

# Analysis of the Strip Shape and Microstructure with Consideration of Roll Crossing and Shifting

Z. Y. Jiang, H. B. Tibar, A. Aljabri

**Abstract**—Optimisation of the physical and mechanical properties of cold rolled thin strips is achieved by controlling the rolling parameters. In this paper, the factors affecting the asymmetrical cold rolling of thin low carbon steel strip have been studied at a speed ratio of 1.1 without lubricant applied. The effect of rolling parameters on the resulting microstructure was also investigated. It was found that under dry condition, work roll shifting and work roll cross angle can improve the strip profile, and the result is more significant with an increase of work roll cross angle rather than that of work roll shifting. However, there was no obvious change in microstructure. In addition, effects of rolling parameters on strip profile and microstructure have also been discussed.

**Keywords**—Reduction ratio, rolling speed ratio, strip shape, work rolls cross angle, work roll shifting.

## I. INTRODUCTION

COLD rolling is passing the work piece between two compressive rolls to reduce its thickness which produces thin strips [1]. The process is very important for thin strip to provide remarkable material properties, such as increased strength and fine thickness tolerances can be achieved [2], [3]. The key motivations for the development and manufacturing of thin gage strips with superior shape and profile are the current industry demands for superior quality and applications which require increasing thinner strip. Studies of thin strip have stated that thin strip has wide applications in the electronics and instrument industries [4], [5]. A variety of advanced shape control rolling mills have been the focus on improving the strip shape and profile. Shape and profile of thin strip are the most significant characteristics that have essential influences on both the rolling process and the quality of the products [6], [7]. The quality of the strip is mainly governed by the optimisation of the rolling parameters, such as the rolling speed, reduction ratio, strip width, friction, pair cross angle and work roll shifting value. If the rolling parameters are imperfectly specified, the loading force causes elastic deflections of rolls [5], [8], [9], which results in effect on microstructure, shape and profile of the strip, and thus the strip quality.

A typical thin strip rolling involves hot rolling to break down ingots into blooms and billets which are known as semi-finished products. This is followed by further hot rolling into plate, sheet, rod, bar, pipe, rails or structural shapes. Cold rolling is then performed to produce sheet, strip and foil with high surface finish and mechanical strength, as well as, close

control over the dimensions of the product [10], [11].

Elastic deflection of the mill components occurs simultaneously with the elastic-plastic deformation of the rolled strip. This leads to non-uniform thickness profile of the strip [12]. An important parameter that has a direct impact on strip profile is friction [13]. All rolling parameters, for example, rolling speed, reduction, rolling forces, pressure distribution, work roll diameter and shape and profile, are all dependent on the coefficient of friction [14], [15].

Continuous Variable Crown (CVC) and Pair Cross (PC) mills are appropriate to control the strip shape, profile and flatness when the rolling process is applied to the rolling of thick strip, and the control of the microstructure, strip shape, profile and flatness, no longer present a serious challenge to rolling mill operation for relatively thick products [16]. However, for thinner gage strip such as the thickness less than 0.2 mm is still a challenge in rolling practice, this involves the control of the strip dimensional accuracy, the strip crown and surface finishing, and the microstructure that ultimately impact the mechanical properties. The influenced factors are related to the deformation characteristic in the roll bite and to surface roughness during rolling process [16]. Therefore, it is necessary for researchers and manufacturers to comprehend the strip shape performance in cold rolling of thin strip.

In a practical work roll crossing system, the upper and lower backup rolls are kept parallel, whereas the upper and lower work rolls are crossed in the opposite direction, which is depicted in Fig. 1 (a). By using this strategy, the roll gap profile adapts itself to allow roll gap to increase as the distance from the roll centre increases. This helps in achieving a large efficiency of shape and profile control [17]. On the other hand, work roll shifting system involves cyclic shifting of the work rolls to prevent uneven wear on rolls and obtain smooth thermal crowns. It improves schedule free rolling and strip profile efficiency [18], as shown in Fig. 1 (b). In the current study, a low carbon steel strip is cold rolled at a speed ratio of 1.1 without lubricant applied to study the effect of work roll cross angle and work roll shifting value on the strip shape and profile and the resulting microstructure.

