

Analysis of Band Curvature in Asymmetrical Rolling Process by FEM Method

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ABSTRACT

Today, the rolled products, i.e. sheet, plate and foil is used in marine applications, including platforms, hatch covers, mast, hulls of boats and superstructures on pleasure boats and the bridges and superstructures of passenger ships and merchant ships. In this paper, simulation of asymmetric cold rolling is presented by using explicit analysis procedure. In asymmetric cold rolling, the workpiece is often bent downwards or upwards. A two dimensional explicit dynamic finite element model with adaptive meshing technique has been employed to simulate asymmetrical condition are here due to different roll radii. To validate the simulation, the results of simulation and experiment are compared. Effects of asymmetry due to roll radii ratio and speed ratio mismatch on sheet curvature variations are discussed. Finally, optimum roll speed ratio in various of roll radii ratio could be found to produce flat sheet.

1. 1. Introduction

Rolled products, i.e. sheet, plate and foil constitute almost 50% of all aluminium alloys used. Sheet is also used extensively in marine applications, including offshore platforms, superstructures and hulls of boats furthermore the sheet is used in building for roofing and siding, in transport for airframes, road and rail vehicles. Plate is used for airframes, military vehicles and bridges, ships superstructures, cryogenic and chemical vessels and as tooling plate for the production of plastic products. Foil applications outside packaging include electrical equipment, insulation for buildings, lithographic plate and foil for heat exchangers. Therefore, Theoretical and experimental studies have been carried out to investigate the deformation mechanics of asymmetric plane strain rolling. Sachs and Klingler [1] used the slab method to develop a homogeneous deformation model. They concluded that there exists a region where the frictional forces on the driven and undriven rolls act on the strip in opposite directions and identified it as the region of cross shear. Holbrook and Zorowski [2] extended the earlier model to include nonsymmetry of the roll pressure distribution. On a twin roll driven asymmetrical rolling mill Kennedy and Slamar [3] rolled steel strip, and Buxton and

Browning [4] rolled strips of plasticine. Their results show that under certain conditions a decrease in roll force of as high as 40% is possible. Johnson and Needham [5] carried out a few experiments using lead as a model material to study curvature. They developed analytical models based on the upper bound method [6] and the slip line field analysis [7] to predict strip curvature. Kiuchi and Hsiang [8] used an upper bound technique for calculating curvature in plates by rolls of different diameters and roll speed mismatch. Pospiech [9] investigated the effect of thickness reductions on curvature developments for the asymmetrical rolling conditions. Richelsen [10] investigated the influence of the degree of deformation and the initial thickness on bending of the asymmetrically rolled strip using FEM. Shivpuri et al. [11] used an explicit integration finite element method to investigate curling due to speed mismatch asymmetrical rolling. A similar FEM simulation was also performed by Lu et al. [12]. Hwang and Chen [13] made an attempt to analyze the asymmetrical rolling by using the stream function method. Salimi and Sassani [14] Pietrzyk et al. [15] simulated the asymmetrical plate rolling by the finite element method in a steady state condition. Hamuzu et al. [16] studied the asymmetrical rolling process in unequal

surface speed conditions using the rigid perfectly plastic model.

2. The Finite Element Models

Many three dimensional models of the steady state processes are based on the flow formulation in a fixed mesh. The finite element mesh used in flow formulation is usually fixed in a Eulerian system. Thus, Eulerian elements undergo no distortion due to material motion and cannot properly predict the outgoing material shape, as the treatment of moving boundary and interface is difficult with this method. To follow the material movement and to estimate the plate curvature Lagrangian meshes are more convenient. Unfortunately for simulation of processes such as asymmetrical rolling, where the material is severely deformed and the outgoing plate may be deformed in an unexpected shape.

