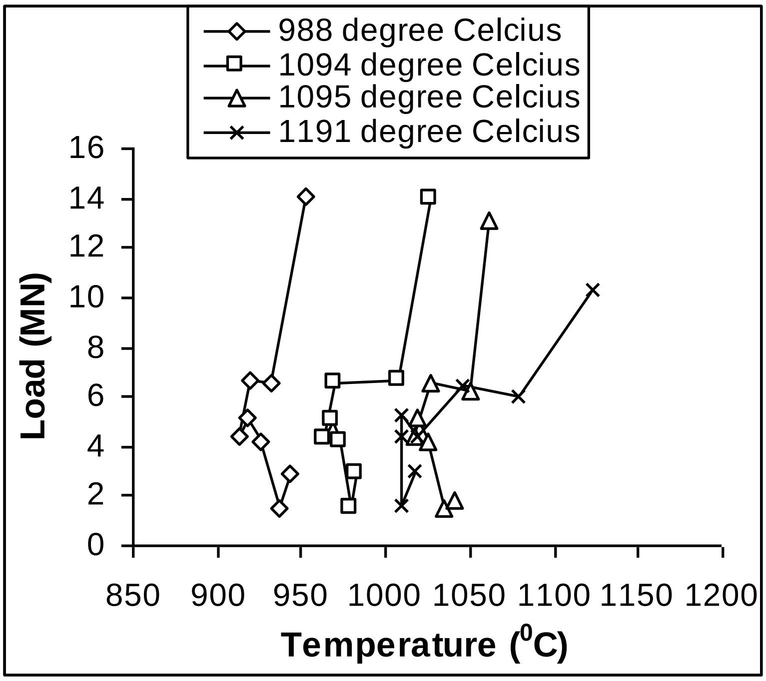

Fig. 4: Plot of load versus temperature for rolling using grooved rolls at initial starting strain of $0.8s^{-1}$ for four mean temperatures

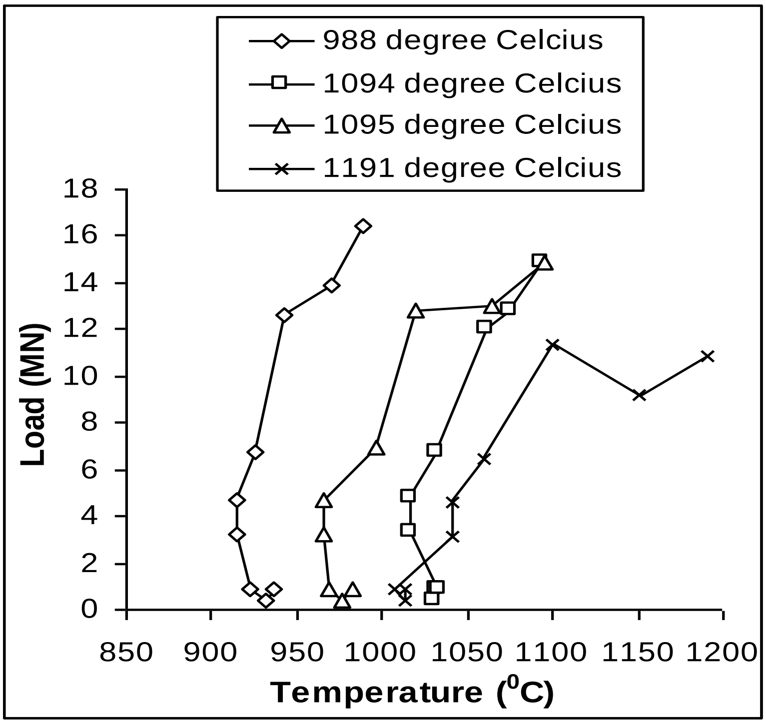

Fig. 5: Plot of load versus temperature for rolling using flat rolls at initial starting strain of $1.2s^{-1}$ for four mean temperatures