## II. EXPERIMENTAL METHODS

The experimental setup involved a 4-high Hille 100 rolling mill employed to carry out the cold rolling of low carbon steel strip (0.5 mm x 400 mm) at 80 mm and 100 mm widths. Table I lists the process parameters used in this study. A load cell mounted on the backup roll is used to measure the rolling force and a sensor cell connected to the gearbox and backup roll measures the torque. Various cross angles and roll shifting

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values were obtained by adjusting the roll nick using screw shafts in the upper and lower side blocks to axially slide the upper work roll and lower work roll towards the operator side and drive side, respectively. A speed ratio of 1.1 was selected at 20 and 30 rpm roll speeds under dry condition. The selected cross angles were  $0^\circ$ ,  $0.5^\circ$  and  $1.0^\circ$  and roll shifting values 0, 4.0 mm and 8.0 mm. The resulting microstructure has been studied under Scanning Electron Microscopy (SEM).

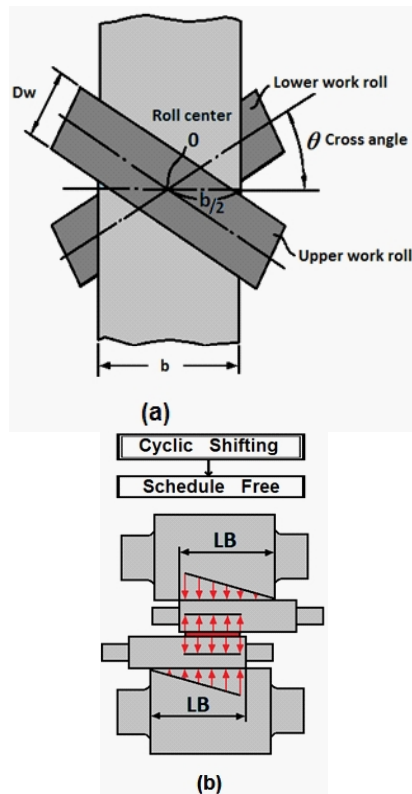


Fig. 1 (a) Work Roll Crossing System, (b) Work Roll Shifting System

### III. RESULTS AND DISCUSSION

#### A. Effect of Work Rolls Cross Angle and Work Roll Shifting Value on Strip Shape and Profile

The thickness profile of exit strip at various cross angles and no shifting under dry condition is shown in Fig. 2. Results indicate that with increasing work rolls cross angle, there is an increase in strip thickness from  $0^\circ$  to  $1^\circ$ . This is also accompanied by a significant improvement in strip profile. This is due to the fact that the roll gap distribution becomes more uniform with increasing work rolls cross angle, therefore, results in an improved strip profile. The resulting microstructures are shown Fig. 3. The estimated grain size ranges from 10 to 20  $\mu\text{m}$ . The increase in work roll cross angle has an effect on the microstructure (grain size of rolled strip), but the change is not significant.

Fig. 4 shows the effect of workroll shifting on strip profile and thickness without work rolls cross angle. There is a slight improvement in strip profile with increasing work roll shifting value for a speed ratio of 1.1. However, this is not as good as compared to the effect of work rolls cross angle. The resulting microstructures are shown in Fig. 5. Similar to what has been observed with increasing work roll cross angle, the work roll shifting values can change the microstructure of rolled strip, but the effect is insignificant.

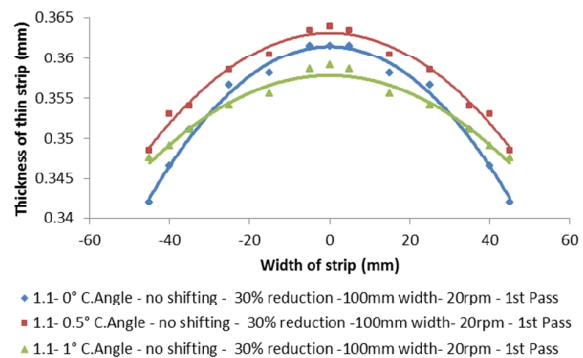


Fig. 2 Effect of work rolls cross angle on strip profile under dry condition

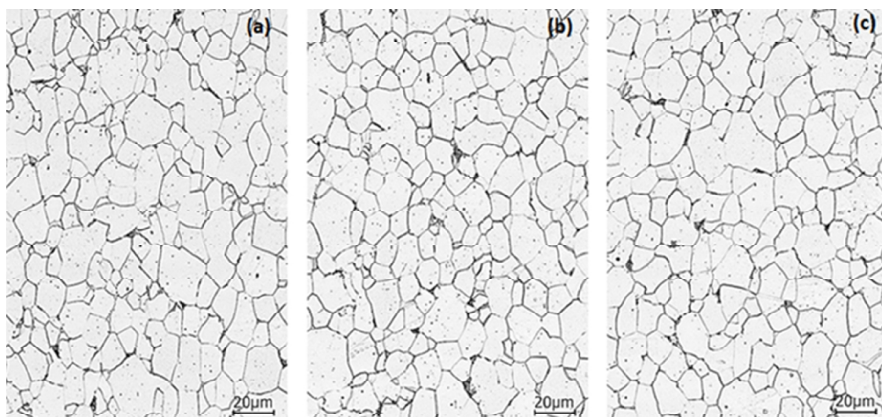


Fig. 3 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 30rpm, 20% reduction and no work roll shifting and work roll cross angles: (a)  $0^\circ$ , (b)  $0.5^\circ$ , and (c)  $1^\circ$

