Journal of Research and Applications in Mechanical Engineering
ISSN: 2229-2152 (Print); 2697-424x (Online)
(2021) Vol. 9, No. 2, Paper No. JRAME-21-9-017
[DOI: 10.14456/jrame.2021.17]

Research Article

DAMAGE OF PUNCH/DIE TOOLS IN STEEL WIRE ROD SHEAR CUTTING

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Received 28 December 2020
Revised 16 February 2021
Accepted 18 February 2021

ABSTRACT:
In this research work, damage of punch/die tools in a steel wire rod shear cutting was investigated. The tools (punch and die) used in a steel wire rod (JIS SCM420) cutting ranging from 50,000 to 150,000 cutting shots were collected for the investigation. Experimental results showed that the main damage of the tools at the sheared zone was tool edge chipping. The edge of the die was chipped severely when passing 150,000 cutting shots. To investigate the cutting characteristics of the wire rod by the damaged tools, the tools were applied for a shear cutting test using a developed shear cutting tool holder. It was found that the damage of the tools did not remarkably affect the cutting load resistance of the wire rod. However, when cutting the wire rod with the higher-cutting-shot tools, the quality of the sheared edge deteriorated. Namely, the sizes of the rollover and the burr at the sheared edges of the wire rod tended to increase.

Keywords: *Shear cutting, Steel wire, Tool damage, Sheared edge*

1. INTRODUCTION

Steel wire rod is a raw material used in metal part industries, e.g. bolt and nut cold forging, needle roller bearing production, transmission chain manufacturing, etc. Steel wire rods supplied to metal part manufacturers are in the form of coils. A manufacturing process starts from the recoiling. Then, the wire rod is drawn into a straightening machine. After that, it is cut by shear cutting to get a designed length of initial workpiece. Although the shear cutting is not always the finishing process of manufacturing, the characteristics of the initial sheared workpiece determine the production completeness. For example, in the initial billet preparation for a steel nut cold forging, a long-surface-crack is sometimes generated near the center of the sheared surface. After upsetting-mode forging, the surface crack could be appeared as a crack on the nut, especially at its flange area. This caused the part rejection. Basily and Das [1] also explained the similar problem, namely stress cracks on the sheared surface of billet occurred and caused difficulty during forging. As explained above, eventually, the shear cutting must be operated, meticulously.

Natpukkana, et al. [2] investigated the cutting characteristics of a JIS SCM420 steel wire rod havng a diameter of 4.48 mm. They revealed that the punch/die clearance was a dominant parameter affecting the cutting load resistance, the separation of the wire rod and the features of the sheared edge. The speed of the shear cutting was also found to be an important factor affecting sheared billet quality. On a high-speed shearing (5 m·s^{-1}), the excellent geometric shape of the sheared billet could be obtained [1].

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Apart from those parameters, the punch/die tools damage seems to strongly affect the cutting characteristics of the wire rod. In case of sheet metal shearing, many researchers investigated and reported the damage characteristics of the punch/die tools [3-5]. However, the deformation of material during sheet shear cutting mainly occurs in two dimensions (no out-of-plane deformation), the punch/die tools damage and their cutting characteristics may be different from the case of wire rod shear cutting since the deformation of the wire rod is in three dimensions.

The authors have found no research works or reports concerning the damage of the punch/die tools and its cutting results from the wire rod shear cutting. Therefore, in this research work, the authors collected the damaged punch/die tools from an industrial site. Then, the damage characteristics were deeply investigated. In additions, a shear cutting test using the damaged punch/die tools was conducted in laboratory. The cutting results, i.e. the cutting load resistance, and the sheared edge features were analyzed and reported.

2. Material and Methods

The experimental investigation consisted of two parts, the investigation of the damaged punch/die tools and the study of the cutting characteristics of the wire rod by the damaged tools. For the tool damage investigation, three sets of new tools were produced from a JIS SKH51 (hardness ≈ 62 HRC). The tool was used for cutting off a JIS SCM420 steel wire rod which had a diameter of 4.48 mm. The chemical compositions and the mechanical properties of the wire rod are shown in Table 1 and 2. In order to investigate the tool damage progression, the workpiece cutting shots for the cutting tools were determined to be 50,000, 100,000 and 150,000. After reaching the shots, the tools were removed from the cutting machine and cleaned. A stereoscope (Model: Leica EZ4) was utilized to examine overview damage of the tools. To reveal the damage characteristics of the tool in detail, the authors chose the replica technique. The replica agent (Provil® novo light impression silicones) was applied at the damage zones of the tools. After the replica agent was completely set, it was pulled out from the tool and prepared for the examination by a Scanning Electron Microscope (SEM). Figure 1 shows the main procedures of the tool damage investigation using the replica technique.

