

Investigation of Notch Shear Cutting for JIS SCM420 Steel Wire Rod

P Natpukkana^{1,*}, S Pakinsee¹, S Boonmapat¹, P Mitsomwang¹, R Borrisutthekul¹, R Panuwannakorn² and L Khoa-phong²

¹School of Metallurgical Engineering, Suranaree University of Technology, 111 University avenue, Muang, Nakhon Ratchasima, 30000, Thailand

²Thai Motor Chain Co., Ltd., 7/138 M.4, Amata City Industrial Estate, Pluakdaeng, Rayong, 21140, Thailand

*pusit@sut.ac.th

Abstract. This paper aims to study the notch shear cutting of JIS SCM420 steel wire rod. In the notch shear cutting experiment, the wire rod specimens were initially notched on the surfaces using a sharp insert installed at a lathe turning machine. Then, the specimens were cut off using the punch/die shearing tool. After the shear cutting, the sheared edge features of the wire rod were investigated and compared with the results obtained from the conventional shear cutting. In addition, the geometry of the notch, the notch depth, was varied ranging from approximately 333 to 537 μm and studied. The experimental results revealed that the cutting load resistance significantly decreased with the notch shear cutting technique. The roll over and the size of the burr zones also decreased, compared to the conventional shear cutting. This technique also improved the quality of the sheared edge in term of the roundness of the wire rod. Concerning the notch depth, it was a primary factor affecting the cutting results, especially the cutting load resistance and the occurrence of the long burr protruded from the surface of the wire rod. The improvement of the sheared edge quality by the notch shear cutting seemed to be caused by the suppression of the plastic deformation of the wire rod during shearing.

1. Introduction

Metal wire rods, especially steel wire rods, are important raw materials for large numbers manufacturing such as the production of roller chains, needle roller bearings, screws, bolts, etc. The steel wire rods are typically available in the form of long products (wire rod coils) and subjected to the punch/die shear cutting in order to cut off into designed length for their subsequent manufacturing. Normally, the edge of sheared product consists of different four zones, i.e. the roll over, the burnish, the angular fracture and the burr zones [1]. Among these, the features of the roll over and the burr zones which are resulted by the plastic deformation of the sheared rod during shearing seem to strongly affect the applications of the sheared products. For example, in the assembly of the roller chain using the steel sheared pin, when a large burr forms at the sheared edge of the pin, it cannot be assembled with the link plate of the chain.

There are researchers concentrating their studies on the features of the roll over and the burr zones with respect to the mechanical conditions of the shear cutting process. G Fang and N Hatanaga studied the effects of punch/die clearance on the sheared edge features of aluminum alloy and mild steel sheets. They showed that the roll over and the burr zones tended to be larger when increasing the



punch/die clearance [2-3]. Z Tekiner studied the effects of the punch/die clearance on the cutting results of the aluminum alloy sheet. They revealed that the clearance affected the roll over, the burnish and burr zones. Namely, when the clearance increased, the roll over depth and burr length increased, while the burnish zone decreased [4]. T Kwak applied a finite element analysis to study the effects of the die clearance on the shear cutting results. From the simulation, the width and the depth of the roll over increased with the die clearance, while the burnish zone decreased with the shearing parameter [5].

In order to improve the sheared edge quality of sheet metals, especially to suppress the formation of the burr zone, the shear cutting of pre-notched sheets was carried out by some researchers. M Krininger studied the notch shear cutting of an aluminum alloy sheet. In this study, the notches were prepared on the aluminum alloy surfaces before subjecting it to the punch/die shearing tool. From the results, the cutting load resistance and the size of the burr zone decreased when increasing the depth of the notch [6]. P Sachnik carried out the notch shear cutting of DC04 steel, 1.4301 steel, AA6014 aluminum alloy and CuSn6 alloy sheets and investigated. The experimental and simulation results revealed that the possibility of the burr formation and the burr geometries depended on the mechanical properties of the sheared sheets, the position of the notch tip and the depth of the notch [7].