3. Modeling of Asymmetric Rolling

Fig. 1 shows the schematic of asymmetric rolling. The figure also shows the positions of the neutral points. The deformation zone is divided into three stages. In this article, the indexes 1 and 2 were used for top rolls and bottom rolls, respectively. In stage (I), the friction force applied on the top and the bottom surfaces are coincided with the flow of materials. The opposite situation is seen in stage (III). In stage (II), the friction force on the top and the bottom surface of the sheet are against each other, i.e., the shear zones are created. Where R_1 and R_2 are the top and the bottom rolls radius, h_i and h_0 are the initial and final sheet thickness. The Holloman elastic plastic equation was used to describe the behavior of sheets (i.e., $\sigma = c\varepsilon^n$, where σ was stress, ε the strain and n the strain hardening constant, c and n were material constants). The material constants used were $c = 162.3$ MPa, $n = 0.0353$ [17]. All the simulations were carried out with aluminum 1050P ($E = 69$ GPa, $\sigma_y = 69$ MPa) and for the sheet width of 100 mm.

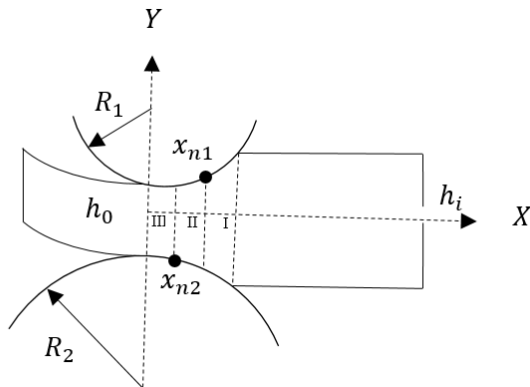


Fig. 1. Schematic of asymmetric rolling.

μ the coefficient of friction, m the friction factor. The magnitude of m corresponding to various coefficients of friction was obtained by Eq. (1), i.e.,

$$\mu = \frac{m}{1 + 0.5\pi + \cos^{-1}(m) + \sqrt{1 - m^2}} \tag{1}$$

The rolls were rotated by the constant angular velocity of ω about their axes. No lateral transitions were assumed for the rolls in the analyses. The sheet velocity equaled to the x -component of the roll surface velocity. The sheet was fixed along its width. The latter condition caused the sheet to be moved in the x -direction only. The sheet was allowed to deflect in any direction at the exit. In this study, ABAQUS explicit analyses were used to simulate the symmetric asymmetric rolling [18].

4. Validation of The Simulation Results

4.1 Mesh Dependency Study

Mesh dependency study was carried out and it has been demonstrated that further increasing in mesh density makes little difference on the results. In order to set up a grid independent solution, numerical simulations have been conducted for different meshes and the optimum mesh consisted of 6250 quadrilateral elements. The number and type of mesh elements have been selected in an iterative solution with a minimal time step to obtain an accurate solution. The same geometry and mesh elements, as well as initial and boundary conditions, were used for all numerical simulations. Here, the mesh refinement sensitivity is summarized in Table 1 and Fig. 2,3. According to the findings, the refined mesh was chosen for the rest of the simulations.

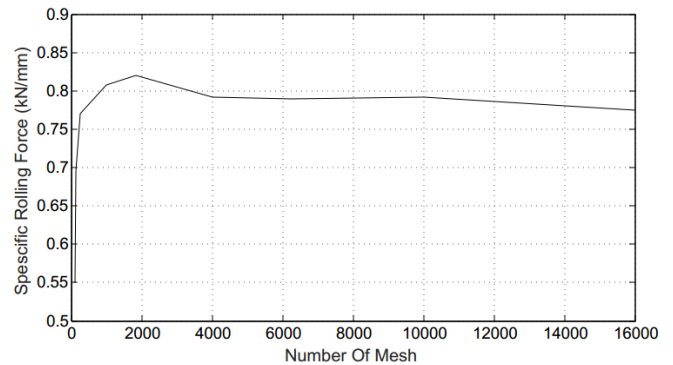


Fig. 2. Mesh refinement sensitivity

Table 1: Mesh refinement sensitivity

Mesh Case	Number of Element	Sheet Force (KN/mm)
(1)	100	0.549
(2)	125	0.695
(3)	250	0.769
(4)	1000	0.808
(5)	1850	0.820
(6)	4000	0.791
(7)	6250	0.780
(8)	10000	0.797
(9)	16000	0.775