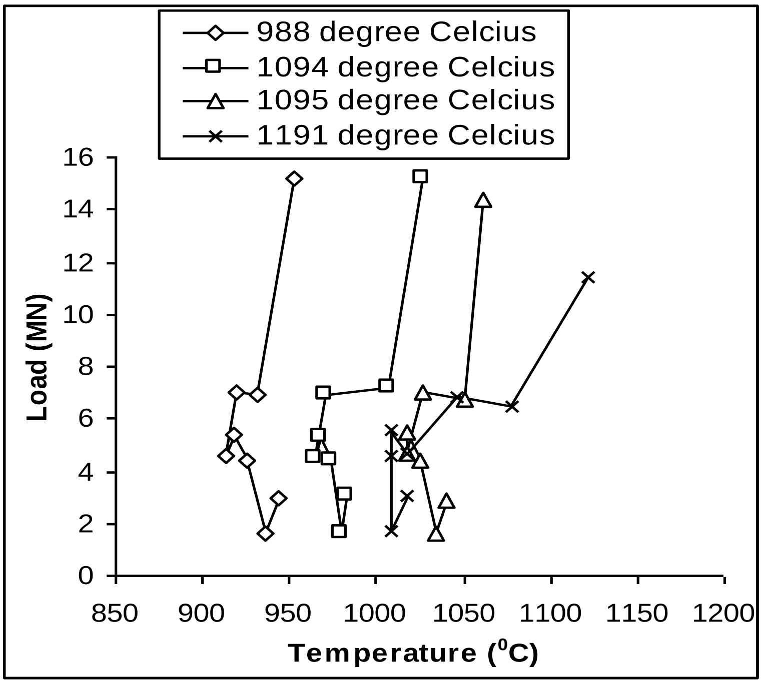

Fig. 6: Plot of load versus temperature for rolling using grooved rolls at initial starting strain of $1.2s^{-1}$ for four mean temperatures

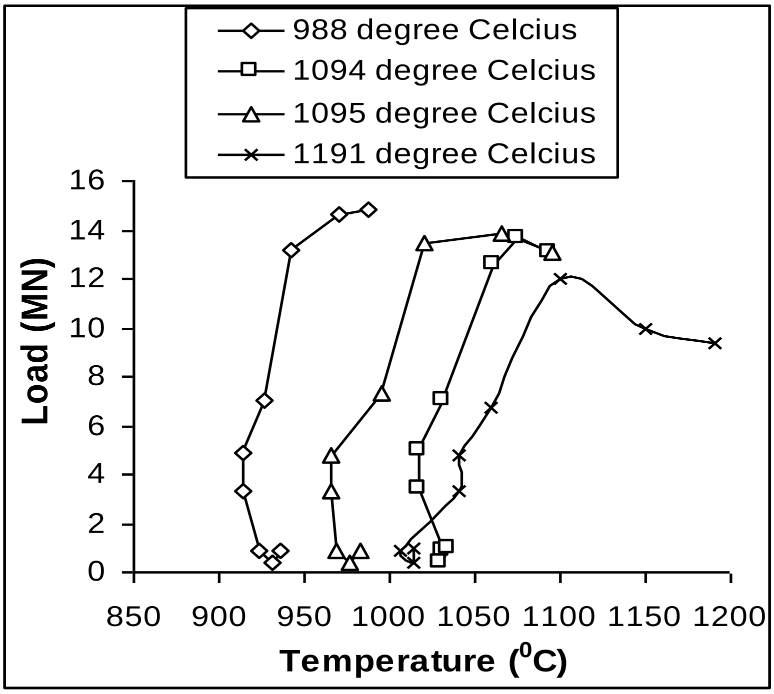

Fig. 7: Plot of load versus temperature for rolling using flat rolls at initial starting strain of $1.6s^{-1}$ for four mean temperatures

