EXPERIMENTAL AND NUMERICAL ANALYSES ON THE CHARACTERISTICS OF TWIN SKEW ROLLING

TAKASHI UCHIMURA*, YOKI OKUDA† , MASAYOSHI AKIYAMA‡

* MSc Course Student, Department of Mechanical and System Engineering
Kyoto Institute of Technology, Gosho-Kaido-cho, Matsugasaki, Sakyo-ku, Kyoto, 606-8585, Japan
e-mail: m1623008@edu.kit.ac.jp, http://www.mesh.kit.ac.jp

† Retinal Imaging Group, Retinal Instruments Department, Eye Care Business Unit,
TOPCON CORPORATION, 75-1, Hasunuma-cho, Itabashi-ku, Tokyo, 174-8580, Japan
email: y.okuda@topcon.co.jp

‡ Department of Mechanical and System Engineering, Kyoto Institute of Technology,
Gosho-Kaido-cho, Matsugasaki, Sakyo-ku, 606-8585, Kyoto, Japan
email: akiyama@mech.kit.ac.jp, http://www.mesh.kit.ac.jp

Key words: Twin Skew Rolling, Flat Rolls, Blooming Mill, Porosity, Infiltration of strain.

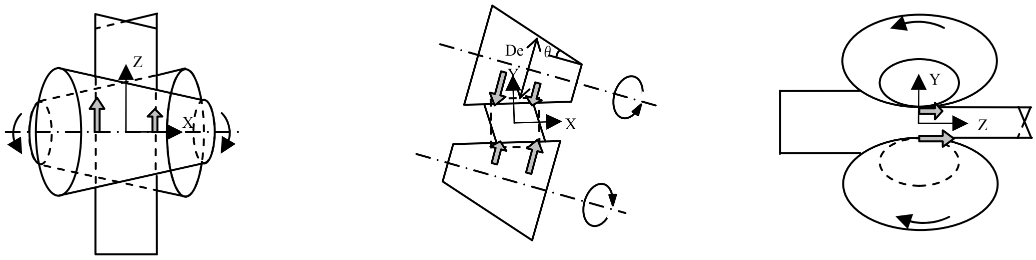
Abstract. Elastic-plastic FEA was carried out on the rolling process of twin skew rolling for a blooming mill to evaluate the influences of roll diameter, skew angle, and coefficient of friction on the suppression effect of porosities in the vicinity of centre axis of the material. Rolling by using a proto-type mill and modelling clay was then carried out to verify the validity of numerical analysis. Both results showed that the larger the roll diameter, and also the larger the coefficient of friction, the higher the suppression effect of porosities.

1 INTRODUCTION

Technology development for suppressing the porosities in blooming mill has a long history and many trials have been tried out mainly on the groove geometry of a pair of rolls [1], but there has been something more to do for the complete suppression. Recently a trial was proposed from a different point of view in which adoption of a pair of cone-type rolls showed a considerable effect in suppressing the porosities [2,3]. It is concluded in this proposal that use of a pair of cone rolls has a high advantage and the higher the skew angle the larger the effect. However, one important viewpoint has been missing from this result. According to the increase in the skew angle the working roll diameter increases and direct comparison of the results must be carefully done. In the present work rolling by a pair of simple cylindrical rolls was carried out both numerically and experimentally and influence of skew angle was evaluated on two sets of rolls; a pair of cylindrical rolls and a pair of skew rolls of which working diameter at the roll centre is the same as that of the cylindrical roll. In the experiment modelling clay was used for a parent billet and the parent billets were rolled through a proto-type rolling stand manufactured for this experiment.

2 MILL CONCEPT

The features of twin skew rolling method are illustrated in Figure 1. The major component of the mill is a pair of conical rolls of which half cone angle is θ and the difference in roll peripheral speed in the roll axis allows the three dimensional distribution of shearing force exerting on the billet surface and makes it possible to ease the generation of plastic deformation. This mechanism enhances the infiltration of compressive deformation to the billet centre that leads to the suppression of porosities [2,3]. Three features other than the roll geometry with half skew angle θ are that the roll axes are parallel each other, the angular velocities of two rolls are the same, and two rolls have the same geometry.