TABLE I  
ROLLING MILL PARAMETERS

Mill System	Work Roll Crossing and Shifting
Upper work roll	63mm diameter, 250mm long
Lower work roll	69mm diameter, 250mm long
Back up roll	228mm diameter, 250mm long
Rolling force	0-1500 KN
Rolling torque	0-13 KN.m

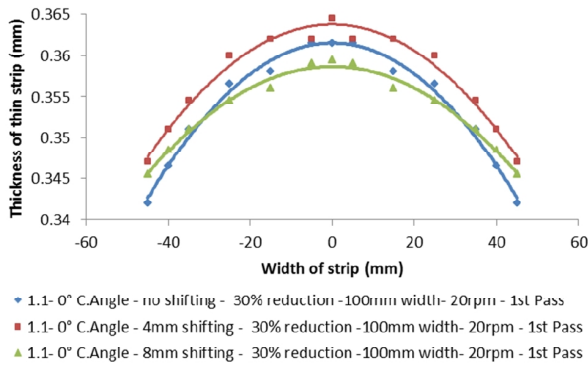


Fig. 4 Effect of work roll shifting on strip profile under dry condition

The cumulative effect of work rolls cross angle and work roll shifting under dry conditions at a speed ratio of 1.1 is shown in Figs. 6 and 7. The strip profile appears to significantly improve with work rolls cross angle at maximum work roll shifting of 8 mm as shown in Fig. 6. Similarly, the strip profile improved with increasing work roll shifting at a maximum work roll cross angle of  $1^\circ$  as seen in Fig. 7. Therefore, increasing work roll shifting value and work rolls cross angle produce the most improved strip profile for the given rolling parameters i.e., a speed ratio of 1.1. This is achieved by uniform roll gap distribution as well as uniform distribution of rolling forces on the strip.

The effects of work roll cross angle and roll shifting value on rolling force are shown in Fig. 8. It can be seen that an increase in work rolls cross angle is effective in reducing the required rolling force under these conditions. This is also true for work roll shifting under the same conditions. The uniform roll gap distribution achieved by increasing work rolls cross angle provides minimum resistance to the transverse flow of the metal, and the uniform distribution of rolling force achieved by higher work roll shifting value are both responsible for reducing the pressure on the rolls.

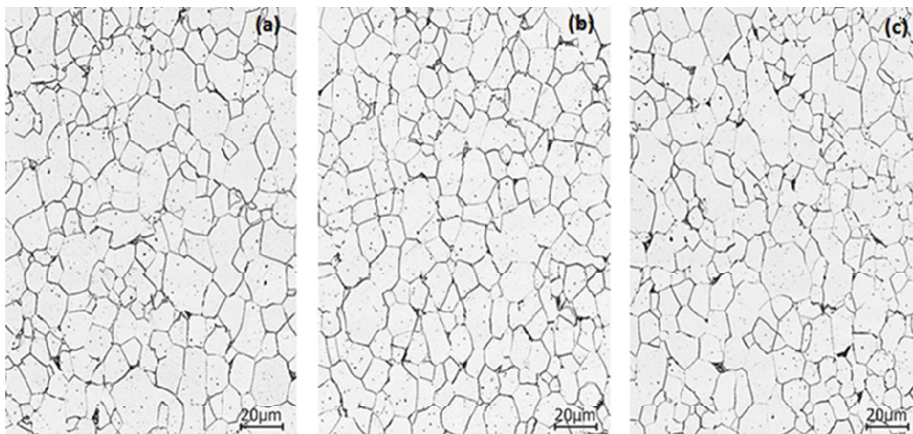


Fig. 5 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 30 rpm, 20 % reduction and no work roll cross angles and roll shifting values: (a) 0, (b) 4 mm, and (c) 8 mm