From the above literature, the notch shear cutting seems to be an effective method for improving the quality of the sheared edge in term of the burr reduction. However, those research results are based on the metal sheet shearing (two-dimensional deformation) and not sufficient for understanding the features of the sheared edge of the wire rods which are deformed in three-dimension during the shear cutting. In this work, the authors aim to investigate the notch shear cutting of a wire rod. The JIS SCM420 steel wire rod was chosen as the investigation material. The features of the sheared edge were examined and compared with those obtained by the conventional shear cutting. In addition, the effects of the notch depth on the notch shear cutting results were studied.

2. Material and experimental conditions

For the shear cutting experiment, a JIS SCM420 steel wire rod which had a diameter of 4.48 mm was chosen. The mechanical properties of the JIS SCM420 steel are reported in Table 1. The shear cutting specimens were prepared to have a length of 31 mm. To investigate the notch shear cutting of the wire rod, the specimens were notched in the circumference with a sharp insert installed at a lathe turning machine.

Table 1. Mechanical properties of JIS SCM420 steel rod [8].

Properties	Metric
Young's modulus (GPa)	210
Tensile strength (MPa)	790
Yield strength (MPa)	380
Poisson's ratio	0.3

Figure 1 represents the punch/die shearing tool and the specimen configuration for the shear cutting experiment. During cutting, the punch was moved downward by the pushing head of an universal testing machine. The load cell (Capacity: ± 100 kN) was installed at the machine for measuring the cutting load resistance. The main cutting tools, the punch and the die were made of a high-speed tool steel which had a hardness of approximately 62 HRC. The cutting tools were hold in the die jacket made from a plain carbon steel. The clearance between the edges of the punch and the die was adjusted to be 40 μm . The movement velocity of the punch (the cutting speed) was fixed as 5 $\text{mm}\cdot\text{min}^{-1}$.

The geometry of the notch, its depth, was varied ranging from 333 to 537 μm . The variation of the notch depth was obtained by altering the feed distance of the insert into the surface of the wire rod in the notching step. Apart from the notch shear cutting, the conventional shear cutting of the wire rods

was also carried out in order to examine the differences between the two cutting techniques. To do the conventional shear cutting, the wire rod specimen without notch was subjected to the same punch/die shearing tool. Other shearing parameters were the same as those explained above. The shear cutting was performed five times for each condition. After cutting, the features of the sheared edge were investigated using an optical microscope and an image analysis software, VW-9000. In addition, to evaluate the change in the sectional profile of the wire rod due to the shear cutting, the roundness at the sheared edge of the wire rod was measured.

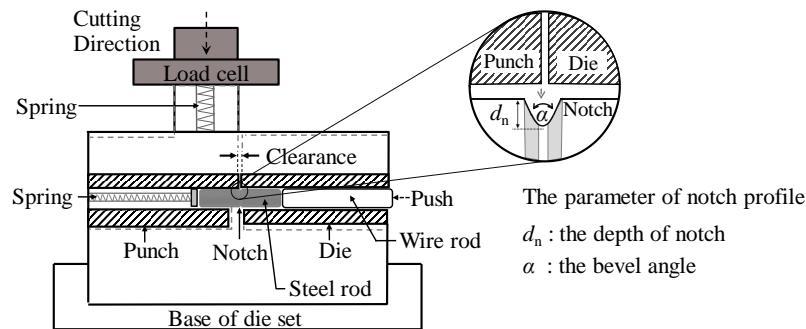


Figure 1. Experimental setup of notch shear cutting.

3. Cutting results of JIS SCM420 wire rod

3.1 Notch punch/die shear cutting versus conventional shear cutting

To investigate the notch shear cutting of the steel wire rod, the notch, which had a depth d_n and a bevel angle α of 426 μm and 50° was made on the surface of the wire rod before shearing.