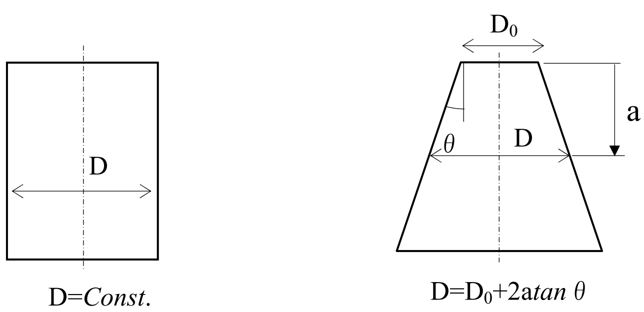


(a) Plane view (b) Elevation (c) Side view

Figure 1: Schematic illustrations of roll configuration for twin skew rolling method

In the previous work attention was focused on the effect of cone angle on the infiltration of deformation to the billet centre and a wide range of rolls with different cone angles were used to investigate the effect in the laboratory. However, roll diameter changes in the roll axis when cone angle is given and the lager the cone angle, the larger the working diameter of roll is. In a strict sense, therefore, influence of roll diameter and that of cone angle must be evaluated separately.

In the present work four pairs of rolls with a simple cylindrical geometry (flat roll) were manufactured corresponding to the skew rolls with different skew angles. The roll diameter of each cylindrical roll was the same as that of a skew roll measured at the centre in the axial direction.



(a)Conventional roll (b)Skew roll

Figure. 2: Schematic illustration of flat roll and conical roll

3 NUMERICAL ANALYSES

Elastic-plastic FEA was carried out on the hot rolling by the twin skew rolling. The software used for the analyses was ELFEN [4] developed at University of Swansea, U.K.. A pair of rolls was assumed rigid and the parent billet was regarded an elastic-plastic material. Figure 3 shows a schematic illustration of rolling. The billet centre coincides with the roll centre in the axial direction. At the initial stage of analysis the tail end of billet was pushed by a rigid plane to urge the bite and as soon as the rolling starts the constraint by rigid plane was released. The material was hot medium carbon steel and the flow stress was calculated by the Misaka's equation [5] that is given by equation (1) that is often used in the analyses of hot steel rolling, where C, T, ε , $\dot{\varepsilon}$ are carbon content, temperature, strain and strain rate.

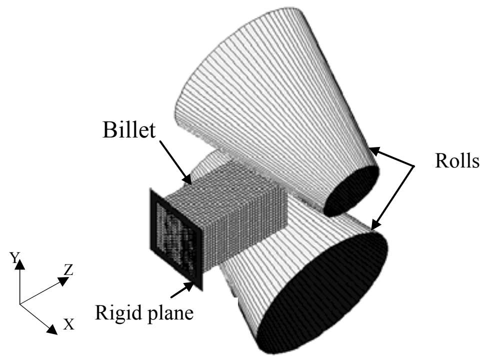


Figure 3: Configuration of rolls and billet.

$$\sigma = 9.8 \cdot \exp\left[0.126 - 1.75C + 0.594C^2 + \frac{2851 + 2968C - 1120C^2}{T}\right] \cdot \varepsilon^{0.21} \cdot \dot{\varepsilon}^{0.13} \quad (1)$$

Coulomb friction rule was assumed on the contact surface and 0.3 and 0.4 were the values of the coefficient of friction. The skew angle was 15 degrees that was found optimum in the previous work [2,3]. The list of condition of numerical rolling is shown in Table 1.

Table 1: Conditions of numerical analyses

Material	S45C
Rolling temperature, T	1273K
Friction coefficient, μ	0.3, 0.4
Mesh division	16×16×64
Specimen size	35mm×35mm×70mm
Draft	10%
Skew angle, θ	0°, 15°
Centre diameter of roll	φ70mm, φ140mm
Strain late, $\dot{\varepsilon}$	$30s^{-1}$

4 RESULTS OF NUMERICAL ANALYSES

4.1 Influence of roll diameter

Distributions of equivalent plastic strain in a cross section where the state of rolling is steady are compared in Figure4. When a pair of skew roll is adopted clear shear deformation is observed but the intensity of equivalent plastic strain increases in the vicinity of centre axis. Axial distributions of equivalent plastic strain are compared in Figure5. It is clearly observed that infiltration of compressive deformation is higher for the rolling by twin skew rolling.

