A MODIFIED METHOD FOR LATERAL SPREAD IN THIN STRIP ROLLING

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ABSTRACT

A rolling method to increase the width of the metal would have advantages in multi pass strip production, giving high productivity and control of texture or planar anisotropy. In conventional flat rolling, however, it is difficult to produce metal flow in the lateral direction. A new method for spread rolling has been proposed in the literature, in which several portions of strip width are rolled between a roll that has many circumferential grooves and a flat roll. In the present work, new modifications in roll profile and number of grooves are introduced. The advantages of the new modifications are evaluated through rolling of pure commercial aluminum strips. It is found that a strip of 70 mm wide and 1 mm thickness have been widened up to 3.1% under a reduction of 35%. It is found also that the planar anisotropy decreases. A special purpose nonlinear finite element program has been developed to deal with continuous change of contact between the roll and the strip in each rolling pass. The calculated strain tensor is utilized to investigate the localized necking.

KEYWORDS

Spread rolling, Planar anisotropy, Thin strip rolling, Finite element modelling.

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1-INTRODUCTION

In conventional flat rolling, the material elongates in the rolling direction and no deformation occurs in the lateral direction i.e. plane strain deformation. As a result, the mechanical properties and the microstructure along the rolling direction differ from those in the lateral direction. On the other hand, the spread rolling method can introduce strain in the lateral direction as well as in the rolling direction. It also has an advantage of giving high productivity and control of mechanical properties [1]. Cross rolling [2] or intermittent pressing [3] has been proposed as a spread rolling methods which showed less planar anisotropy, although they have problem of productivity.

Recently, saito et al [4] and Utsunomiya et al [5] proposed a new method for spread rolling in thin strip using three-pass rolling operations. In the first pass, the strip is rolled between a roll having many regular trapezoidal circumferential grooves and a flat roll. Several portions of the strip width which get in contact with the grooved roll are reduced , whilst the other portions bulge in the grooves. In the second and the third passes, strips are flattened between flat rolls. They used the Plasticine (clay) to examine the spread ability of the proposed method. It is found that, strips of 1 mm thickness and 100 mm wide increased in width by 5 mm under a reduction of 30%. When aluminum strips are rolled in the above sequence [6], some defects such as : necking and fracture occurred near edges under certain rolling conditions. Therefore, achieved lateral spread was limited by the occurrence of these defects. In order to avoid these defects, the method is improved to five-pass: the first and the third passes utilized the grooved roll against the flat roll, whilst, in the rest of the passes flat rolls are utilized to flatten strips. In ref. [7] Utsunomiya et al. modified the shape of the circumferential grooves to half circle and adopted the same rolling sequence and used delivery guide to obtain wide and sound strips. They utilized taper-crown rolls as upper ones in the second and fourth passes. The effect of the spread rolling method on the mechanical properties of the rolled strips is investigated. The spread rolling method is further employed for a copper alloy to verify the capability of spreading and control of texture [8]