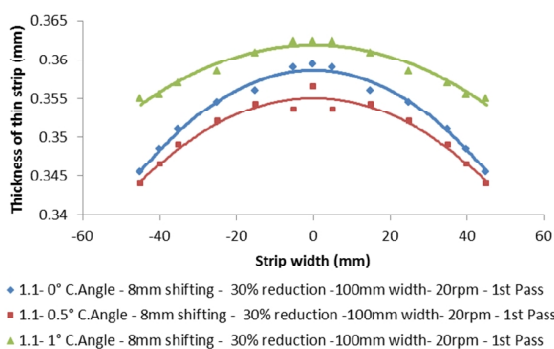


Fig. 6 Combined effect of work roll shifting and work roll cross angle on strip profile

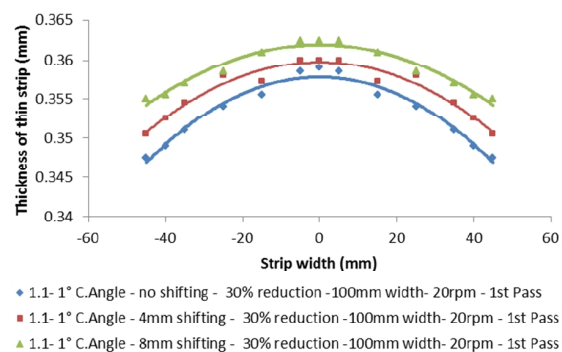


Fig. 7 Combined effect of work roll shifting and work roll cross angle on strip profile

### B. Effect of Rolling Speed on Strip Shape and Profile

Figs. 9 and 10 show the strip profiles obtained using various work roll cross angles and 4mm work roll shifting at roll speeds of 20 rpm (0.0659 m/s) and 30 rpm (0.0986 m/s). At 0.0659m/s, the strip profile tends to improve with an increase of work rolls cross angle from 0° to 1°. Similarly, at 0.0986m/s, the strip profile increased, however, only slightly better than that at 0.0659m/s with an increase of work rolls cross angle. This indicates that an increase in rolling speed is effective in improving the strip profile under the same rolling conditions. The resulting microstructure is shown in Figs. 11 and 12. A change in rolling speed does not seem to affect the microstructure of the rolled strip. The maximum grain size is estimated to be 20  $\mu\text{m}$  in all cases.

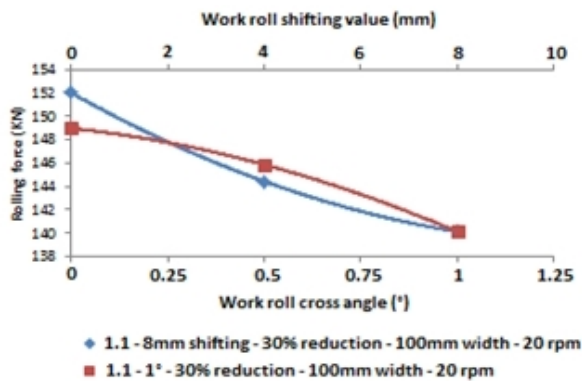


Fig. 8 Effect of work roll cross angle and work roll shifting on rolling force

Fig. 13 shows the effect of work rolls cross angle on the rolling force at different rolling speeds at a specified work roll

shifting value of 4mm. With an increase of work rolls cross angle, the rolling force essentially decreases showing the same trend at 0.0659 and 0.0986 m/s rolling speeds.

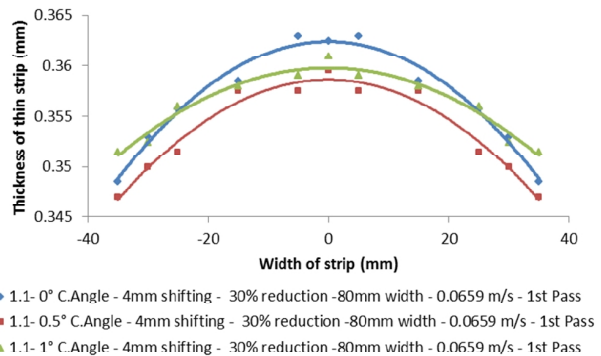


Fig. 9 Strip profile with increasing work rolls cross angle at rolling speed of 0.0659 m/s