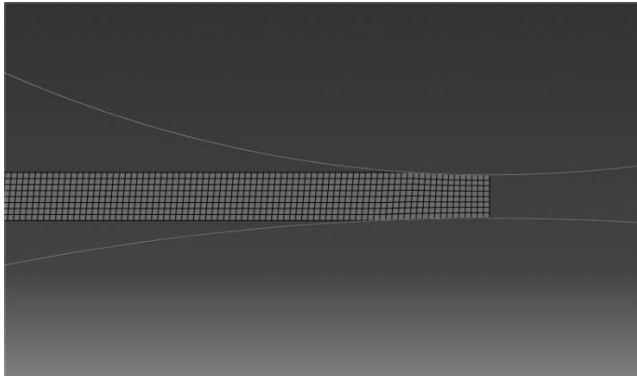


Fig. 3. Two Dimensional Grid

4.2 Validation of The Simulation Results

The rolling parameters obtained from the simulations, were compared with the experimental studies of references [17] and theoretical study of [17,19]. The material constants and the condition of the simulation were similar to those used in references [17,19]. To validate the rolling force, the experimental results of reference [17] was employed (see Fig. 4). The effects of reduction on rolling force are depicted in Fig. 4. The analytical results of reference [17,19] also showed in the graph. Good agreements were obtained between the simulation results and the experimental results.

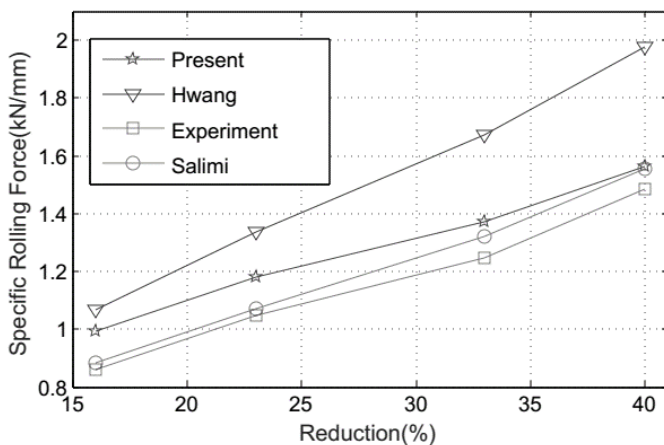


Fig. 4. Comparison of rolling force predicted by the present model with other researchers, Result: ($R_u = 50mm, R_l = 105mm, m_u = m_l = 0.359, h_i = 2mm, V_A = 1.05, \sigma_{x1} = \sigma_{x0} = 0$)

5. Specifications of Simulated Models

All the simulations were performed by assuming the constant friction coefficient of 0.359 for the top and the bottom sheet surfaces. In addition, the linear

velocity of the top roll was presumed to be constant and equaled to $V = 0.556$ m/s. The top roll radius was assumed to be constant and equaled to $R_u = 105$ mm. The percentage reduction is %10 selected for all simulations. The asymmetry was produced due to change of linear velocity and radius of the bottom rolls. In this paper, the curvature is positive when the Y axis is in the negative direction that is shown in Fig. 5.