3.1.1 Cutting load resistance of wire rod Figure 2 shows the relationship between the cutting load resistance (f) and the indentation depth of the punch (d) for the notch and the conventional shear cutting. Here, the indentation depth d was defined to be zero, when the surface of the punch touched the upper surface of the specimen during the shear cutting. As seen in this figure, the cutting load resistance at the shallow indentation depth, $0 < d < 0.4$, was similar for the two cutting cases. Seeing the peak load resistance, the maximum load resistance (f_{Max}) in the case of the notch shear cutting was significantly lower than that of the conventional shear cutting case. However, the peak position (d_{Peak}) of the cutting load resistance was similar for both cutting cases. Considering the position where the wire rod separated ($d_{\text{Sep.}}$), it was seen that the separation position was earlier when applying the notch shear cutting technique. In addition, from the characteristic of the cutting load, the drop of the load resistance from the peak point for the two shearing cases was fairly similar. This seemed to indicate that the notch on the wire rod surface did not completely change the fracture behavior of the sheared wire rod. However, the notch resulted in the reduction of separation resistance, remarkably.

3.1.2 Sheared edge features of wire rod Figure 3 shows the side-view images of the sheared rods from the conventional and the notch shear cutting. As seen in this figure, the large roll over zone was observed in the case of the conventional shear cutting, while this zone did not form in the case of the notch shear cutting. Typically, the roll over is caused by the plastic deformation of the rod before its separation. Since the notch made on the wire rod surface reduced the separation resistance of the rod, the plastic deformation during shearing reduced. The reduction of the plastic deformation seemed to remarkably suppress the formation of the roll over.

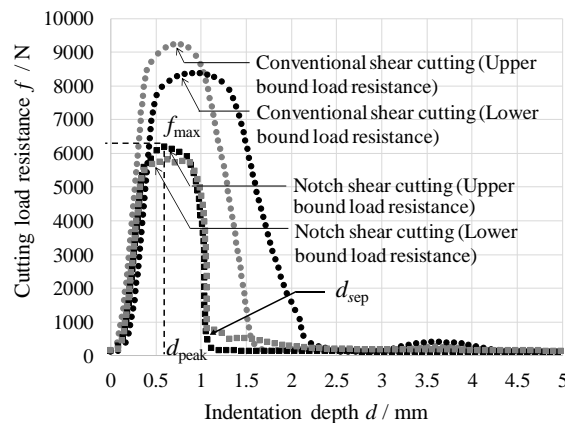


Figure 2. Load resistance of steel rod for conventional and notch shear cutting.

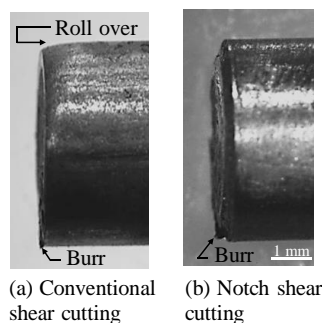


Figure 3. Side-view images of sheared wire rods cut by conventional and notch shear cutting.

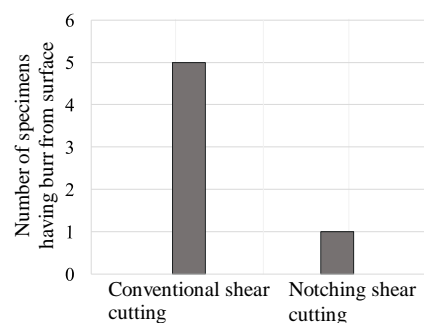


Figure 4. Number of specimens having burr protruded from surface of wire rod for conventional and notch shear cutting.

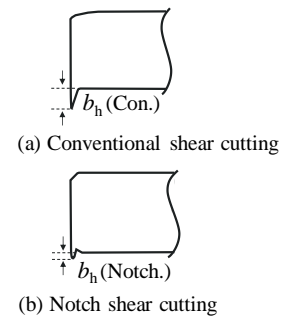


Figure 5. Definition of $b_{h(Con.)}$ and $b_{h(Notch.)}$.

Apart from the difference of the roll over zone, seeing the burr at the sheared edge, it was found that, in the case of the conventional shear cutting, the long burr protruded from the surface of the wire rod formed, as seen in figure 3 (a). In the case of the notch shear cutting, as seen in figure 3 (b), the burr at the sheared edge seemed to still generate, but it was shorter than the depth of the notch and did not protrude from the surface of the wire rod.