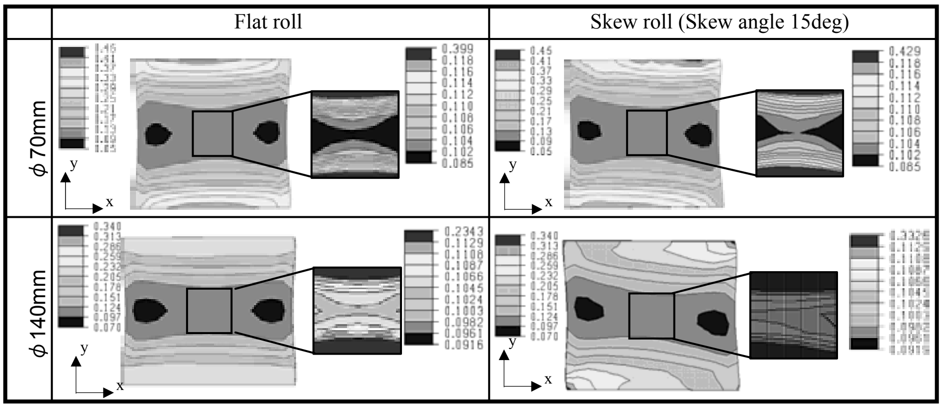


Figure 4: Distribution of equivalent plastic strain in cross-section after rolling

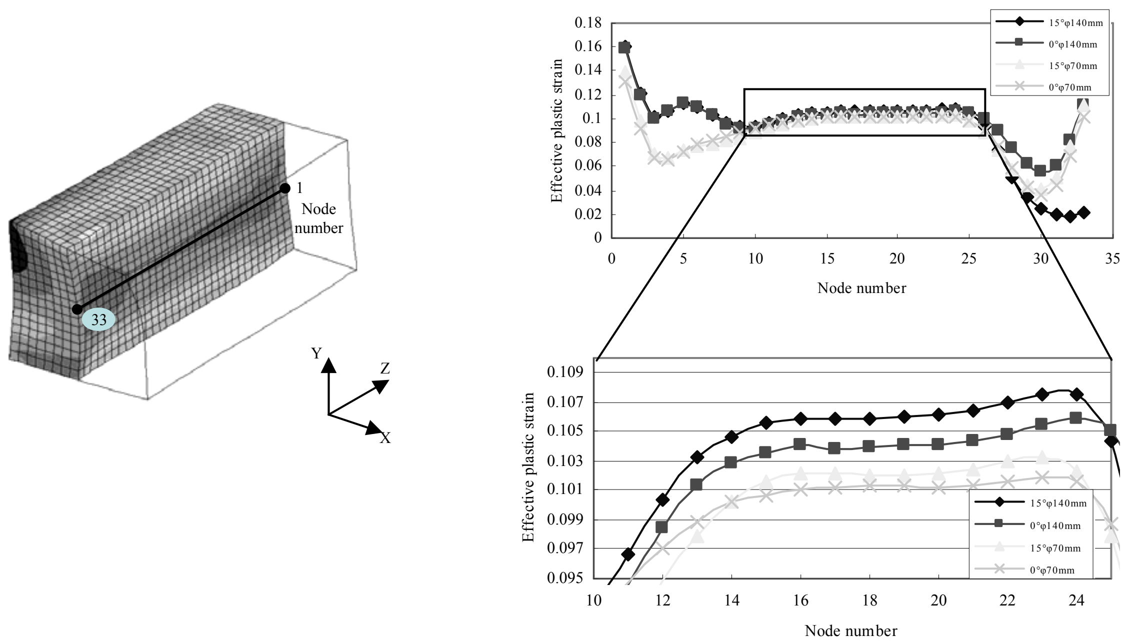


Figure 5: Distribution of effective plastic strain on centre axis of billet

4.2 Influence of friction

Influences of friction on deformation in a cross section and on the rolling axis are illustrated in Figure 6 and Figure 7 respectively. The tendencies of both rolling methods are very close and equivalent plastic strain increases according to the increase in friction, but the intensity of this tendency is higher for twin skew rolling. Distribution of roll peripheral speed due to the existence of skew angle realizes stronger three dimensional deformation that leads to higher infiltration of compressive deformation near to the billet axis.