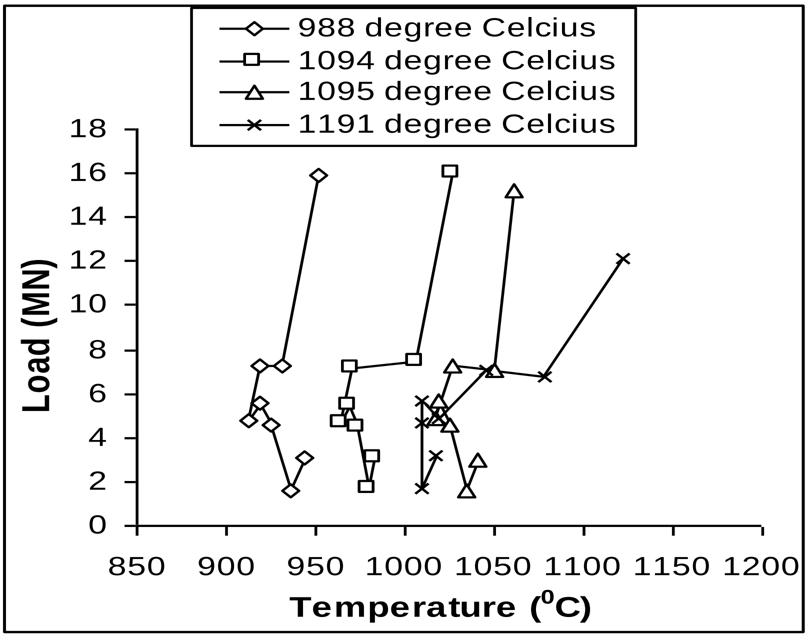

Fig. 8: Plot of load versus temperature for rolling using grooved rolls at initial starting strain of $1.6s^{-1}$ for four mean temperatures

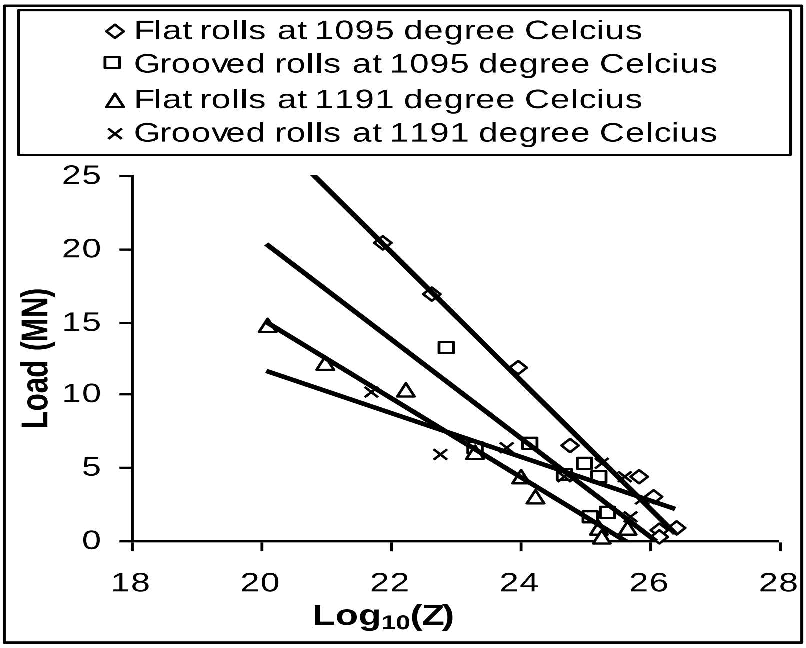

Fig. 9: Plot of load versus $\log_{10}(Z)$ for seventeen passes for starting temperatures of 1095^0C and 1191^0C, and strain of $0.8s^{-1}$ using flat and grooved rolls

The plot of load against strain rate for flat rolls is shown in figure (10). The figure shows a gradually decreasing load as strain rate increases; this also applies to grooved rolls. This indicates an inverse relation between strain rate and load.