Next, the authors furthermore investigated the occurrence of the burr protruded from the surface of the wire rod. Figure 4 shows the number of the specimens having the burr protruded from the surface of the wire rod for the conventional and the notch shear cutting. As shown in this figure, the protruded burr was observed in all the wire rods sheared with the conventional shear cutting, while it was observed at only one wire rod cut using the notch shear cutting technique.

The geometry of the burr was furthermore investigated. Here, the length of the burr for both shear cutting cases ($b_{h(Con.)}$ and $b_{h(Notch.)}$, as defined in figure 5) were measured. In the case of the conventional shear cutting, the length of the burr protruded from the surface of the wire rod $b_{h(Con.)}$ was measured as $89.73 \mu\text{m}$ ($160.05 \sim 63.22 \mu\text{m}$), while the length of the protruded burr $b_{h(Notch.)}$ for the case of the notch shear cutting was significantly shorter. Namely, it was approximately $26.70 \mu\text{m}$.

From figures 3 and 4, the notch shear cutting technique was confirmed to be an effective technique for improving the quality of the sheared edge, especially in terms of the reductions of the roll over size, the possibility of the long burr formation, and the length of the burr protruded from the surface of the sheared wire rod.

3.1.3 Roundness of sheared wire rod The roundness at the sheared zone is an important property of the sheared wire rod. It is always considered, when the sheared rods are assembled with small holes or other components. Therefore, in this study, the authors investigated the roundness of the sheared wire

rod when applying the notch shear cutting technique. To evaluate the roundness of the sheared edge, the images of the sheared surfaces from both shearing cases, as shown in figures 6 (a) and (b), were prepared. Then, the vertical and the horizontal distances of the sheared edge, D_y and D_x shown in figure 6 (c), were measured. After that, the D_y/D_x ratio was calculated. In the case of the sheared specimens having the burr protruded from the surface of the wire rod, the length of the protruded burr was excluded from the distance D_y before calculating the D_y/D_x ratio.

Figure 7 shows the roundness at the sheared zone of the wire rod, compared to the roundness of the steel wire rod before shear cutting. From this figure, it was found that, in the case of the conventional shear cutting, the average D_y/D_x ratio was 0.977. This value indicated that the wire rod tended to be laterally deformed during shearing. In this shearing case, the lateral deformation deteriorated the roundness of the sheared wire rod. Considering the case of the notch shear cutting, the average D_y/D_x ratio was nearly 1.00 and equal to that of the raw wire rod. It was indicated that the wire rod almost did not deform in the both directions. Then, the roundness of the sheared wire rod could be kept to be the same as that of the raw material.

For the case of the conventional shear cutting, since the separation resistance of the wire rod was higher, the sheared zone of the wire rod underwent the large amount of the plastic deformation before the separation. This seemed to be a mainly cause of the poor roundness. On the other hand, in the notch shear cutting case, the notch made on the steel wire rod reduced the separation resistance. Then, the plastic deformation at the sheared zone during the shearing reduced. As a result, the roundness of the sheared zone was kept and superior, compared to that of the conventional shear cutting case.

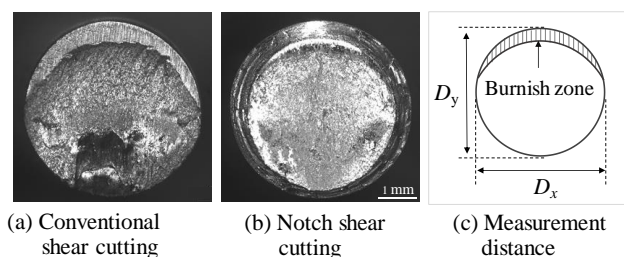


Figure 6. Sheared surface of wire rod and measurement distances for roundness.