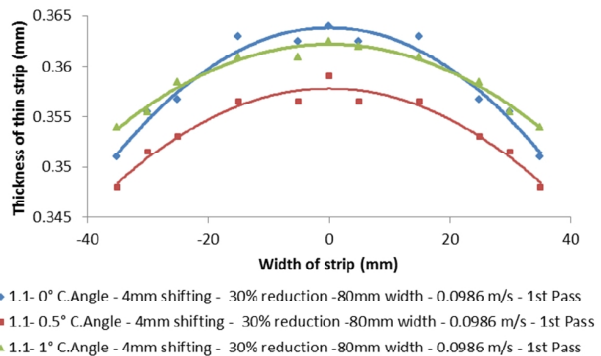


Fig. 10 Strip profile with increasing work rolls cross angle at rolling speed of 0.0986 m/s

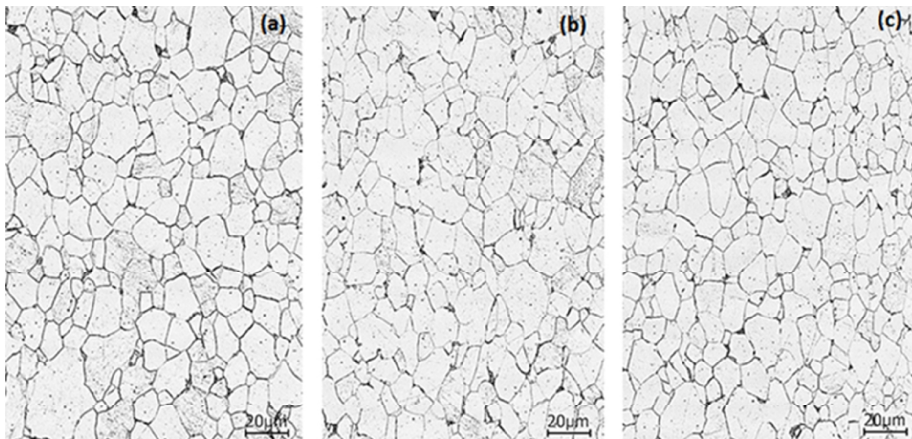


Fig. 11 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 20 rpm (0.0659 m/s), 20 % reduction and 4mm work roll shifting and (a) 0°, (b) 0.5°, and (c) 1° work roll cross angles



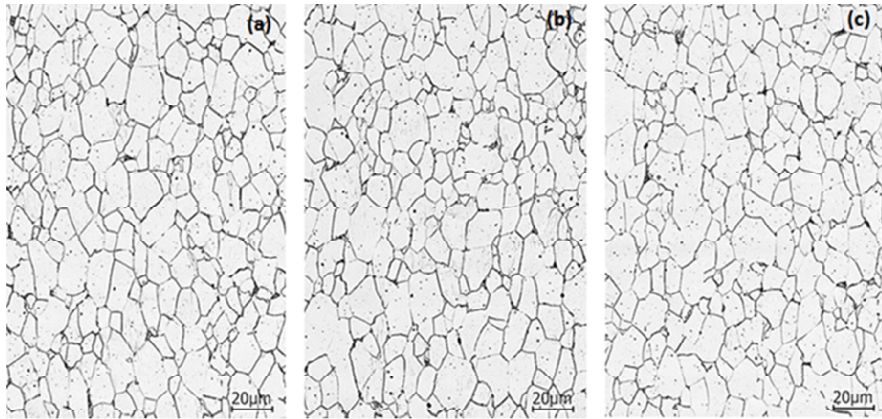


Fig. 12 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 30 rpm (0.0986 m/s), 20 % reduction and 4mm work roll shifting and (a) 0°, (b) 0.5°, and (c) 1° work roll cross angles

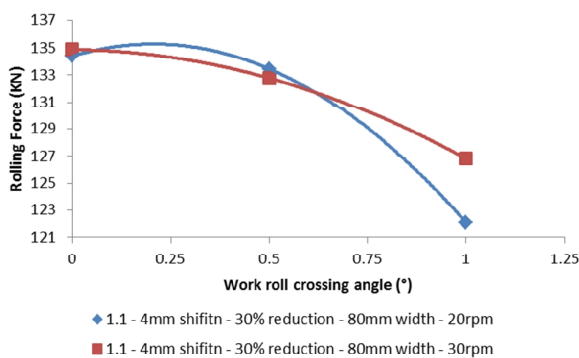


Fig. 13 Effect of work roll cross angle and rolling speed on rolling force

#### C. Effect of Width on Strip Profile

Figs. 14 and 15 show the effect of width strip on strip profile with an increase of work roll cross angle without work roll shifting value at widths of 80 and 100 mm, respectively. For the given strip width, the strip profile tends to improve with an increase of work roll cross angle, however, the effect is insignificant. When the work roll cross angle increases, the rolling force is distributed uniformly throughout the contact area, thus improving the strip profile. There is no significant improvement in strip profile that can be attributed to strip width. The microstructure obtained for strip widths of 80 mm and 100 mm are shown in Figs. 16 and 17. There is no apparent difference in microstructure (grain size and distribution) that can be associated with change in the strip width. However, with an increase of strip width, the required rolling force is significantly higher. This is very well demonstrated in Fig. 18. Therefore, the increase of strip width does not significantly improve the strip profile, however, it increases the required rolling force significantly.