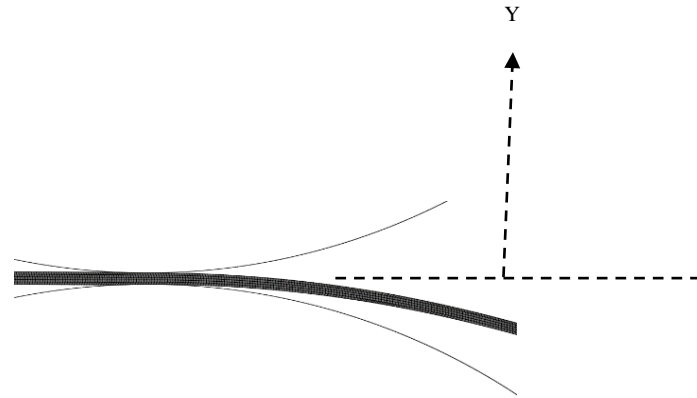


Fig. 5. The schematic of positive curvature

6. Application of Rolled Aluminum in Marine Industries

Rolled aluminum sheet and plates are a remarkably versatile material. The major incentive for employing aluminum is its weight saving compared to steel, because it is common practice to use weldable aluminum alloys having strengths approaching or comparable to mild steel, equal strength structures can be designed to a weight saving of 55 to 67 percent. However, to compensate for the lower modulus of elasticity of aluminum and to conform to normal deflection limitations, a somewhat lower, but substantial, reduction in weight is usually obtained. Its applications are too many to list completely. As shown in Fig. 6 is rolled aluminum is used in deckhouses, hatch covers of commercial ships, shell plating, round bilge, superstructures of large merchant and military ships, small boat hulls, aircraft skins, bulkheads, as well as in equipment items, such as ladders, railings, gratings, windows, doors and in marine platforms used in Helidecks, Multipurpose modules, Accommodation modules, Cladding, Fire blast wall, Mud mats, Internal fittings, Link bridges, Access systems and Air filtration systems.

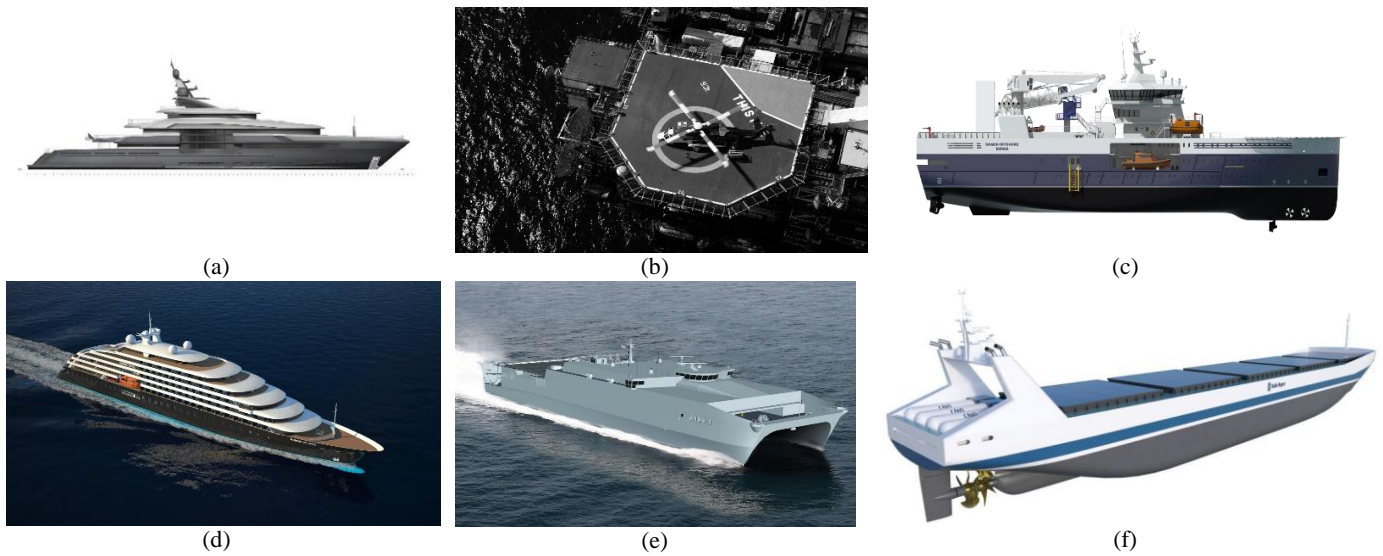


Fig. 6. Application of Rolled Aluminum, (a). Small Boat Hulls, (b). Helideck of Marine Platform, (c). Superstructures of Merchant Ships, (d). Accommodation of Cruise Ships, (e). Shell Plating, (f). Hatch Covers of Commercial Ships

7. Results and Discussion

It should be noted that although reducing the load and torque is one of the advantages in the asymmetric rolling, however, producing the sheet with no curvature is preferable. It is also advisable to produce the zero sheet curvature with lower load and torque. Therefore, the study was further conducted to find the optimum linear velocity in order to create the zero sheet curvature in the asymmetric rolling. Fig. 9 to Fig. 14 shows the variation of sheet curvature with the linear velocity ratio for six radii ratio of 1, 1.01, 1.02, 1.03, 1.04 and 1.05.