Table 1: Chemical compositions of wire rod [6]

Chemical compositions (wt%)							
C	Si	Mn	P	S	Cr	Mo	Fe
0.18-0.23	0.15-0.35	0.6-0.85	<0.03	< 0.03	0.9-1.2	0.9-1.2	Bal.

Table 2: Mechanical properties of wire rod [6]

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

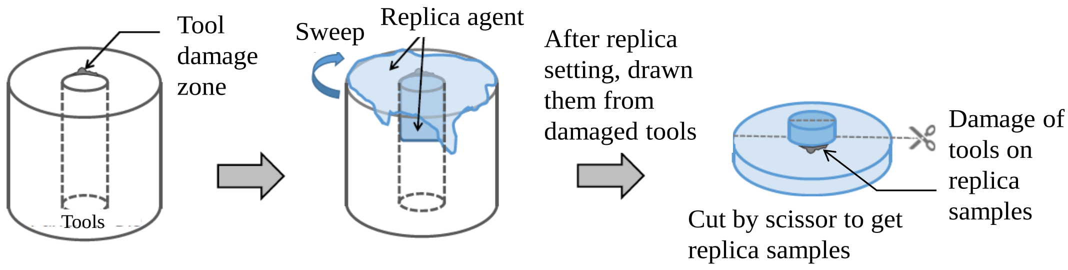
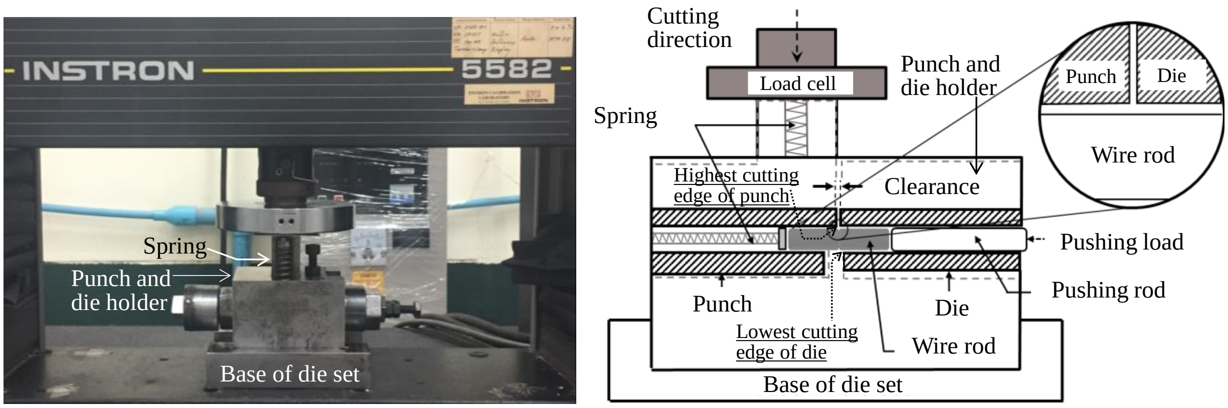


Fig. 1. Procedures of replica technique for investigation tool damage.

For the investigation of the cutting characteristics, the shear cutting setup seen in Fig. 2 was developed and used. During the shear cutting test, the punch/die clearance was fixed as 40 μm. This clearance was the same as that used for the wire rod shear cutting in the industrial site. The punch was moved downward with the speed of 5 mm·min^{-1}. The load cell (Capacity: ± 100 kN) was installed for recording the cutting load resistance of the wire rod. The punch/die sets (collected from the industrial site after reaching 50,000, 100,000 and 150,000 cutting shots) were installed in the setup. For each tool set, the shear cutting test was performed five times. After cutting, the features of the sheared wire rods were examined by the SEM.



(a) Photograph of experimental setup (b) Details of punch/die shear cutting setup

Fig. 2. Setup for wire rod shear cutting test.