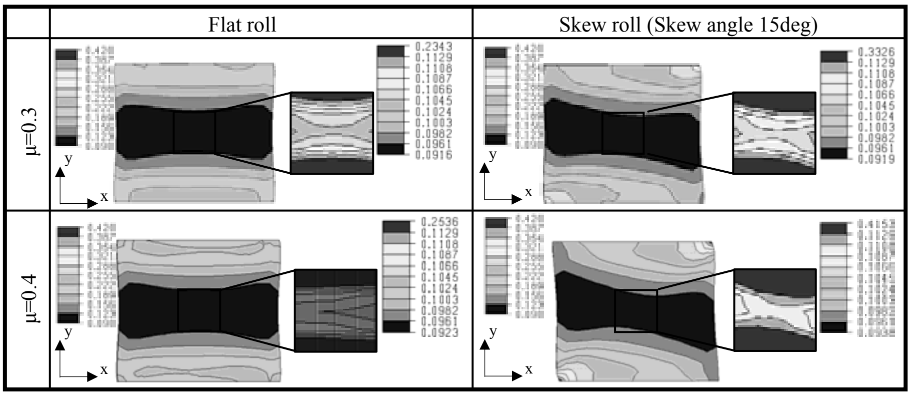


Figure 6: Comparison of influence of friction on distribution of equivalent plastic strain

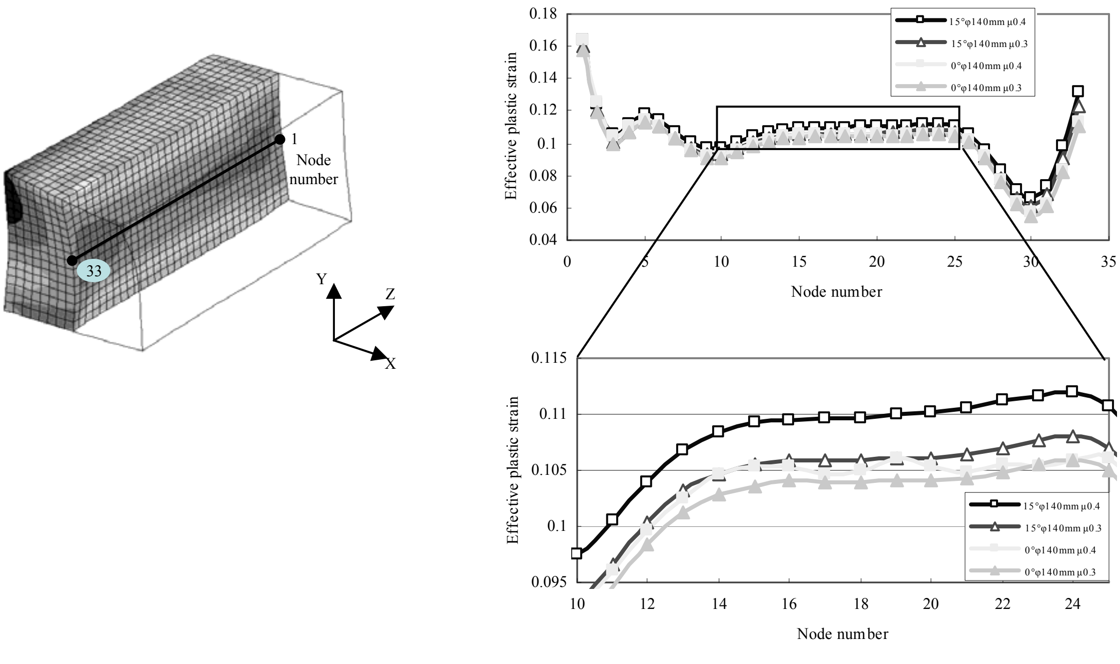


Figure 7: Distributions of equivalent plastic strain on rolling axis in steady state rolling

5 EXPERIMENT

5.1 Evaluating influence of roll diameter

A proto-type mill used for laboratory experiment is shown in Figure 8, and a set of four skew rolls and corresponding flat rolls are shown in Figure 9. The roll diameters of flat rolls were equal to the roll diameters of corresponding skew rolls at the centre in the axial direction. In Figure 10 an example of parent billet is shown that has a square cross section with a hole around the centre axis. The parent billet was made of a modelling clay, of which relationship between the flow stress and plastic strain resembles to that of hot steel, and the size of billet was 35mm×35mm×120mm and the diameter of centre hole was 5mm.

