Novel Method to Spread the Width of Strip

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The authors propose a new method for continuous spreading of long materials based on cross rolling method in this paper. The scheme of the new method is simple and it may be industrialized with high yield efficiency and productivity. Its equipment consists of a flat platen and a roll. The idle roll may be mounted on linear bearings, and reversingly travels over the material width along the transverse direction. The roll axis is slightly tilted against the horizontal plane, so the roll gap decreases towards downstream. The material is fed consecutively by some constant length. The thickness of material is reduced in the gap between the platen and the travelling roll. The material is widened gradually downstream. The rapid repetition of these operations realizes virtually continuous spreading of long materials. With the plasticine clay as a model material, the effectiveness of this method is investigated. In the case of 20% reduction of 2.5 mm thick and 60 mm wide plasticine strip, the achievable lateral spread is approximately 20%. Although the lateral spread increases with the reduction, the edge waves occur when the reduction is greater than 20%.

KEY WORDS: spreading; cross rolling; lateral spread; edge waves; elastic recovery; plasticine.

1. Introduction

The change in width is often negligible in flat rolling so that the metal only elongates along the rolling direction. Changing method of width is required. In hot strip mills, sizing presses or edging mills are most effective facilities. From the viewpoint of production costs, yield efficiency and productivity, the width changing method in the downstream processes has greater advantage, although some portion of this demand can be solved by slitting. However, the above two machines are not applicable to thin strips. This is because the buckling may occur owing to their large width/thickness aspect ratio. So new methods of controlling material width are expected. Such a method may decrease the numbers of mould width in continuous casting, and it may realize the multi-width strip production. Although cross rolling machines,1,2) where rods were rolled along the width direction consecutively and formed to strips, were already industrialized, it has a problem in applicability to wide materials. Although the authors proposed a continuous spreading method of coiled materials using tandem rolling mill with grooved rolls,3–7) the amount of the lateral spread is still limited. Therefore new spreading method of strip width is demanded. The method may be met with the recently growing continuous casting of thin slabs or strip casting. Furthermore, it can be used as a method of controlling the properties or textures of materials. The authors propose a novel spread rolling method based on cross rolling in this paper, and its effects are made clear.

2. The Scheme of the Novel Spread Rolling Method

Figure 1 shows a schematic illustration of the proposing novel spread rolling method. The method is based on cross rolling and its equipment consists of a platen and a roll. The roll is not driven, i.e. idle roll, and it is mounted on linear bearings. The roll axis is tilted slightly against the horizontal plane, so the roll gap decreases towards downstream. The roll can reversingly travel over the material width along the transverse direction by a crank shaft. The roll axis is tilted slightly against the horizontal plane. The roll gap decreases towards downstream. The material is fed consecutively by some constant length. The thickness of material is reduced in the gap between the platen and the travelling roll. The material is widened gradually downstream. The rapid repetition of these operations realizes virtually continuous spreading of long materials. With the plasticine clay as a model material, the effectiveness of this method is investigated. In the case of 20% reduction of 2.5 mm thick and 60 mm wide plasticine strip, the achievable lateral spread is approximately 20%. Although the lateral spread increases with the reduction, the edge waves occur when the reduction is greater than 20%.

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to 1 or 2°. The bearing part, where the roll gap was constant,
CaCO₃ was utilized as a lubricant. The deformation charac-
teristics were investigated. Definitions of the lateral spread 
s and the reduction in thickness r are the followings,

\[ r = \frac{h_1 - h_2}{h_1} \]  \[ s = \frac{w_1 - w_2}{w_1} \]

where \( h_1 \) and \( h_2 \) are the initial thickness and the product 
thickness. \( w_1 \) and \( w_2 \) are defined as the corresponding 
widths, respectively. The contact length \( L \) in Fig. 2 is calcu-
lated as

\[ L = \frac{h_1 - h_2}{\tan \theta} \]

For instance, in the case of 30% reduction of 3 mm thick 
strip with a roll at the inclination angle \( \theta = 2° \), the length \( L \) 
is 25.8 mm.

4. Experimental Results

Figure 3(a) shows the appearances of partially rolled 
strips with various reduction 20%, 33% and 50%, rolling 
with the angle \( \theta = 2° \). The dotted line at the center of width 
is a marker to apply the feeding amount precisely. The 
contact length increases with the reduction. The width increas-
es almost linearly in the roll bite. In the case of 20% reduc-
tion, the lateral spread \( s \) is 24% and there is no significant 
variation along its length. The rolled strip shows the sound 
shape with no apparent shape defects. In the case of 33% 
reduction, the lateral spread 45% is obtained while edge 
waves can be observed. In the case of 50% reduction, the 
larger lateral spread is obtained, width is almost one and a 
half as large as the width before the spread rolling and edge 
waves occur more obviously. It is found that proposed 
process is feasible, however the lateral spread is limited by 
formation of edge waves. Figure 3(b) depicts the effects of 
feeding amounts. The lateral spreads of strips are not sensi-
tive to the feeding amount, which is approximately 45%. 
Steep edge waves are observed under the condition. Figure 3(c) shows the effects of the inclination angle of roll; \( \theta = 1° \) 
and \( \theta = 2° \). The lateral spread slightly increases with the in-
clination angle. This is because the contact length \( L \) is 
much larger than the feeding amount under the experimental 
conditions. Therefore the deformation can be regarded 
as plane strain condition, so that it does not depend on the 
feeding amount and the inclination angle much. Figure 4 
illustrates the influence of the reduction on the steepness of 
edge waves. The steepness is defined as the ratio of the 
wave height \( a \) divided by the wave pitch \( b \), as described in 
the following equation:

\[ \lambda = \frac{a}{b} \times 100 \]

No edge waves are observed in the cases of the reduction 
less than 20%. When the reduction is above 20%, the 
steepness increases linearly with the reduction. Therefore it 
is found that the obtainable lateral spread is limited by the 
occurrence of the edge waves. The relationship between the 
lateral spread and the reduction is pictured in Fig. 5. The 
solid line stands for the ideal lateral spread assuming plane 
strain deformation without longitudinal elongation. The 
trend of lateral spreading agrees with that of the ideal lateral 
spread qualitatively, however, the actual amount is slight-
ly lower. So the maximum lateral spread of the sound strip is estimated to be 20%.

