

# Effect of Rolling Parameters on Thin Strip Profile in Cold Rolling

H. B. Tibar, Z. Y. Jiang

**Abstract**—In this study, the influence of rolling process parameters such as the work roll cross angle and work roll shifting value on the strip shape and profile of aluminum have been investigated under dry conditions at a speed ratio of 1.3 using Hille 100 experimental mill. The strip profile was found to improve significantly with increase in work roll cross angle from 0° to 1°, with an associated decrease in rolling force. The effect of roll shifting (from 0 to 8mm) was not as significant as the roll cross angle. However, an increase in work roll shifting value achieved a similar decrease in rolling force as that of work roll cross angle. The effect of work roll shifting was also found to be maximum at an optimum roll speed of 0.0986 m/s for the desired thickness. Of all these parameters, the most significant effect of the strip shape profile was observed with variation of work roll cross angle. However, the rolling force can be significantly reduced by either increasing the the work roll cross angle or work roll shifting.

**Keywords**—Rolling speed ratio, strip shape, work roll cross angle, work roll shifting.

## I. INTRODUCTION

COLD rolling of thin strip is essentially reduction and change in thickness of a strip by compressive pressure exerted by rotating rolls at room temperature [1]. The result of such a process is to provide significant material properties, i.e. to improve strength and accomplish fine thickness distribution. This thin rolled strip has found wide applications in electronics and instrument industries [2]. Shape and profile of thin strip are one of the significant characteristics that have essential influences both on the rolling process and on the quality of the products [3], [4]. Although these geometric characteristics of the strip have been comprehensively studied by [5] and [6], the market requirements for higher quality and increasingly thinner strip have recently motivated a growth of efforts for the development of new technology for predicting and controlling thinner strip shape and profile. In the case of strip profile, depending on mill parameters and the effect of profile control mechanism, practically, it tends to take a convex parabolic form due to the fact that distribution of rolling force is normally greater near to the strip edges [7]. This also causes a non-uniform roll gap distribution which can increase in rolling force. Continuous variable crown (CVC) and pair cross (PC) mills aim to improve the strip shape and flatness, due to the ability to shift the work rolls, crossing and bending rolls respectively. These 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 strip shape, profile and flatness, no longer presents a significant challenge for rolling mill operation for relatively thick products [8]. It has often been found in some cold rolling mills that the edges of the work rolls touch and deform when a strip is rolled [9]. When the work rolls contact beyond the edges of the strip, it will change the distribution of the roll pressure, the deformation of work rolls, friction at the interface of the rolls and the strip and work roll wear [10], [11]. It has been shown that in combination with asymmetric rolling, an increase in work roll speed ratio results in a better strip profile and an increase in the ratio of work roll diameters, a significant reduction in the length of roll contact can be achieved [9]. Moreover, various rolling mill setups have been implemented in order to overcome the roll edge contact such as pair cross mills, continuously variable crown and variable crown roll, as suggested by [12]. Various rolling parameters are influenced by the magnitude of friction and the type and amount of lubricant used. These include rolling force, rolling speed, pressure distribution, reduction, surface quality, strip shape and profile [13], [16]. The dimensional accuracy and strip surface quality are also highly dependent on friction [14]. It has been demonstrated the coefficient of friction along the strip width during rolling is not constant, however, by increasing the edge friction along the strip width, the shape and profile has shown improvement [14]. The quality of the strip shape and profile has been shown to improve by increasing forward slip zone and reducing the backward slip zone [15]. Work roll cross angle and shifting have shown to improve the strip shape and profile. However, it is also possible that strip shape and profile can further be improved by using work roll cross angle and work roll shifting under asymmetric rolling performed at a certain speed ratio. Key process parameters such as work roll cross angle and work roll shifting can aid in ensuring a uniform roll gap distribution as well as even distribution of rolling force across the roll surface. Therefore, the purpose of this paper is to investigate the effect of work roll cross angle and work roll shifting on the exit strip profile and the rolling force. Other parameters effects on strip shape such as rolling speed ratio and strip width are also discussed.

## II. EXPERIMENTAL METHODS

A 4-high Hille 100 rolling mill was employed to carry out the non-lubricated (dry) cold rolling of 0.5mm × 400mm aluminum strip at 80 and 100mm widths. The rolling mill parameters are listed in Table I.