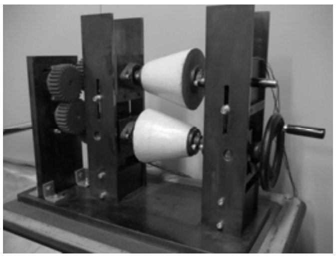
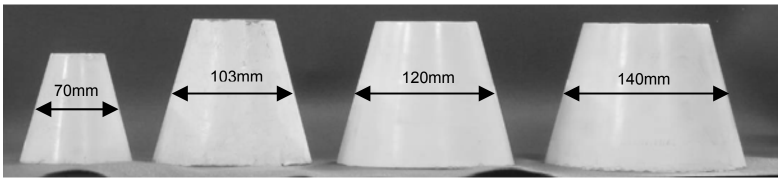
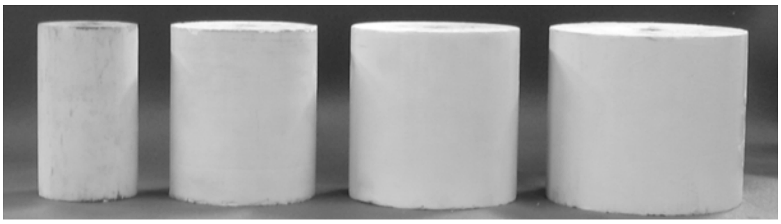


Figure 8: Twin skew rolling mill



Skew rolls



Flat rolls

Figure 9: Comparison of geometry of skew and flat rolls used for laboratory experiment

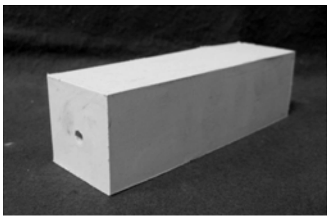


Figure 10: Modelling clay specimen

Similarly to the previous work [2,3] intensity of infiltration of compressive deformation was evaluated by measuring the ovality, i.e. aspect ratio, of the centre hole b/a as it is shown in Figure11. The smaller the ovality is, the higher the influence is.

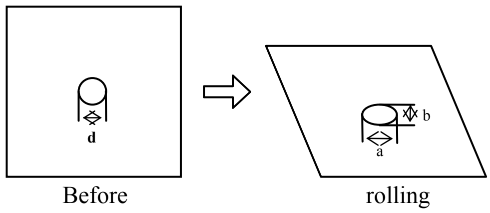


Figure 11: Schematic illustrations of initial round hole in cross-section and oval hole after rolling

The basic lubricant adopted was $CaCO_3$ that is often used for a laboratory experiment using modelling clay for simulating the rolling phenomenon of hot steel. Conditions of the rolling experiments are given in Table 2.

Table2: Conditions of rolling experiment in laboratory

Material	Modelling clay
Rolling temperature	293K
Specimen size	35mm×35mm×120mm
Round hole size	ϕ 5mm
Draft	10%, 20%
Skew angle	0°, 15°
Centre diameter of roll	ϕ 70mm, ϕ 103mm, ϕ 120mm, ϕ 140mm
Lubricant	$CaCO_3$

5.2 Evaluating influence of friction

Similarly to the previous work [2,3] influence of friction was evaluated by changing the lubrication condition. As it is shown in Table 3 three types of lubrication condition were adopted on the rolling using modelling clay billet; no lubricant, $CaCO_3$ and solution of soap.