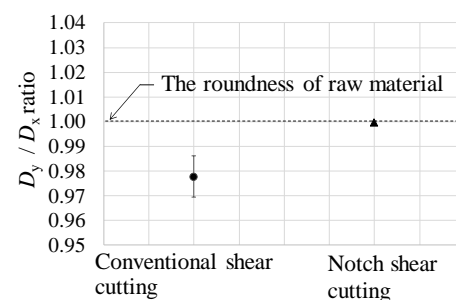


Figure 7. Roundness at sheared edge of wire rod for conventional and notch shear cutting

3.2 Effects of notch depth on notch shear cutting results of wire rod

After knowing the effectiveness of the notch shear cutting for the wire rod, the effects of the notch geometry, the depth of the notch was varied and investigated. To vary the depth, the feed distance of the insert into the wire rod was altered as 750, 950 and 1000 μm . However, since the wire rod elastically deformed during making the notch, the actual depth of the notch was slightly lower than the feed distance. Namely, the actual depths d_n of 333, 426 and 537 μm were obtained from the applied feed distances. For this investigation, the bevel angle of the notch was fixed to be 40°.

3.2.1 Effects of notch depth on cutting load resistance of wire rod Figure 8 shows the cutting load resistance when varying the notch depth of 333, 426 and 537 μm . It was seen that the f_{Max} was significantly decreased with increasing the depth of the notch. For the position d_{Peak} , it occurred at a shallower indentation depth when increasing the notch depth. Seeing the separation position of the wire rod, it appeared to be invariant when varying the depth of the notch. From this cutting load resistance, it was indicated that the separation resistance of the wire rod significantly decreased with increasing the notch depth. However, from the characteristic of the load drop, the final fracture of the wire rod did not change with the notch depth.

3.2.2. Effects of notch depth on sheared edge features of wire rod Figure 9 shows the representative side-view photographs of the sheared edges for the cases of $d_n = 333$, 426 and 537 μm . As seen in this figure, the roll over was not observed for all notch depths. Next, seeing the lower side of the sheared edge, for the shallow notch, $d_n = 333$ and 426 μm , the burr protruded from the wire rod surface seemed to be observed. However, when the notch depths increased to 537 μm , the protruded burr tended to be absent.

Figure 10 represents the possibility of the protruded burr occurrence when varying the notch depth. From this figure, it was found that the possibility of the protruded burr formation decreased remarkably, when the notch depth increased from 333 μm to 426 and 537 μm . From the protruded burr length measurement, the tendency of the length with respect to the notch depth was not observed. Here, the average length $b_{h(\text{Notch.})}$ was 36.77 μm (50.73 ~ 22.48 μm), 48.46 μm (63.45 ~ 33.48 μm) and 34.33 μm (40.43 ~ 28.23 μm) for the notch depths of 333, 426 and 537 μm , respectively. From the non-monotonic tendency of the protruded burr length, it indicated that there was a large variation of the protruded burr length, when varying the notch depth.

3.2.3. Effects of notch depth on the roundness of wire rod Figure 11 shows the sheared surface of the wire rod for the difference notch depth, while figure 12 represents the plot of the D_y/D_x ratio for various notch depths. From figure 12, the ratio was almost equal to one for all notch depth conditions. It was indicated that the roundness of wire rod could be kept and was not deteriorated due to the shear cutting, when varying the notch depth.

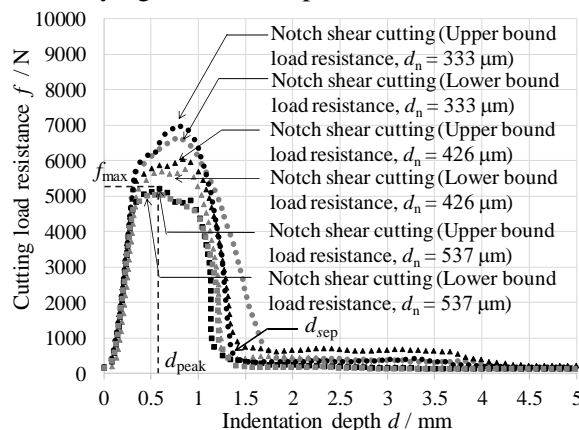


Figure 8. Load resistance of steel rod cut by various depths of notch ($\alpha \approx 40^\circ$).