First, one can imagine that the sheets must be bent to roll that has a lower speed. Since the linear velocity of the upper roller surface is less than the linear velocity of the lower roller surface must be bent upward sheet. As the velocity vector of lower surface of sheet greater than the velocity vector of upper surface of sheet therefore the sheet bent upward that is shown in Fig. 7. But unlike the first impression by increasing the radii ratio (or speed ratio) sheet is bent downward, but with greater this ratio, the sheet is bent upward.

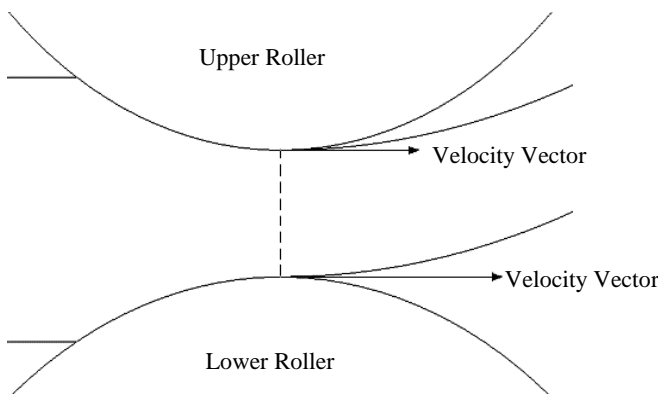


Fig. 7. Velocity Vector of Surface

For interpretation must also consider the position of the neutral point, the neutral point is the point where linear velocity of the roller and sheet is equal. Assume that the radii ratio (or speed ratio) is equal to r_A when the linear velocity of the upper roller is equal to V then the linear velocity of the lower roller is $V \times r_A$ therefore the upper neutral point velocity is V and the lower neutral point velocity is $V \times r_A$. When r_A is very small in asymmetric and symmetric mode, almost at the same time, a specified length of sheets to be rolled. So it can be concluded that the average speed is equal in both cases. In Fig. 8 A and C points are neutral point in asymmetric mode, Similarly B and E points are neutral point in the symmetric mode. As in the case of symmetrical upper and lower roller speed is equal, it can be concluded that in the case of symmetric mode the linear velocity on the line BE is constant and equal to V .

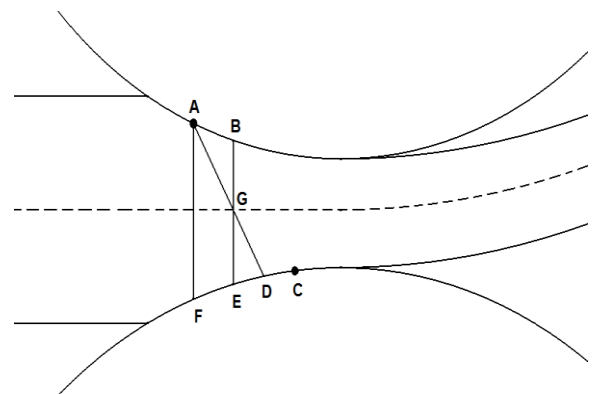


Fig. 8. Schematic of Neural Point in Symmetry and Asymmetry Mode

Since the speed of symmetric and asymmetric mode in the middle of the sheet should be equal, then the velocity of G point in two modes is V and equal. Because the velocity of the A point that it is the neural

point of the upper roller, is equal V and the sheet thickness is very small it can be assumed that the velocity profile of the sheet is linear. By drawing lines AG and extending it to point D can be concluded that the speed of points on the line AD is equal to V .

According to the previous definitions to know that the velocity of the F point must be less than the velocity of the D point, Because the F point before D point. So we conclude that A point on AF line and on top of the sheet are rated more velocity. So we can say that the average velocity of the upper points more than the average velocity of the lower points that is located on sheet. So the average velocity on each side that is more than sheet bent to the other side.