Rolling force was measured through a load cell mounted on the backup roll, whereas, the torque was measured by a sensor

H. B. Tibar is with the Department of Mechanical Engineering, University of Wollongong, Wollongong, Australia (e-mail: hbt796@uowmail.edu.au).

cell connected to the gearbox and backup roll. The roll nick was adjusted to obtain the various roll cross angles and the roll shifting value was obtained by using screw shafts in the upper and lower slide blocks to axially slide the upper work roll towards the operator side and lower slide block towards the drive side. Cold rolling was performed under dry condition (without lubrication) at a speed ratio of 1.3, roll speeds of 20 and 30rpm cross angle of 0, 0.5 and 1° and roll shifting values of 0, 4, and 8mm.

TABLE I  
ROLLING MILL PARAMETERS

Mill System	Work Roll Crossing and Shifting
Upper work roll	63mm diameter, 250mm long
Lower work roll	82mm diameter, 250mm long
Back up roll	228mm diameter, 250mm long
Rolling force	0-1500 KN
Rolling torque	0-13 KN.m

### III. RESULTS AND DISCUSSION

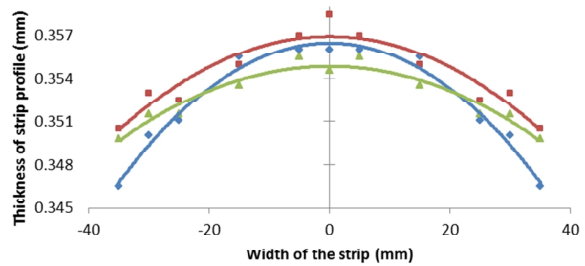
#### A. Effect of Work Rolls Cross Angle

The effect of work roll cross angle on the thickness profile of exit strip is shown in Fig. 1 without any work roll shifting involved. The strip thickness decreases significantly at the edges at no work rolls cross angle resulting in a strip crown. As the cross angle increases to 0.5°, there is reduction in the strip crown and the thickness resulting in an improved strip profile. The exit strip profile further improves at 1° work rolls cross angle with a smaller strip thickness, making the strip flat. When the work rolls cross angle increases, the roll gap distribution can be uniformly maintained, which results in a flatter strip profile. In order to illustrate this more clearly, the metric of crown and edge can be used to estimate the strip profile. The strip crown  $C_5$  is defined as the variation value between the thickness at the strip centre and thickness at a 5mm distance from the strip edge, and the edge drop  $C_e$  is defined as the variation value between the thickness at the 35mm distance from strip edge and the thickness at 10mm distance from the strip edge. Fig. 2 shows the effect of work roll cross angle on  $C_5$  and  $C_e$ . Both  $C_5$  and  $C_e$  decreased with increasing cross angle. This is attributed to the fact that by controlling the crossing angle, the transverse flow of the material can be controlled. The rolling force measured at various work rolls cross angles are shown in Fig. 3. There is a significant decrease in rolling force (about 9 kN at 30% reduction) as the work rolls cross angle changes from 0° to 1°. This is attributed to the uniform roll gap distribution achieved by work rolls cross angle, which allows minimum resistance to the transverse flow of the metal, therefore reducing the force on the rolls.

#### B. Effect of Work Roll Shifting

The effect of workroll shifting on strip profile and thickness under dry condition is shown in Fig. 4. Rolling was carried without work rolls cross angle to investigate only the effect of work roll shifting on the strip shape. There is a marked decrease in thickness of the strip with increasing shifting values (from 0 to 8mm), however, there is only a slight

improvement in the strip profile. Due to relative shifting between the upper and lower rolls, there is a uniform distribution of rolling forces, essentially decreasing the rolling force required to achieve the desired thickness. This is evident from the measurement of rolling force as shown in Fig. 5. The rolling force significantly dropped from 49N for no work roll shifting to 43.5kN at 8mm work roll shifting and 30% reduction. The strip crown and edge drop also decreased with increasing roll shifting values, as shown in Fig. 6.