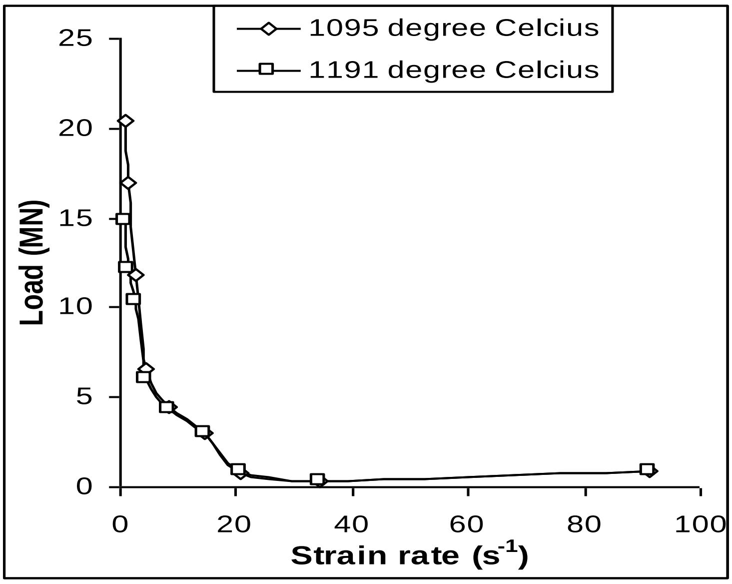

Fig. 10: Plot of load versus strain rate for rolling in flat rolls at starting temperatures of 1095^{0}C and 1191^{0}C

4. Conclusion

Load plays a very significant roll during rolling operation. Therefore, there is the need to minimize them so as to reduce both cost and weight, which ultimately translates into low energy dissipation and consumption. It was observed that:

1. Increasing strain rate and temperature lead to a decrease in load values;
2. Larger contact area between roll and stock and additional frictional effect due to side walls of roll lead to increased load requirements for grooved rolls when compared to flat roll;
3. In view of 2 above, rolling in grooved rolls requires more power than for flat rolls.

5. References

[1] Antonio, a. G. and Renato, R. V. (1996). The effect of finishing temperature and cooling rate on the microstructure and mechanical properties of as-hot rolled Dual Phase Steel. Antonio Augusto Gorni home page, http://www.Geocities.com.

[2] Schaffer P J, Sexana A, Antolovich D. S, Sanders T. H. Warner B. S, "Science and Design of Engineering Materials" 2nd edition, McGraw-Hill Company Inc., 1999, pp. 679-680.

[3] Venkadesan S., Sivaprasad P. Venugopal S., Seetharaman V. "Tensile Deformation Behaviour of Warm-Rolled Type 316 Austenitic Stainless Steel" Journal of Mechanical Working Technology, vol. 12 (1986) p. 351.

[4] Rollason E.C, "Metallurgy for Engineers" 4th edition, Edward Anorld, 1992.

[5] Qamark H., Buckley G. W and Lewis M, "Computer Programmed Speed Roll-Torque Data Calculation", Journal of Iron and Steel International, vol. 53, No 1, February, 1980, pp. 29-37.

[6] Kawai R., "Simulation of Rod Rolling of Carbon-Manganese Steel", M.Phil. Thesis, Department of Metallurgy, University of Sheffield, 1985.

[7] Oseghale L. E, "Simulation of Load and Torque During Rod Rolling Using the 'Phanthom Roll' Method", M.Sc. Thesis, Department of Mechanical Engineering, Univesity of Ibadan, 1998.

[8] Aiyedun, P.O. (1984). A study of loads and torque for light reduction in hot flat rolling at low strain rates. Ph.D. Thesis, University of Sheffield, UK.

[9] Honey Combe R. W. K, "The Plastic Deformation of Metals", 2nd edition, Anorld, 1983.

[10] Alamu, O. J. and Durowoju, M. O. (2003). Evaluation of Zener – Hollomon parameter variation with pass reduction in hot steel rolling. International Journal of Environmental Issues, 1 (1): 148 – 159.

[11] Sparling, L. G. M. (1983). The evaluation of Load and Torque in hot flat rolling from slipline field.