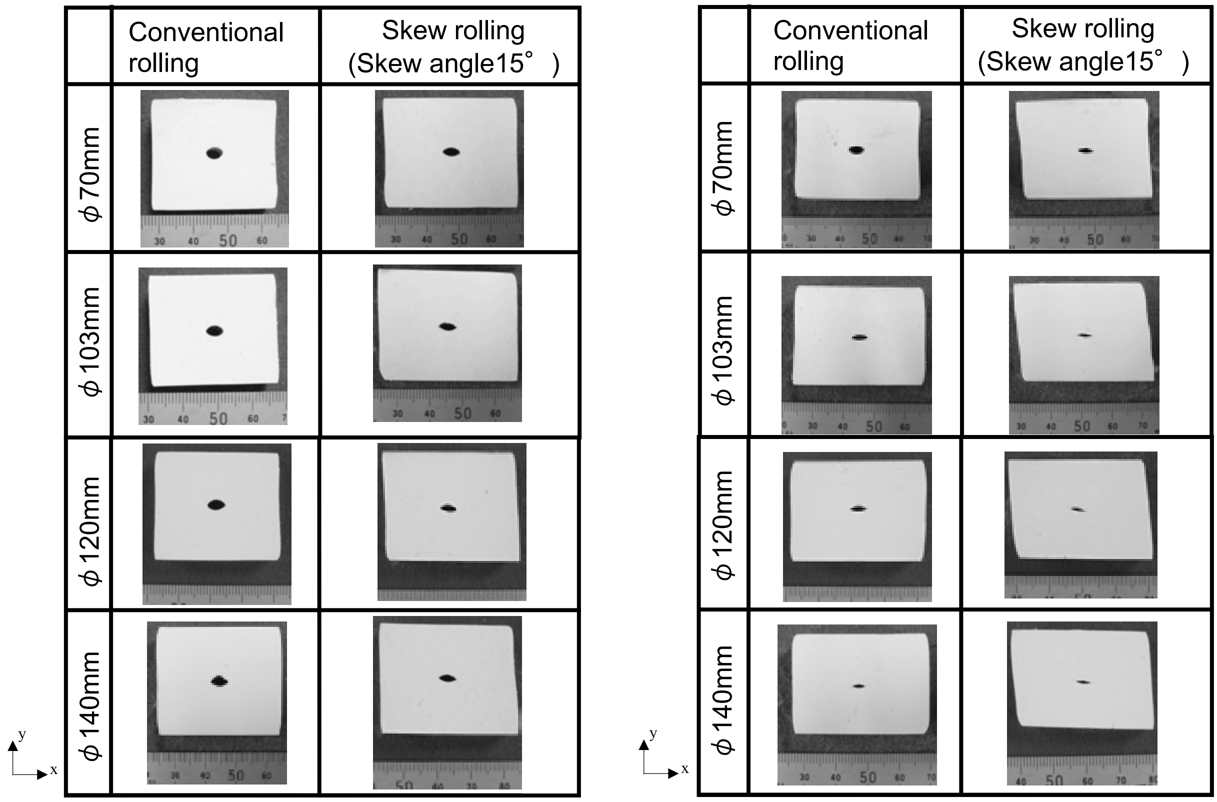
Table 3: Condition of rolling experiment by changing friction

Material	Modelling clay
Rolling temperature	293K
Specimen size	35mm×35mm×120mm
Round hole size	ϕ 5mm
Draft	20%
Skew angle	0°, 15°
Centre diameter of roll	ϕ 103mm
Lubricant	No lubricant, $CaCO_3$, Solution of soap