◆ 1.3- 0° C.Angle- no shifting - 30% reduction - 80mm width- 20rpm - 1st Pass  
■ 1.3- 0.5° C.Angle- no shifting - 30% reduction - 80mm width- 20rpm - 1st Pass  
▲ 1.3- 1° C.Angle- no shifting - 30% reduction - 80mm width- 20rpm - 1st Pass

Fig. 1 Effect of work roll cross angle on strip profile under dry condition

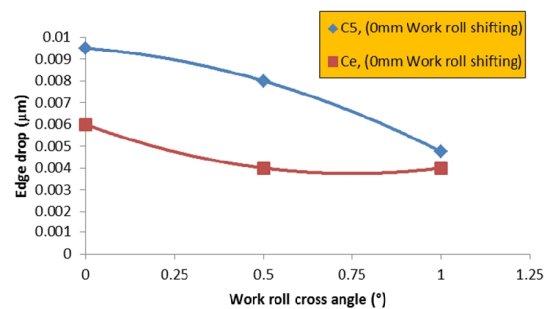


Fig. 2 Effect of work roll cross angle on the strip crown and edge drop

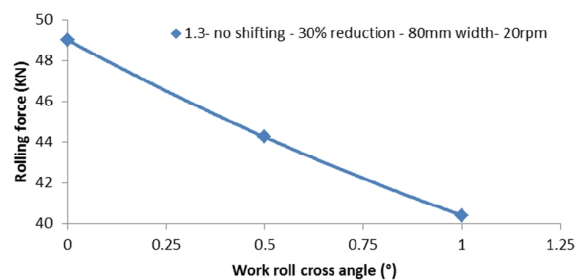


Fig. 3 Effect of work rolls cross angle on rolling force under dry condition

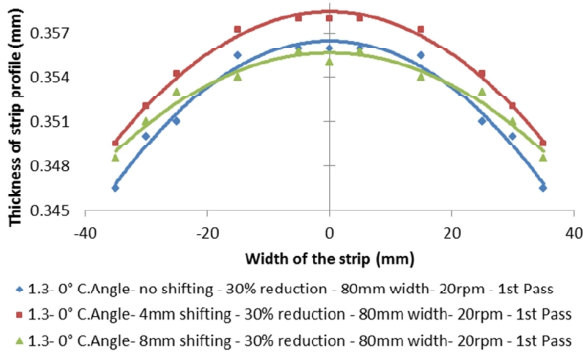


Fig. 4 Effect of work roll shifting on strip profile under dry condition

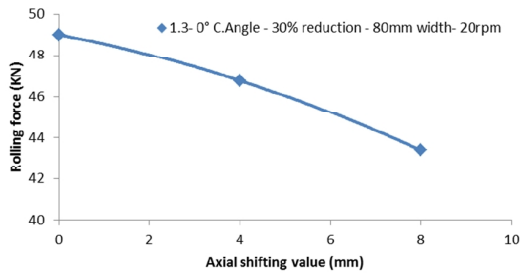


Fig. 5 Effect of work roll shifting on rolling force under dry condition

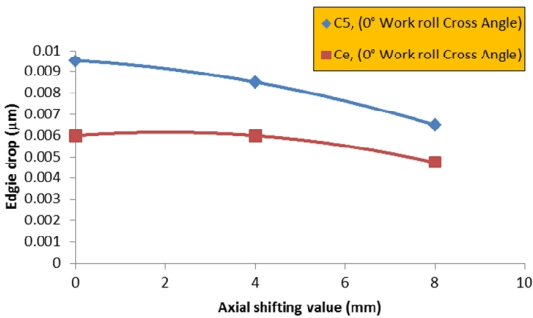


Fig. 6 Effect of cross angle on the strip crown and edge drop

C. Combined Effect of Cross Angle and Work Roll Shifting

As indicated from Figs. 1 and 4, increase in work rolls cross angle and work roll shifting value improves the thickness distribution and profile of the exit strip, with more significant effect in the first case. The combined effect of work roll cross angle and work roll shift value is shown in Fig. 7. An increased work rolls cross angle combined with an increased work roll shifting produces almost a flat strip profile. This is attributed to the uniform roll gap distribution for the transverse metal flow as well as uniform distribution of roll forces on the strip, resulting in an improved (almost flat) strip profile. However, in terms of rolling force, either increasing the work roll shifting to 8mm or work rolls cross angle to 1° yields the same result, as shown in Fig. 8.