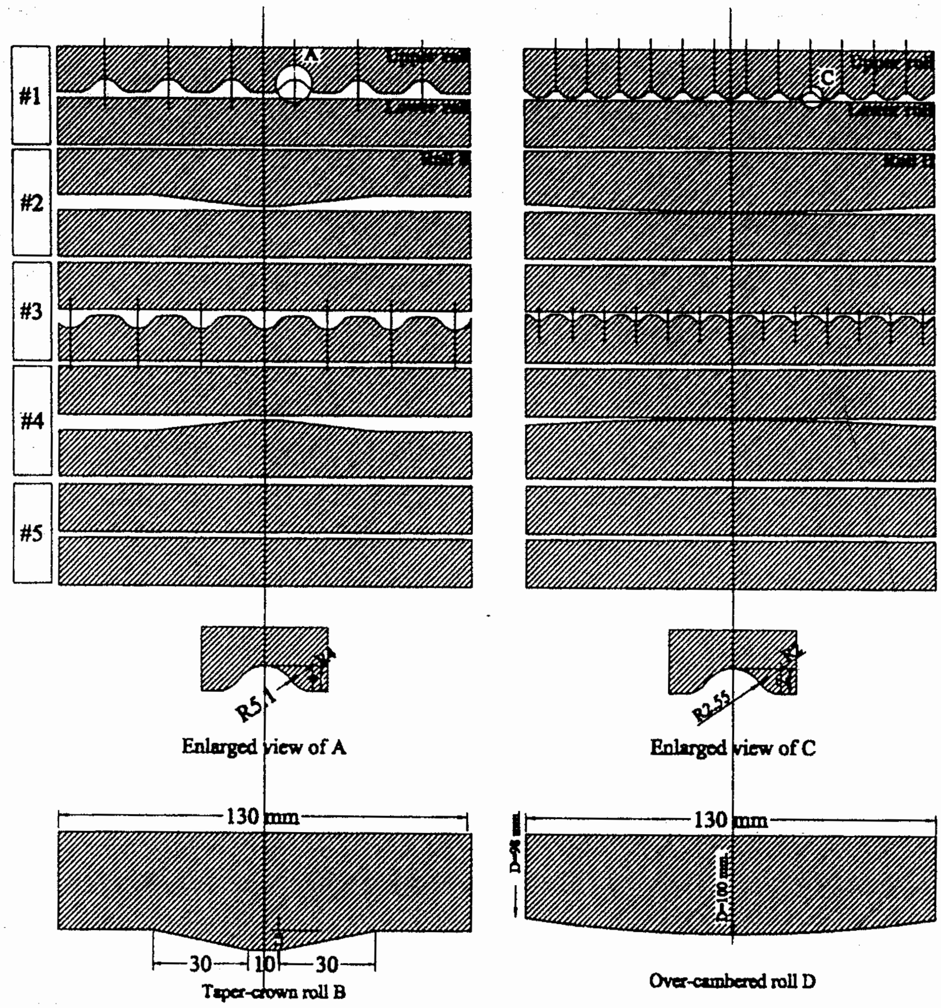
The present study includes two parts. The first part introduces new modifications such as: roll profile, circumferential groove profile and number of the grooves, which have great effect on the lateral spread. A portable rolling device is designed and manufactured. Special rolls of 100 mm diameter and 130 mm width are machined with new groove geometry. Commercial annealed aluminum (1050) strips of 1 mm thickness and width of 30, 50, and 70 mm are rolled. The advantages of the proposed spread rolling method as compared with the flat rolling are investigated by evaluating the mechanical properties and the planar anisotropy of the rolled strips.

In the second part, a special purpose nonlinear finite element program is developed based on the incremental updated Lagrangian formulation. The program takes into account the geometrical (large strain) and the material nonlinearities as well as the continuous change in contact between the rolls and the strip. Comparisons between the obtained values of lateral spread and the measured ones are made. The calculated strain tensor is utilized to investigate the localized necking.

2-EXPERIMENTAL WORK

2.1 Principle of the Spread Rolling Method

Figure (1) schematically illustrates the sequence set up of the spread rolling method used by Utsunomiya et al. [7] and the present model. In the first pass, the thickness of several portions of the strip width is reduced due to rolling between a roll having circular circumferential groove and a flat one. Portions not in contact with upper roll bulge into the grooves as shown in Fig.1. In the present model, the dimensions of the circumferential grooves are reduced to half and their number is doubled to avoid surface defects and necking, see Fig. 1 The second pass is a roll-forming pass, where the bulged portions are flattened. In order to increase the lateral spread, an over-cambered roll with a flat one are employed in this pass, instead of using a taper-crown roll in the work of Utsunomiya et al. [7] as shown in Fig. 1. It is believed that employing the over-cambered roll can enhance the metal flow along the lateral direction. In the third pass, the grooved roll is used as the bottom roll. The bulged parts in the first pass are rolled in this pass and vise versa. The over-cambered roll is used as the bottom roll in the fourth pass. Two flat rolls are used to flatten the strips in the fifth pass.



a) Utsunomiya et at. model [7] b) Present model

Fig. 1 Diagrammatic representation of spread rolling arrangements..