#### D. Effect of Reduction Ratio on Strip Profile

Figs. 19 and 20 show the effect of reduction ratio on strip profile at various work roll cross angles without work roll shifting value. There is a slight improvement in strip profile

with an increase of reduction ratio from 20.0 to 30.0 %. The higher rolling force required due to increase in reduction ratio may provide better flow of material within the roll gap and a uniform distribution is ensured. The resulting microstructures of grain size and distribution at different reductions have little change as shown in Fig. 21 and 22.

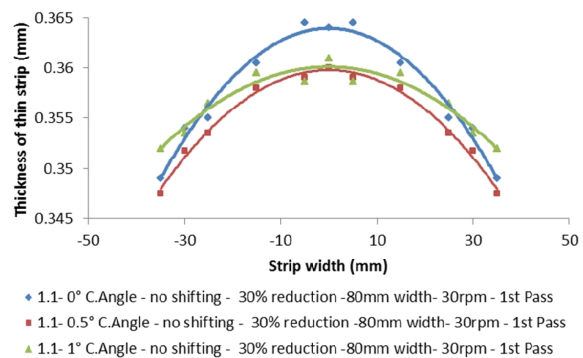


Fig. 14 Strip profile with increasing work roll shifting values for a strip width of 80 mm

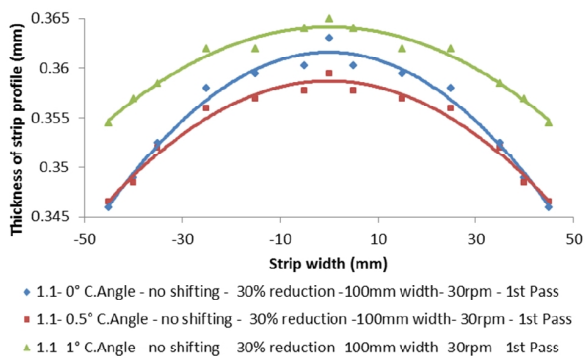


Fig. 15 Strip profile with increasing work roll shifting values for a strip width of 100 mm

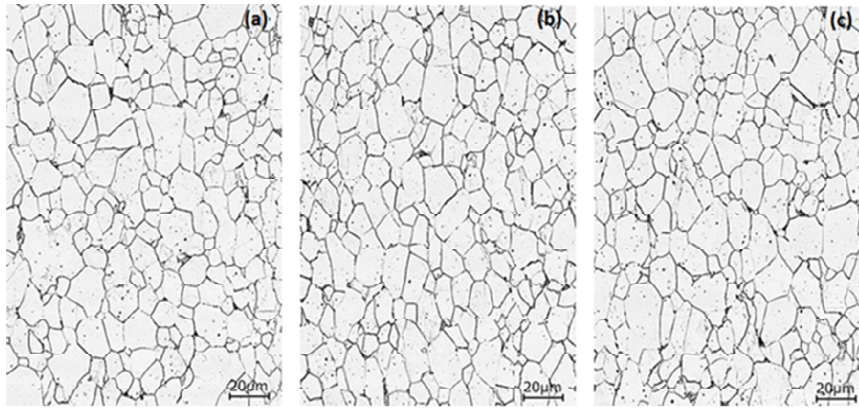


Fig. 16 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 30 rpm, 20 % reduction and 0° work roll cross angle and (a) 0, (b) 4 mm, and (c) 8 mm work roll shifting values