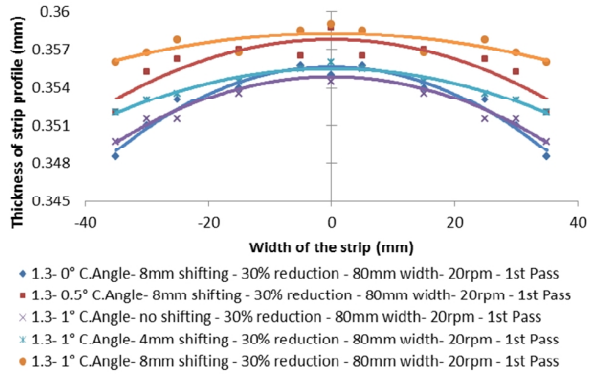


Fig. 7 Combined effect of work roll cross angle and work roll shifting on strip profile under dry condition

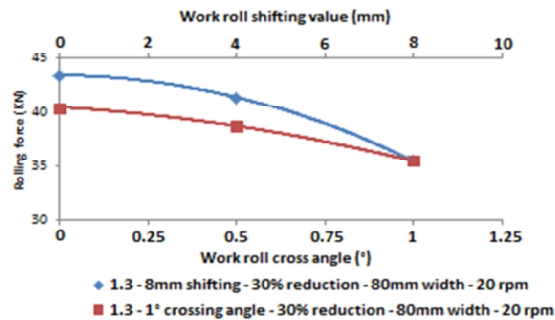


Fig. 8 Combined effect cross angle and work roll shifting on rolling force under dry condition

D. Effect of Rolling Speed

The strip profiles obtained using various work roll shifting at roll speeds of 0.0659 m/s (20 rpm) and 0.0986 m/s (30 rpm) are shown in Figs. 9 and 10, respectively. At 0.0659 m/s, there is no significant improvement (only slight improve with angle 1°) in the strip profile with increasing work roll shifting, however, there is a significant decrease in thickness. A similar trend is observed at 0.0986 m/s in terms of strip profile (no significant change), however, the lowest thickness is achieved at 4mm shifting value, rather than 8mm shifting value. This indicates that there is an optimum rolling speed at which the effect of work roll shifting is the maximum to achieve desired thickness, however, without clear improvement in strip profile. Even the rolling force measured for an 8mm shift is lower at 0.0659 m/s, as shown in Fig. 11. However, a slight increase in both strip crown and edge drop are observed with increase in rolling speed, as shown in Fig. 12.

E. Effect of Strip Width

Figs. 13 and 14 show the effect of strip width on strip profile with increasing work rolls cross angle and 4mm shifting at widths 80 and 100mm, respectively. The strip profile tends to improve with increasing in work rolls cross angle for a specific width. However, there is significant improvement in strip profile for smaller width (80mm) compared to the larger width (100mm). An increased width causes non uniform roll gap distribution leading to strip

As the strip width decreases, the material is distributed more evenly with the roll gap making the strip profile better. This also indicates that the overall force required to plastically flow the material with the roll gap is much less for the smaller width, as demonstrated in Fig. 15. The strip crowns  $C_5$  for 80 and 100mm widths are compared at various cross angles in Fig. 16. It is clear that with an increase in strip width, the strip crown also increased, regardless of work roll cross angle.