2.2 Rolling Experiments

A portable rolling device is designed and manufactured. Four rolls : two flats, one with the half circular circumferential grooves and finally the over-cambered roll are machined from stainless steel. All rolls are of 100 mm diameter and of 130 mm width. The profile of the circular grooves is designed with a pitch of 10 mm and a curvature radius of 2.5 mm as shown in Fig. 1. These dimensions are chosen to avoid surface defects and necking. The diameter of the over-cambered roll is 100 mm in the middle whilst at both ends it equals 98 mm. It is found that the over-cambered roll is effective not only in the achieved lateral spread but also in the strip shape after rolling.

Commercial annealed aluminum (1050) strips of thickness of 1 mm and width of 30, 50 and 70 mm. are used to investigate the spread rolling capability of the introduced modifications. The strips are annealed for four hours at 450°C. The prime reason of choosing the material and the dimensions is to compare the obtained results with those presented in ref. [7].

Strips are processed with total reduction in thickness of 35%, whilst the reduction in the first, the third and in the fifth passes are 20%, 20% and 35% of the initial thickness respectively. The lateral spread is measured by comparing the projected width after rolling with the initial strip width in each pass. Conventional three-pass flat rolling is also conducted for the sake of comparison.

The mechanical properties as well as the planar anisotropy of the spread rolled and the flat rolled strips, under the same reduction ratio, are evaluated by conducting a tensile test. In both cases, three tensile test specimens are cut form the rolled strip at 0°, 45° and 90° with the rolling direction, respectively. The gauge length of the specimen is taken 10 mm and the width is 5 mm. The offset yield strength $\sigma_{0.2}$ and the ultimate strength σ_u are recorded in each case.

3-FINITE ELEMENT ANALYSIS

As stated above, the developed nonlinear finite element program takes into account geometrical (large strain) and the material nonlinearities as well as the continuous change in contact between the roll and the strip.. The analysis is carried out incrementally based on the incremental updated Lagrangian formulation. In each increment, The stress and the strain tensors are transformed to the present state (last calculated state) according to the continuum mechanics basis.. The material behaviour is approximated as :

$$\sigma = 150\ \varepsilon^{-0.2} \qquad (1)$$

where σ (in MPa) and ε are the effective stress and effective strain, respectively.

The resulting deformed strip shape and the field variables such as: stress and strain tensors at the exit from a pass are used as input to the subsequent one.

In the finite element modeling, only one-half of the strip width is modeled owing to symmetry. A mesh of 30x70x5 elements is utilized in the longitudinal direction, the lateral direction and through the thickness, respectively. The friction layer technique is employed to model the friction effects at the roll/strip interface.

4-RESULTS AND DISCUSSIONS

4.1 Spread Rolling

The measured, the finite element predictions and those presented in ref. [7] of the percentage lateral spread during the spread rolling are shown in Fig. 2. The results of flat rolling under the same reduction ratio is also plotted. In case of Utsunomiya et al. [7], the lateral spread in the first pass is negative because the edge bended up and the projected width decreased. This is not the case in the present results because the dimensions of the grooves are reduced to half.. On the other hand, the strip does not almost spread in the flat rolling process. It is clear from the figure. that employing the presented sequence has significant effect on the lateral spread which increases from 1.6 % (Utsunomiya et al.) to 3.1% (present results). Figure 3 shows the percentage longitudinal elongation of the strip plotted against the pass number. The elongation in the spread rolling is considerably smaller than that of the flat rolling. The elongation from the first to the fourth is small as compared to final flat rolling pass. This because of the unrolled portions bulge into the grooves in the first and the third passes.

Figure 4 depicts the percentage lateral spread in case of strip width of 30 , 50 and 70 mm. It is shown that the percentage lateral spread decreases as the initial width increases..

Figure 5 depicts the finite element predictions of the strip cross-section after each pass. In the first and the third passes, the unrolled portions of the strip width bulged in the roll grooves, whilst in the the second and the fourth passes, the strip has been flattened and widened. In fifth pass, flat rolling has straightened out the bulged edges of the strip leading to an increase in the strip width