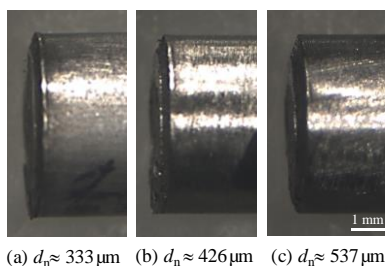


Figure 9. The Side-view photographs of sheared wire rods for depth of notch ($\alpha \approx 40^\circ$).

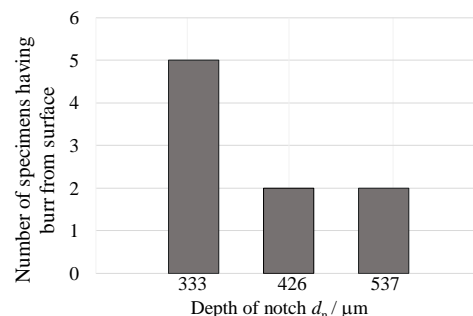


Figure 10. Number of specimens having burr protruded from surface of wire rod for notch depth.

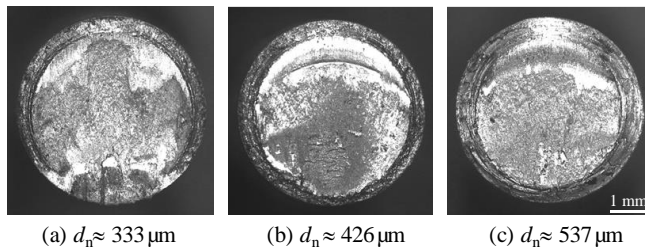


Figure 11. Sheared surface of wire rod for notch depth.

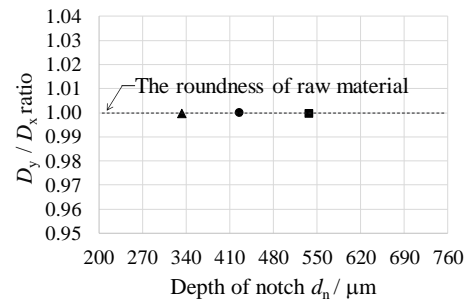


Figure 12. Roundness at sheared edge of wire rod for notch depth.

4. Conclusions

- 1) The notch shear cutting remarkably improved the quality of the sheared wire rod in terms of the roll over, the protruded burr length reductions and the keep of the roundness of the wire rod. Also, the possibility of the protruded burr formation decreased by the technique.
- 2) The sheared edge improvement of the notch shear cutting seemed to be resulted by the small plastic deformation of the wire rod during shearing. The plastic deformation remarkably suppressed due to the low separation resistance of the pre-notched wire rod.
- 3) The roll over at the sheared edge of the wire rod did not occur for all notch depths.
- 4) When the notch depth was varied, the possibility of the protruded burr formation tended to decrease. However, the tendency of the burr length with respect to the notch depth was not observed.
- 5) The roundness of the sheared wire rod could be kept and was similar when varying the notch depth.

References

- [1] Natpukkana P, Mitsomwang P, Borrisutthekul R, Panuwannakorn R and Khoa-phong L 2018 *Proc. Int. Conf. (Bangkok)* pp 20–26
- [2] Fang G, Zeng P and Lou L 2002 *J. Mat. Pro.Tech.* **122** pp 249–54
- [3] Hatanaka N, Yamaguchi K and Takakura N 2003 *J. Mat. Pro.Tech.* **139** pp 64–67
- [4] Tekiner Z, Nalbant M and Gür ün H 2006 *Mat. Design.* **27** pp 1134–38
- [5] Kwak T.S., Kim Y.J. and Bae W.B. 2002 *J. Mat. Pro.Tech.* pp 462–68
- [6] Kringnera M, Feistlea M, Gollea R and Volka W 2017 *Procedia Eng.* **183** pp 53–58
- [7] Sachnik P, Hoque S and Volk W 2017 *J. Mat. Pro.Tech.* **249** pp 229–45
- [8] Lee K.O., Kima J.M., Chin M.H. and Kang S.S. 2007 *J. Mat. Pro.Tech.* **182** pp 65–72