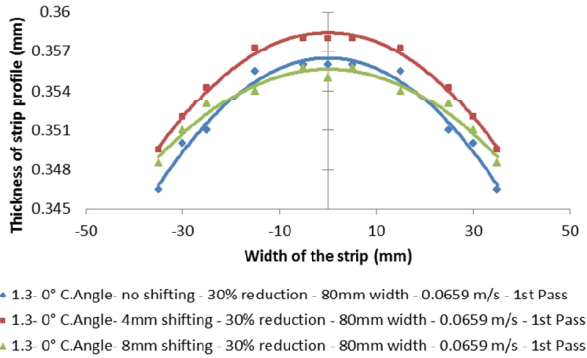


Fig. 9 Strip profile with increasing shift at rolling speed of 0.0659 m/s

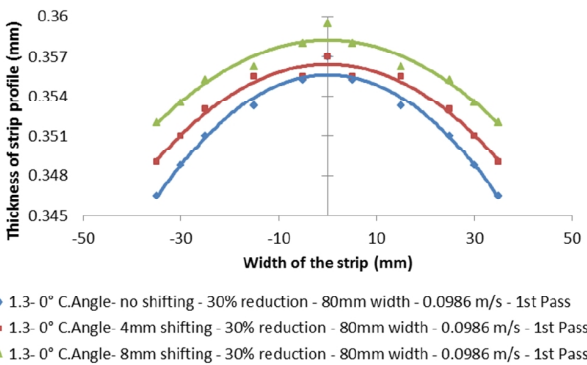


Fig. 10 Strip profile with increasing shift at rolling speed of 0.0986 m/s

Figs. 17 and 18 show a comparison of speed ratios 1.1 and 1.3 at work roll cross angles of 0 and 0.5°, respectively. Without work roll cross angle, the strip profile and its thickness, both improve with an increase in speed ratio from 1.1 to 1.3. At a work roll cross angle of 0.5°, the strip profile appears to be better than at 0°, and shows a significant improvement with an increase in speed ratio. The strip profile seems to be significantly improved by increasing speed ratio and only gets better with increasing work roll cross angle.

IV. CONCLUSION

The exit strip profile of thin strip in cold rolling process of aluminum under dry condition was studied. The effect of work rolls cross angle, work rolls shifting and rolling speed were investigated using the Hille 100 rolling mill. The following conclusions can be drawn:

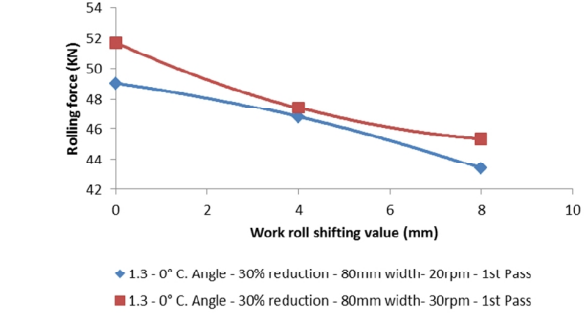


Fig. 11 Effect of rolling speed on rolling force under dry condition

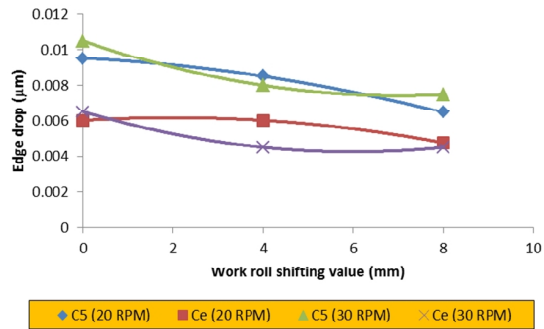


Fig. 12 Effect of rolling speed on strip crown and edge drop

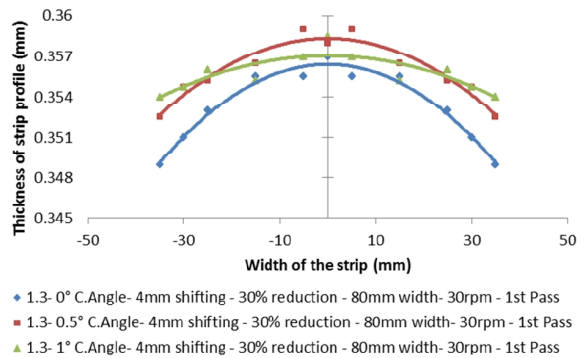
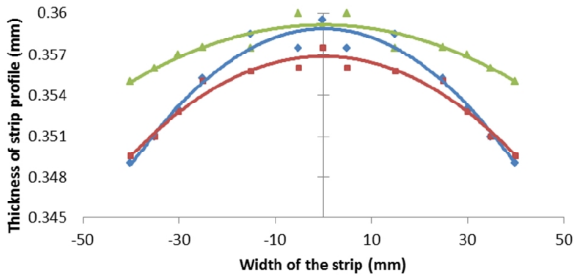


Fig. 13 Effect of work roll cross angle on strip profile under dry condition of 80mm strip width