3. Results and Discussions

3.1 Damage of punch/Die shearing tools

Figure 3 shows the macroscopic photographs of the used punch/die tools. As seen in this figure, three damaged areas were observed on the punches. First, at Zone 1, the damage occurred at the cutting edge of the punches. Since this area was acted directly by the load of shear cutting, the damage could be confirmed to be caused by the shear cutting stress. Then, at Zone 2, scratches appeared on the front surfaces of the punched. This seemed to be resulted by the abrasion between the cut wire rod remained in the die and the surface of the punch. Third, the damage was seen in the edge of the punch (Zone 3). At this zone, an apparent metal loss was detected. Considering the damage of this far area from the sheared zone of the punch, it was not caused by the shear cutting stress. However, vibration of the high-speed moving wire rod during shearing possibly resulted in this damage.

(a) 50,000 cutting shots (b) 100,000 cutting shots (c) 150,000 cutting shots

Fig. 3. Front-view photographs of the used punches and dies.

At the dies, as seen in Fig. 3, the damage due to the shear cutting stress was detected, at Zone 1. Also, viewing the front surfaces of the dies, the scratches appeared. Based on the overview photographs, when the cutting shots of the tools increased from 50,000 to 150,000, the severity of damage, the tool surface scratch, the metal loss at the punch edges and the damage at the sheared zone, tended to increase.

In this work, the authors focused on the examination of the tool damage caused by the shear cutting stress. Since the damage at the sheared zone of the tools occurred at the tool surfaces and splayed inside the tool holes, Two-dimensional micrographs was not usable to clearly see the damage of the tools. So, the authors did the investigation using the replica technique. Figure 4 represents the scanning electron micrographs of the replica samples at the sheared zone. From this figure, it was seen that the damage of the punch and the die due to the shear cutting stress had features of inclined surfaces. Also, this result indicated that the main damage of the cutting tools was edge chipping.

To further investigate the progression of the chipping with respect to the tool cutting shots, the replica samples were subjected to a 3-dimensional laser scanning microscope (Keyence, VK-8710). After scanning, the length (D_l) and the height (D_h) of the chipping (expressed at the chipping zone in Fig. 4) were measured. Figure 5 shows the measurement of the chipping distances by the microscope.