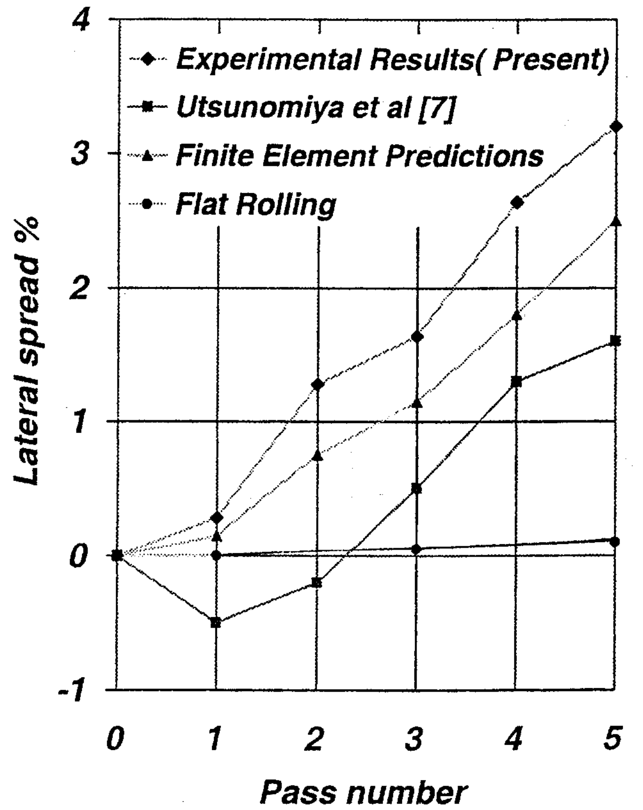


Fig. 2 Variation of percentage lateral spread of the strip during rolling.

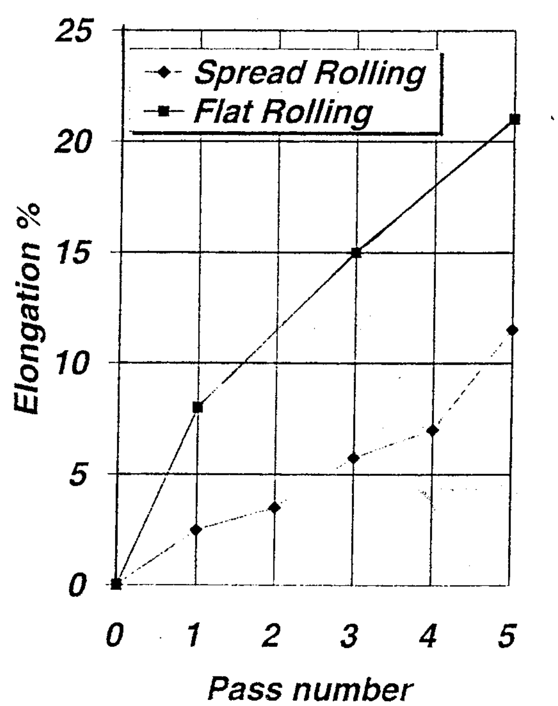


Fig. 3 Variation of percentage longitudinal elongation of the strip during rolling.

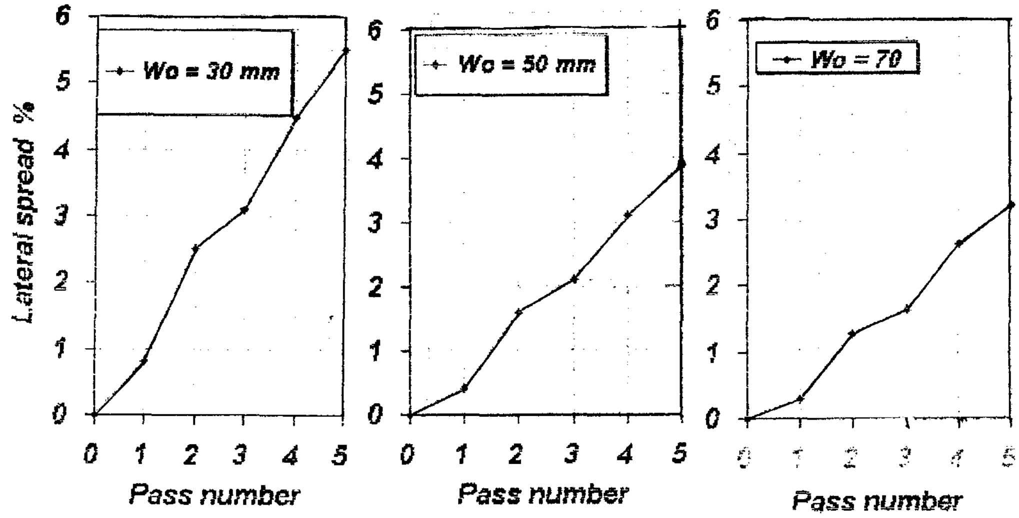


Fig.4 Variation of percentage lateral spread as a function of the initial width.