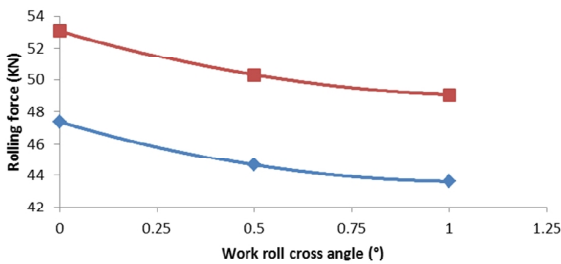
- The strip profile improved significantly with an increase of work rolls cross angle, and a marked reduction in rolling force as well.
- The effect of work rolls shifting was not as significant as the work rolls cross angle. However, an increase in work roll shifting achieved the same reduction in rolling force as that of work rolls cross angle.
- There is an optimum rolling speed at which the effect of work roll shifting is the maximum in achieving the desired thickness, however, no significant improvement in strip profile was observed.
- The strip profile improved with an increasing of work rolls cross angle for a specific strip width. However, there is significant improvement in strip profile with relatively smaller strip width.

- The most significant effect on strip profile was observed with an increase of work rolls cross angle. The rolling force can be significantly reduced either by increasing work rolls cross angle or increasing work roll shifting value. A comparison of strip profile at different speed ratios shows that the strip profile gets better with an increase of speed ratios.



◆ 1.3- 0° C.Angle- 4mm shifting - 30% reduction - 100mm width- 30rpm - 1st Pass  
 ■ 1.3- 0.5° C.Angle- 4mm shifting - 30% reduction - 100mm width- 30rpm - 1st Pass  
 ▲ 1.3- 1° C.Angle- 4mm shifting - 30% reduction - 100mm width- 30rpm - 1st Pass

Fig. 14 Effect of work roll cross angle on strip profile under dry condition of 100mm strip width



◆ 1.3- 4mm shifting - 30% reduction - 80mm width- 30rpm - 1st pass  
 ■ 1.3- 4mm shifting - 30% reduction - 100mm width- 30rpm - 1st pass

Fig. 15 Effect of strip width on rolling force under dry condition

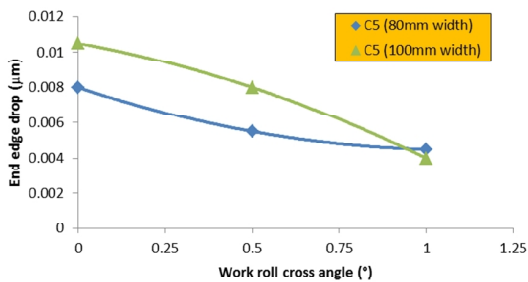


Fig. 16 Effect of strip width on strip crown and edge drop

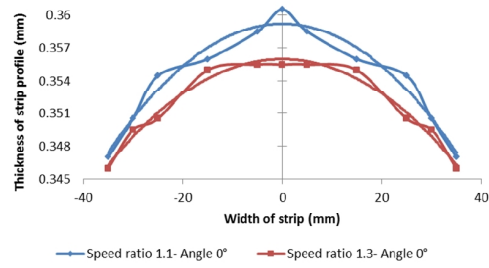


Fig. 17 Effect of speed ratio on strip profile at 0° work roll cross angle

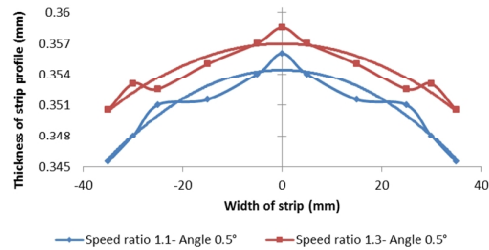


Fig. 18 Effect of speed ratio on strip profile at 0.5° work roll cross angle

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**H. B. Tibar** obtained his Master's degree from University of Wollongong, Australia. He is currently doing the second year of his PhD in the area of cold rolling of thin strips. His areas of research interest includes but not limited to rolling, mechanical properties investigation, data analysis and material characterization.

**Z. Y. Jiang** obtained his PhD from Northeastern University in 1996, and was promoted full professor at Northeastern University in 1998 and at University of Wollongong in 2010. His research interest includes advanced micromanufacturing, rolling theory and technology, tribology, contact mechanics and computational mechanics, numerical simulation of metal manufacturing and artificial intelligent applications.

**A. Aljabri** obtained his Master's degree from the University of Wollongong (UOW), Australia. He is currently conducting his Phd study in strip shape control in cold rolling of thin strip at UOW.