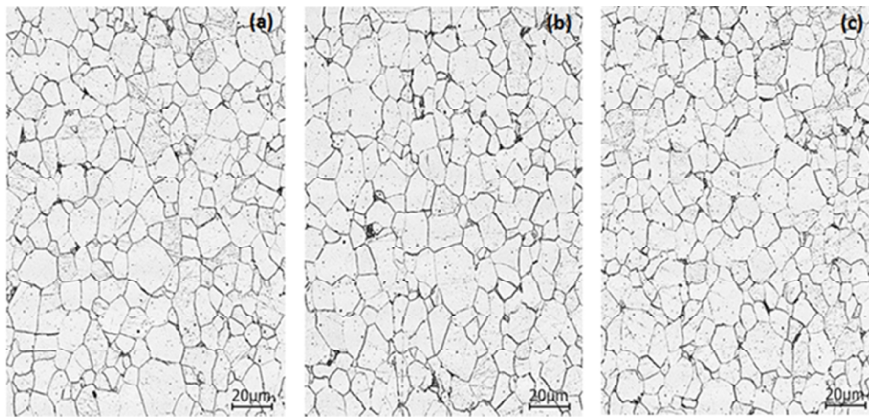


Fig. 17 Cross section microstructure of rolled strip for speed ratio 1.1, 100 mm width, 30 rpm, 20 % reduction and 0° work roll cross angle and (a) 0, (b) 4 mm, and (c) 8 mm work roll shifting values

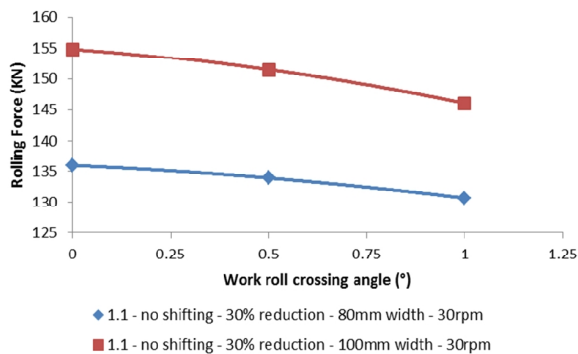


Fig. 18 Effects of work roll cross angle and strip width on rolling forces

#### E. Effect of Work Roll Cross Angle and Work Roll Shifting on Strip Hardness

Figs. 23 and 24 show the effect of work roll cross angle and work roll shifting value on hardness of the exit strip, respectively, for 20% and 30% reduction ratios. The hardness tends to decrease with increase in cross angle as well as work roll shifting value, irrespective of the reduction ratio. However, the decrease in hardness is more prominent at 20% reduction ratio compared to 30%. As observed from Fig. 8, an

increase in cross angle or work roll shifting value causes a significant reduction in required rolling force, resulting in less plastic deformation. Therefore, the hardness of the exit strip drops after the first pass.

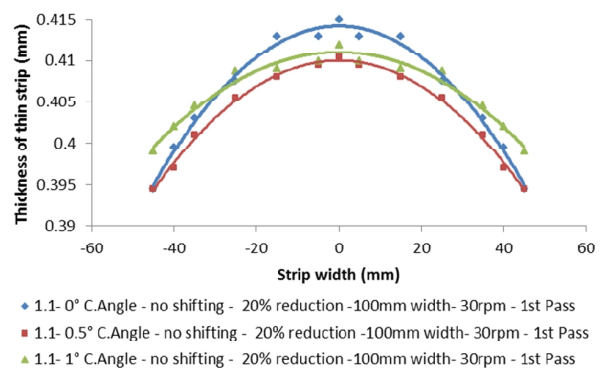


Fig. 19 Strip profile at 20% reduction

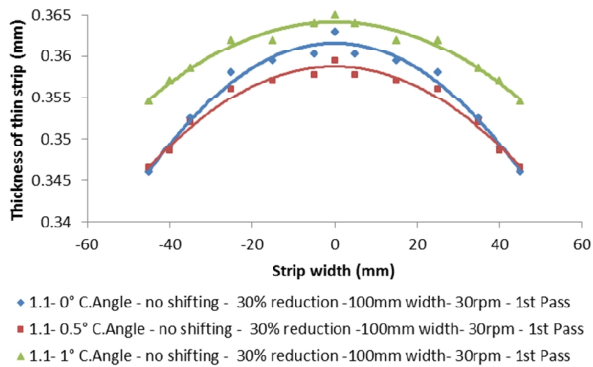


Fig. 20 Strip profile at 30% reduction

#### IV. CONCLUSION

Cold rolling of low carbon steel under dry conditions at a roll speed ratio of 1.1 was studied. The effect of various

rolling parameters was investigated using Hille 100 rolling mill. Results indicate that both the work roll shifting value and work rolls cross angle improve the strip profile, but the efficiency is more significant for change of work rolls cross angle. Moreover, the effect of rolling speed was also not as significant as that of strip width for a given work rolls cross angle and work roll shifting value. An increase of reduction ratio slightly improves the strip profile. There is no significant change in microstructure in terms of grain size and distribution with a change of work roll cross angle, work roll shifting values, rolling speed, and strip width. A slight reduction in strip hardness was observed with increase in either work roll cross angle or work roll shifting value. Overall, the work roll shifting value and work rolls cross angle improve the strip profile under dry conditions at a speed ratio of 1.1. These two parameters have a primary influence on strip profile which can further be improved by optimising other rolling parameters such as rolling speed, strip width and reduction.