With increasing more, the radii ratio the horizontal distance between two neutral point increased and average velocity difference between the top and bottom of the sheet surface increased to reach its maximum. In this case, the curvature of the sheet in the downward direction to reach its maximum value. But then with more elevated the radii ratio (or speed ratio) the neutral point almost proved to be and no other significant displacement. But while more increasing the radii ratio (or speed ratio) the velocity average constantly increased. This process continues to be almost the average velocity of the rollers will be together and in radii ratio (or speed ratio) special and sheet almost horizontally and without inflection is out.

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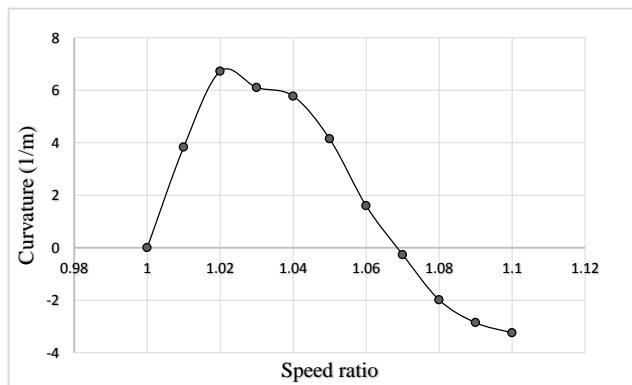


Fig. 9. Sheet Curvature Against Speed Ratio for Radii Ratio 1 ($R_u = 105mm, R_l = 105mm, m_u = m_l = 0.359, h_i = 2mm, \sigma_{x1} = \sigma_{x0} = 0, r = 10$)

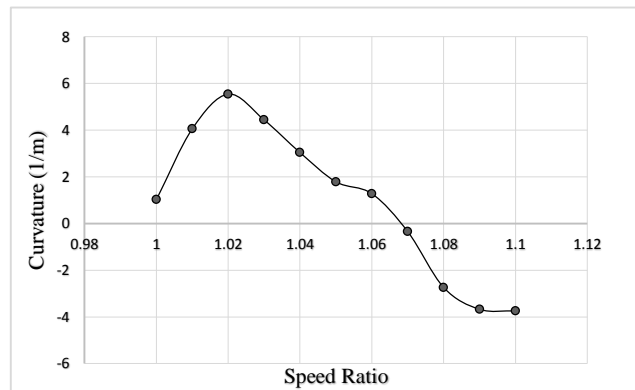


Fig. 10. Sheet Curvature Against Speed Ratio for Radii Ratio 1.01 ($R_u = 105mm, R_l = 106.05mm, m_u = m_l = 0.359, h_i = 2mm, \sigma_{x1} = \sigma_{x0} = 0, r = 10$)

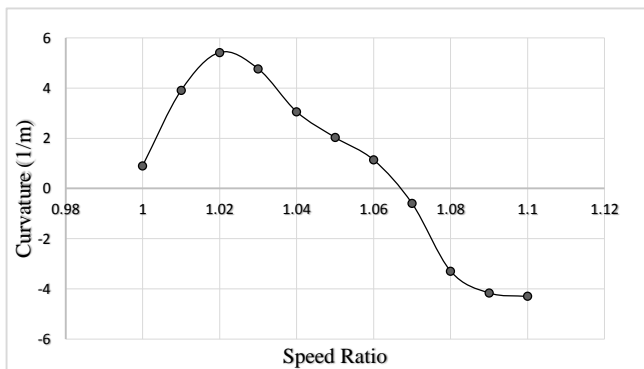


Fig. 11. Sheet Curvature Against Speed Ratio for Radii Ratio 1.02 ($R_u = 105mm, R_l = 107.10mm, m_u = m_l = 0.359, h_i = 2mm, \sigma_{x1} = \sigma_{x0} = 0, r = 10$)