6 RESULTS OF EXPERIMENT

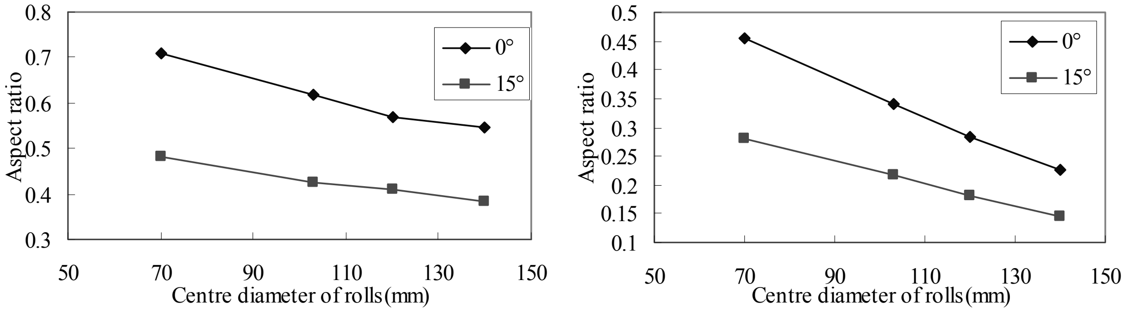
6.1 Influence of roll diameter

Examples of cross section at the steady state rolling are compared in Figure 12. The ovality of centre hole by twin skew rolling is larger when the working diameter of roll is the same, and the ovality becomes larger according to the increase in roll diameter regardless of the type of rolling. These results are summarized and shown in Figure 13.



(a): Rolling reduction 10% **(b)**: Rolling reduction 20%

Figure 12: Deformation pattern of round hole in centre of specimen



(a) Rolling reduction 10% **(b)** Rolling reduction 20%

Figure 13: Relationship between centre diameter and aspect ratio

6.2 Influence of friction condition

Influence of friction condition on infiltration of compressive deformation near to the centre axis is shown in Figure 14. As it was shown in Table 3 three conditions of lubrication were tried but lubrication by solution of soap failed only for twin skew rolling and only two other conditions by no lubricant and CaCO3 were successful. The reason of the failure was assumed as follows. Use of soap solution lead to too much decrease in friction coefficient on the contact surface and transmission of distributed shearing force on the roll surface was difficult, i.e. the distribution of shearing force was mainly used for the generation of lateral metal flow of billet surface ant the biting force in the rolling direction becomes poorer. This result suggests that slightly high coefficient of friction may be necessary for the twin skew rolling compared to the conventional rolling by a pair of flat rolls. Regarding the effect of high infiltration of compressive deformation near to the billet centre the results clearly shows the superiority of twin skew rolling similarly to the results by FEA.

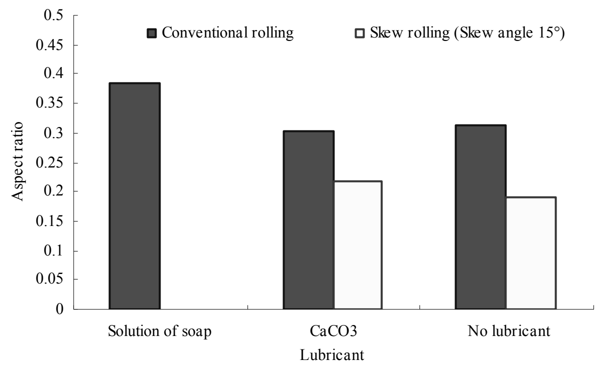


Figure 14: Influence of lubricity on infiltration of compressive deformation near to centre axis

7 CONCLUSIONS

In the present work influences of roll diameter of twin skew rolling and friction on the deformation near the centre axis of billet were evaluated numerically and experimentally. It was clarified that higher intensity of deformation is obtainable by the twin skew rolling method when the roll diameter of skew roll at the roll centre is the same as that of flat roll. Numerical results showed that concentration of strain in the vicinity of contact surface fades out according to the increase in roll diameter and the intensity of the concentration of equivalent plastic strain in the vicinity of billet centre increases. The results of experiment proved the validity of the numerical results. Friction on the contact surface is an important factor that generates the three dimensional shear deformation that is typical for the twin skew rolling method. Influence of friction on the infiltration of deformation to the billet centre was evaluated by changing the coefficient of friction in the numerical analysis and by changing the lubricant in the laboratory experiment. The results showed that the higher the friction is, the larger the infiltration of deformation to the centre is. Friction is more influential on the twin skew rolling than on the ordinary flat rolling. One important point to emphasize is that too low friction leads to failure in biting and rolling does not start in the twin skew rolling method.

NOTE

Some part of this work was carried out by the second author Mr. Yoki Okuda when he was a student at Kyoto Institute of Technology and this paper has nothing to do with his present work at his present affiliation Topcon Corporation.

ACKNOWLEDGEMENT

This research project was financially supported by The Amada Foundation, and the authors would like to express their deep gratitude for all the support.

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