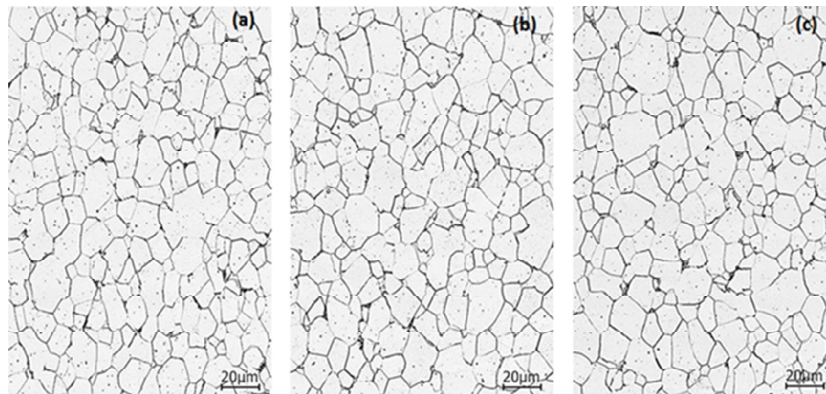


Fig. 21 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 30 rpm, 20 % reduction and 4mm work roll shifting and (a) 0°, (b) 0.5°, and (c) 1° work roll cross angles

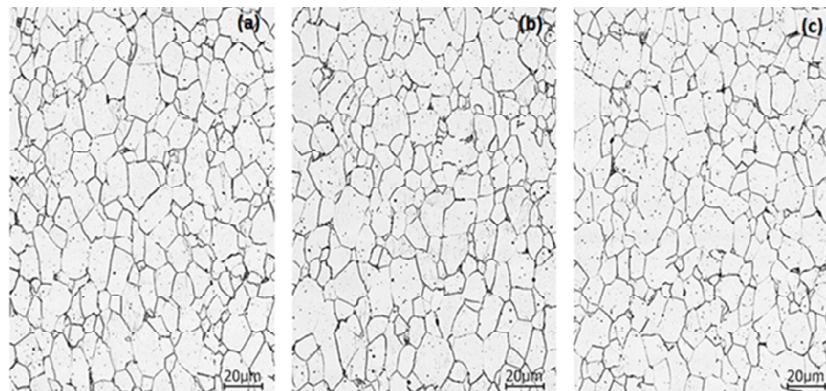


Fig. 22 Cross section microstructure of rolled strip for speed ratio 1.1, 80 mm width, 30 rpm, 30 % reduction and 4mm work roll shifting and (a) 0°, (b) 0.5°, and (c) 1° work roll cross angles



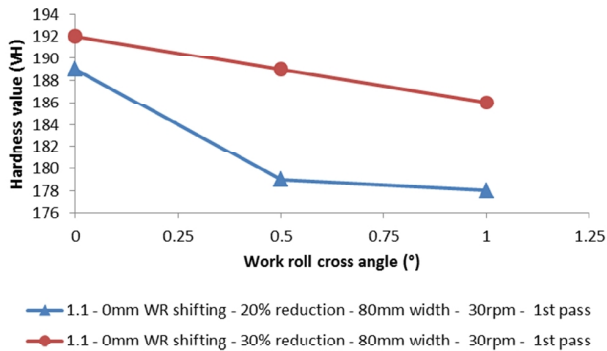


Fig. 23 Effect of work roll cross angle on hardness of strip

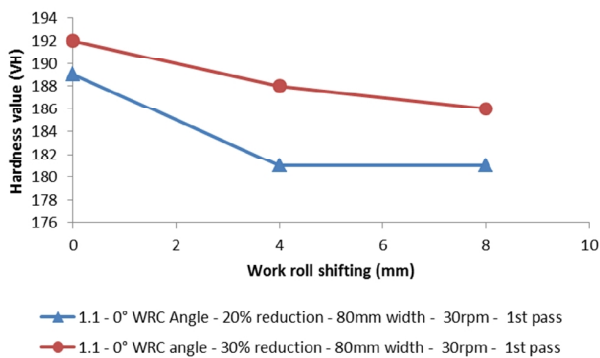


Fig. 24 Effect of work roll shifting on hardness of strip

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