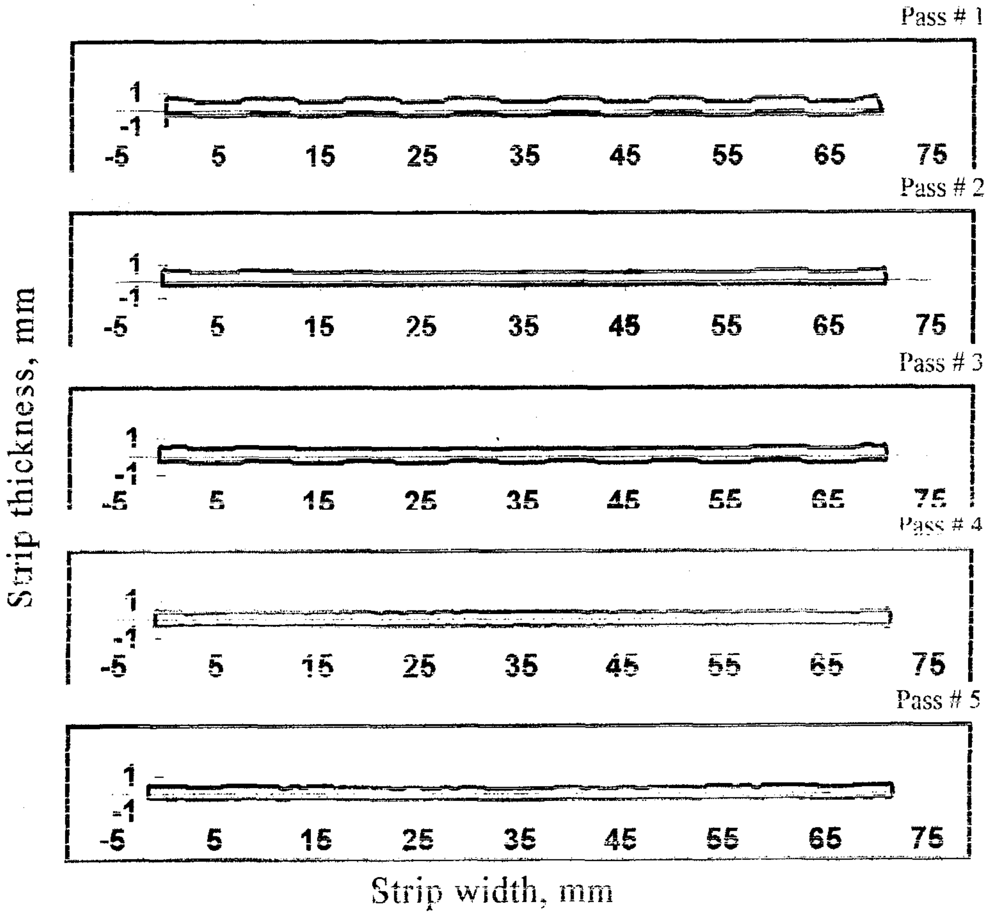


Fig. 5 Finite element predictions of strip cross-section for a strip of 70 mm width.

4.2 Mechanical Properties

The measured mechanical properties in case of 70 mm strip width are shown in Table 1. The offset yield strength $\sigma_{0.2}$ of the as spread rolled material is higher than that of the flat rolled strip. This may be due to redundant deformation introduced by bulging and flattening.

Table 1 Mechanical properties of the spread rolled and the flat rolled strips

	spread rolled			flat rolled		
degree	0°	45°	90°	0°	45°	90°
$\sigma_{0.2}$ MPa	78	73	76	76	71	66
σ_u MPa	103	95	97	101	91	83

The average strain state through the thickness is utilized to investigate the localized necking. The critical strain for localized necking ε_3^L is given by [9] :

$$\varepsilon_3^L = \frac{n}{1+r} \tag{2}$$

$$r = \dot{\varepsilon}_2 / \dot{\varepsilon}_1 \tag{3}$$

where n is the strain hardening exponent, and $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$ are the strain rates in the rolling and in the lateral direction.