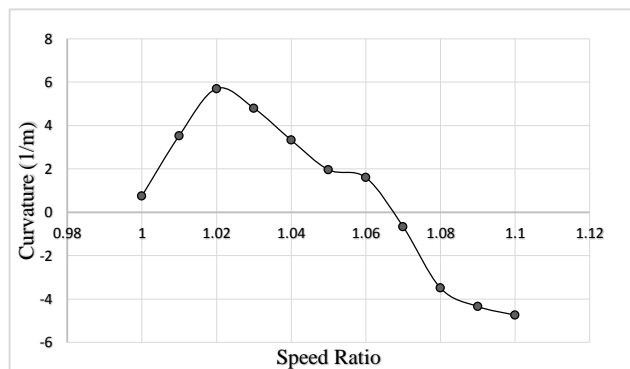


Fig. 12. Sheet Curvature Against Speed Ratio for Radii Ratio 1.03 ($R_u = 105mm, R_l = 108.15mm, m_u = m_l = 0.359, h_i = 2mm, \sigma_{x1} = \sigma_{x0} = 0, r = 10$)

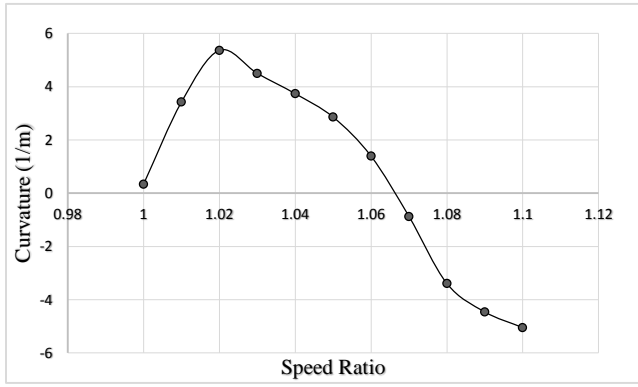


Fig. 13. Sheet Curvature Against Speed Ratio for Radii Ratio 1.04 ($R_u = 105mm, R_l = 109.20mm, m_u = m_l = 0.359, h_i = 2mm, \sigma_{x1} = \sigma_{x0} = 0, r = 10$)

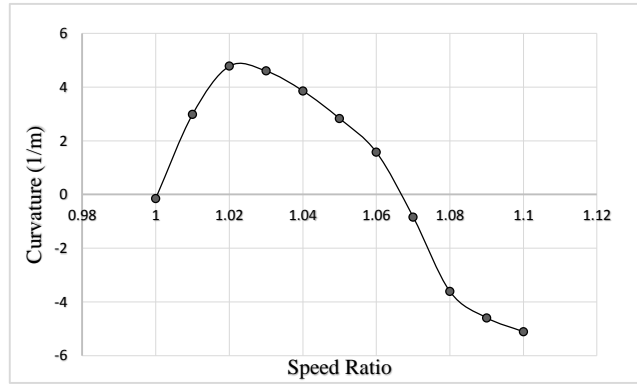


Fig. 14. Sheet Curvature Against Speed Ratio for Radii Ratio 1.05 ($R_u = 105mm, R_l = 110.25mm, m_u = m_l = 0.359, h_i = 2mm, \sigma_{x1} = \sigma_{x0} = 0, r = 10$)

Conclusions

In this paper, the asymmetric rolling was investigated and analyzed by the finite element method. Effects of asymmetry due to roll radii ratio and speed ratio mismatch on sheet curvature variations are discussed. The simulation results agreed well with the past experiments and theoretical studies. The following conclusions can be drawn:

- For each radii ratio, an optimum speed ratio to produce flat sheet calculated that is shown in Table 2.

Table 2: Optimum Speed Ratio

Radii Ratio	1	1.01	1.02	1.03	1.04	1.05
Speed Ratio	1.06831	1.06828	1.06692	1.06732	1.06633	1.06663

- By increasing the radii ratio, the optimum speed ratio which the sheet has zero curvature is reduced.
- As can be seen in Fig. 9 to Fig. 14 by increasing the radii ratio, the maximum sheet curvature is reduced.