Figure 6 shows the appearances of different width strips during rolling. A rolling condition is 33% reduction and the inclination angle is 2°. The grid with a regular interval of 5 mm had been printed on the surface of plasticine strips. The material deforms almost uniformly both along the longitudinal direction and the transverse direction. The region
near edges shows larger lateral spread than the interior. Material flows slightly faster near the width edge. These results mean that the lateral spread is greater at the region near edges. It is because, at the region, the constraint of metal flow is lower so that the folding of side surface may occur. So the lateral spread decreases with increase in the initial width. However, the lateral spread distributes almost uniformly at the interior of the width. An 80 mm wide strip is showing the lateral spread 28.8%. Meanwhile a 60 mm wide strip shows 40.8%. The steepness of an 80 mm wide strip is 12.5% and smaller than a 60 mm wide strip (λ = 18.2%). These results indicate that the aspect ratio has a strong influence on the absolute spreading amount under these rolling conditions. This is because the deviation from the plane strain deformation increases with the initial width. The elongation is larger in the case of wider material because the constraint from the material outside the roll is greater.

Figure 7 shows the variations of strain distributions across the width measured from the grid, accompanied with the thickness distribution. This figure is the case of 33% reduction rolling of 60 mm wide strip and the inclination angle is θ = 2°. The width strain near the edges is larger than that at the width center, as above mentioned. On the other hand, the longitudinal strain distribution is almost constant except the regions near edges. Although the edge wave occurred in the condition, the measurement was conducted on the projected plane view. So it should be reminded that the longitudinal strain values near edges may be underestimated. The edge part shows greater lateral spread and elongation because of less constraint. It causes the decrease in thickness, although the effect is not clear by the elastic recovery.  

5. Discussion

This physical simulation clarified the potential of the proposed method for spreading the width of thin wide materials. In the case of 20% reduction, the lateral spread is around 20% without apparent shape defects. Although the lateral spread further increases with the reduction in thickness, the edge waves occur when the reduction is larger than 20%. The mechanism of edge wave is discussed later.

The obtainable lateral spread can be estimated assuming the plane strain deformation. The processing parameters such as the inclination angle of roll and the feeding amounts do not have much influence on the deformation characteristics of the strips. This is because the contact length L is much larger than the feeding amount. The further lateral spread may be attained by multi-pass operation.

Therefore the achievable lateral spread is limited by the occurrence of edge waves. The mechanism of the occurrence of edge waves can be explained as the following model. The edge waves are caused by the excessive stretching near the edges. The phenomenon is similar to the excessive lateral spread at front and tail ends, that is to say, the flaring phenomenon in conventional rolling process. During spreading, the material in the roll bite deforms inhomogeneously as illustrated in Fig. 8. The excessive stretching is caused by the difference in the paths of stream lines as shown in Fig. 8(b). At first in the entrance of roll bite, the line element on the edge of width is sheared and more stretched than the center. After further repetition of the idle roll’s travelling and feeding of material, the difference increases. At the exit of the roll bite, the elongations of the elements on edge and that in center should be the same if the deformation is virtually in steady-state. Therefore the deformed element at edge is compressed along the feeding direction for the compensation. If the difference is small, i.e. the lateral spread is small, its difference may be absorbed by elastic deformation so that the product can maintain sound strip. However, the difference exceeds the elastic limit, so that the plastic buckling, i.e. edge waves take place. One of the authors presented a similar edge wave formation mechanism for wire rolling, based on the finite ele-
ment analysis. It can explain the fact that edge waves are not formed when the lateral spread is small. In order to eliminate or reduce the occurrence of edge waves, the difference of strain between edge and width center should be small. So the use of profiled platen may be effective.

The industrial application of this new spreading method will promise the multi-width production of strips, which enables to produce various width strips as desired without slitting or sizing. The proposed technique can be employed in the configurations of both hot-working and cold-working processes. The process also may be used to spread the width of thicker materials such as slabs effectively, since edge waves are hard to form. In hot-rolling process, the replacement of sizing mill or edger mill would be expected, however, it requires further studies for evaluation. In other point of view, the spread rolling has an ability to introduce strain in transverse direction as well as in rolling direction. Decrease in the planer anisotropy of the metal strip is also expected application. The combination of conventional rolling and this new spread rolling might be preferred to control the planar anisotropy arbitrarily.

6. Conclusion

A novel efficient method for continuous spreading for thin and wide material is proposed. The results confirm the effectiveness of the proposed new method. In the case of the 20% reduction, the lateral spread was approximately 20%. Although the lateral spread increases with the reduction, the edge waves occur when the reduction is greater than 20%. Therefore the obtainable lateral spread is still limited by the edge waves. The larger spread may be attained by multiple pass operation. So the process also may be more effective to spread the width of thicker materials such as slabs, since edge waves are hard to form. Furthermore, this process can be combined with the conventional rolling so that the planar anisotropy of strips can be controlled.

REFERENCES