The calculated average critical strain through the thickness using the above formula is compared with the average strain ε_3 obtained from the finite element program. It is found that the average strain ε_3 is lower than ε_3^L which means that there is no necking.

Figure 6 depicts the ratio between the induced lateral and the longitudinal strains. It is shown that the lateral spread rolling method induces appreciable lateral strain as compared to the longitudinal one.

Fig. 5 Finite element predictions of strip cross-section for a strip of 70 mm width.

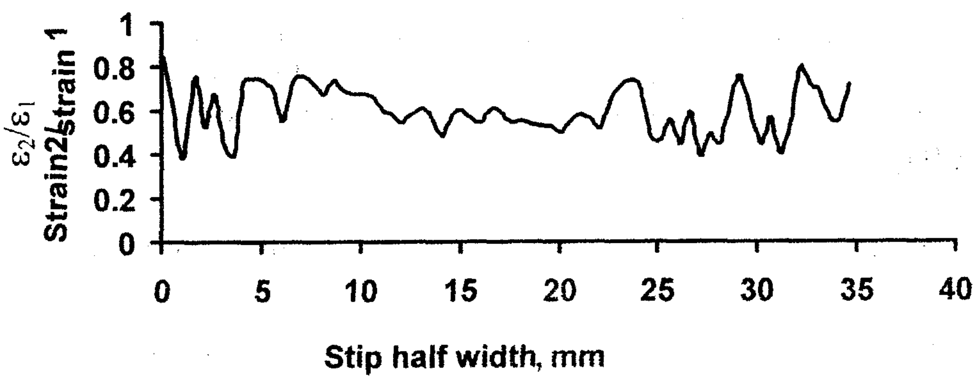


Fig. 6 The ratio between the induced lateral and the longitudinal strains.

5-CONCLUSIONS.

In this study, new modifications such as; roll profile and number and dimensions of the grooves have been introduced to the suggested spread rolling in the literature. Portable rolling device has been designed and manufactured. The proposed modifications are examined through the rolling of commercial pure aluminum strips. The proposed modifications show a remarkable spread ability, where it is found that a strip of 1 mm thickness and 70 mm width has been widened up to 3.1% under a reduction of 35%. The mechanical properties of the spread rolled material is slightly work hardened and with less planar anisotropy.

A special purpose nonlinear finite element program has been developed based on the incremental updated Lagrangian formulation. The calculated strain tensor is utilized to investigate the localized necking. The proposed rolling method is found to be effective in getting wide and sound strips.

6-ACKNOWLEDGEMENTS

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طريقة مطورة للتشكيل العرضى أثناء درفلة الرقائق .

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ملخص البحث :

ان وجود طريقة للتشكيل العرضى أثناء درفلة الرقـائق يكون لهـا عدة مميزات مثل زيـادة الانتاجية و التحكم فى التركيب البلورى و تجانس الخواص المسـتوية. فى الدرفلـة الطوليـة عادة لا يحدث تشكيل عرضى. لهذا استحدثت طريقة جديدة للتشكيل العرضى يتم فيها درفلـة الشريحة بين درفلين العلوى يحتوى على حزوز داخلية محيطية بينما السـفلى مستوى. فى هذا البحث تم تطوير شكل و عدد الحزوز المحيطية وكذلك شكل الدرفيل. لبيان مميزات هذا التطوير تم درفلة رقـائق مـن الالمونيـوم.وجـد ان التشـكيل العرضـى وصـل الـى ٣,١٪ مـن العرض الاصلى للرقيقة ذات عـرض قيمتـة ٧٠ مـم و سـمك ١مـم وكذلـك زيـادة فـى تجـانس الخواص المستوية. تم تصميم و كتابة برنامج عناصر محددة لاخطى لنمذجة درفلة الرقائق. استخدمت مصفوفة الانفعال المحسوبة مـن طريقـة العنـاصر المحـددة لتحديـد حـدوث عمليـة التخصير من عدمه.