List of Symbols (Optional)

E	Modulus of elasticity
R_1	Top roll radius
R_2	Bottom roll radius
R_u	Top roll radius
R_l	Bottom roll radius
μ	Friction coefficient
m	Friction factor
m_u	Top roll friction factor

m_l	Bottom roll friction factor
V_A	Speed ratio
h_i	Initial thickness
h_o	Output thickness
r	Percentage reduction

Greek symbols

σ	Stress
ε	Strain

References

[1] G. Sachs, L.J. Klingler, The flow of metals through tools of circular contour, J. Appl. Mech. 14 (1947) 88.

[2] L. Holbrook, C.F. Zorowski, Effects of non symmetry in strip rolling, J. Eng. Ind. B88 (1966) 401.

[3] G.E. Kennedy, F. Slamar, Turn up and turn down in hot rolling, in: Iron and Steel Engineer Yearbook, 1958, p.233.

[4] S.A. Buxton, S.C. Browning, Turn up and turndown in hot rolling: a study on a model mill using plasticine, J. Mech. Eng. Sci. 14 (1972) 245.

[5] W. Johnson, G. Needham, an experimental study of asymmetrical rolling, in: Applied Mechanics Convention, Institute of Mechanical Engineers, Cambridge, UK, 1966.

[6] W. Johnson, G. Needham, Further experiments in asymmetrical rolling, Int. J. Mech. Sci. 8 (1972) 443.

[7] P. Dewhurst, I.F. Collins, W. Johnson, A theoretical and experimental investigation into asymmetrical hot rolling, Int. J. Mech. Sci. 16 (1974) 389.

[8] M.M. Kiuchi, S. Hsiang, Analytical model of asymmetrical rolling process of sheets, in: Proceedings of the 14th NAMRC, Society of Manufacturing Engineers, Minneapolis, 1986, p. 384.

[9] J. Pospiech, a note on the influence of some factors affecting curvature on the flat rolling of strip, J. Mech. Work. Tech. 15 (1987) 64.

- [10] A.B. Richelsen, Elastic–plastic analysis of the stress and strain distributions in asymmetric rolling, *Int. J. Mech. Sci.* 39 (1997) 1199.
- [11] R. Shivpuri, P.C. Chou, C.W. Lau, Finite element investigation of curling in nonsymmetrical rolling of sheet, *Int. J. Mech. Sci.* 30 (1988) 625.
- [12] L.-S. Lu, O.-K. Harrer, W. Schwenzfeier, F.D. Fischer, Analysis of the bending of the rolling material in asymmetrical sheet rolling, *Int. J. Mech. Eng. Sci.* 42 (2000) 49.
- [13] Y.M. Hwang, T.H. Chen, Analysis of asymmetrical rolling by stream function method, *JSME* 39 (1996) 598.
- [14] M. Salimi, F. Sassani, Modified slab analysis of asymmetrical plate rolling, *Int. J. Mech. Sci.* 44 (2002) 1999–2023.
- [15] M. Pietrzyk, K. Wilk, H. Kusiak, Steady state FEM simulation of the strip bending in asymmetrical rolling process, in: *Proceedings of the Metal Forming 93*, Krynica, 1993, pp. 50–55.
- [16] S. Hamuzu, K. Yamada, T. Kawanmi, et al., Rigid plastic finite element analysis of asymmetrical rolling, in: D.R.J. Owen, E. Hinton, E. Onate (Eds.), *Computational Plasticity*, Pineridge Press, Swansea, 1987, pp. 1087–1096.
- [17] Y.M. Hwang, G.Y. Tzou, Analytical and experimental study on asymmetric sheet rolling, *Int. J. Mech. Sci.* 39 (1997) (1997) 289–303.
- [18] H.D. Hibbitt, B.I. Karlson, D. Sorensen, HKS Inc. *Rolling of Thick Plates (1.3.6)*, Abaqus/Explicit 6.4, 2004.
- [19] M. Salimi, A. Forghani, Prediction of product curvature in rolling with asymmetric condition, in: *The Seventh ISME Annual Conference*, Zahedan, Iran, April 14–16, 1999, pp. 1485–1493 (in Persian).