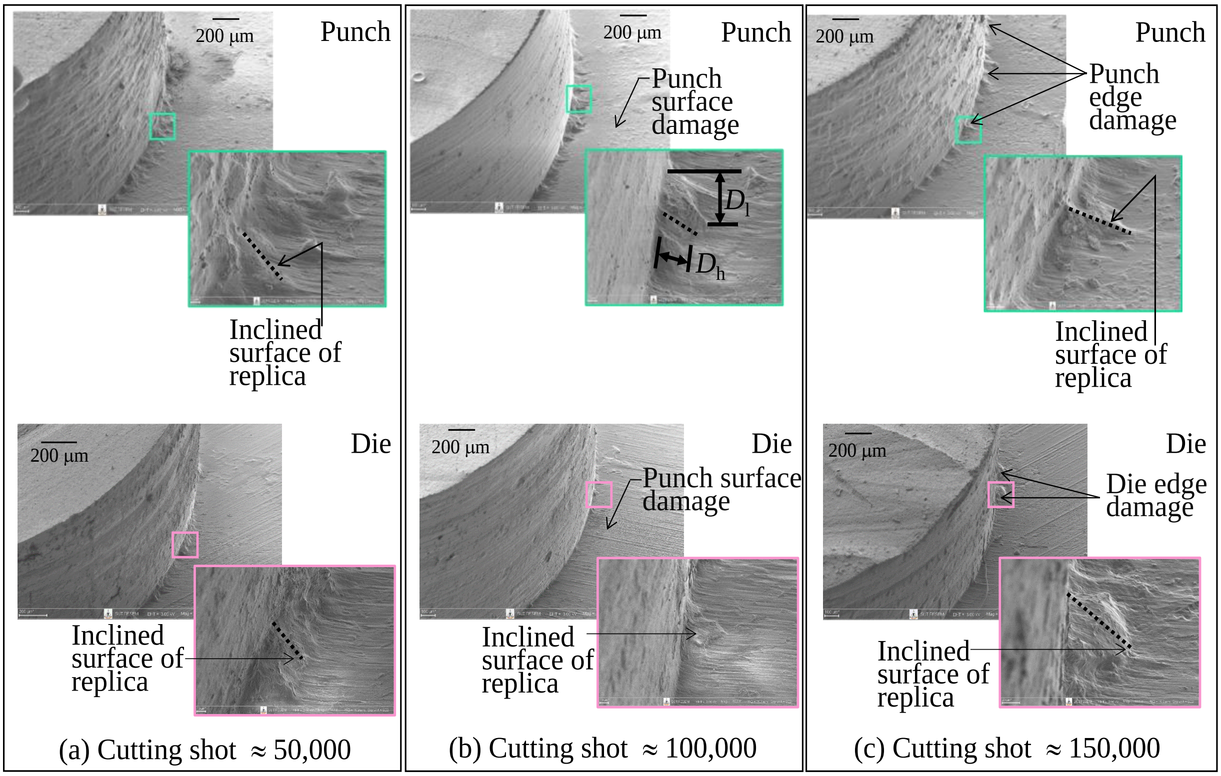


Fig. 4. SEM images of replica samples showing damage of punches and dies.

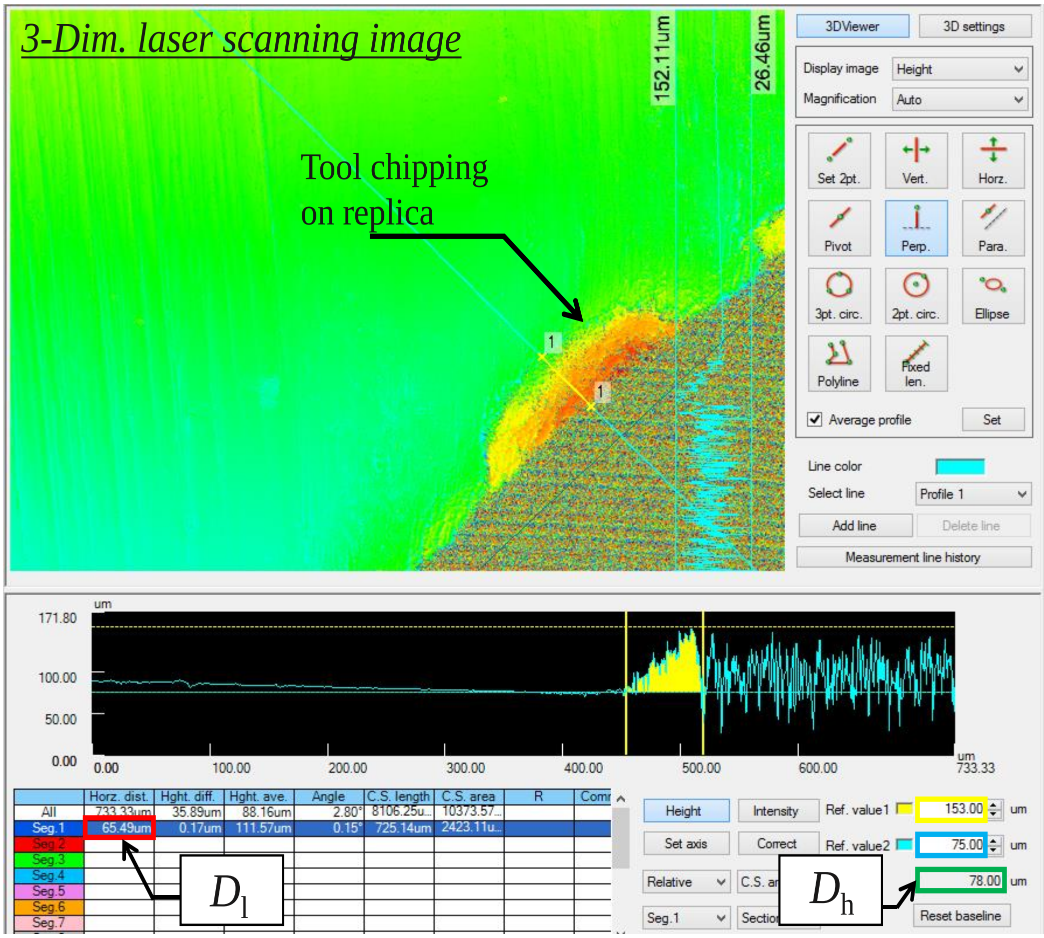
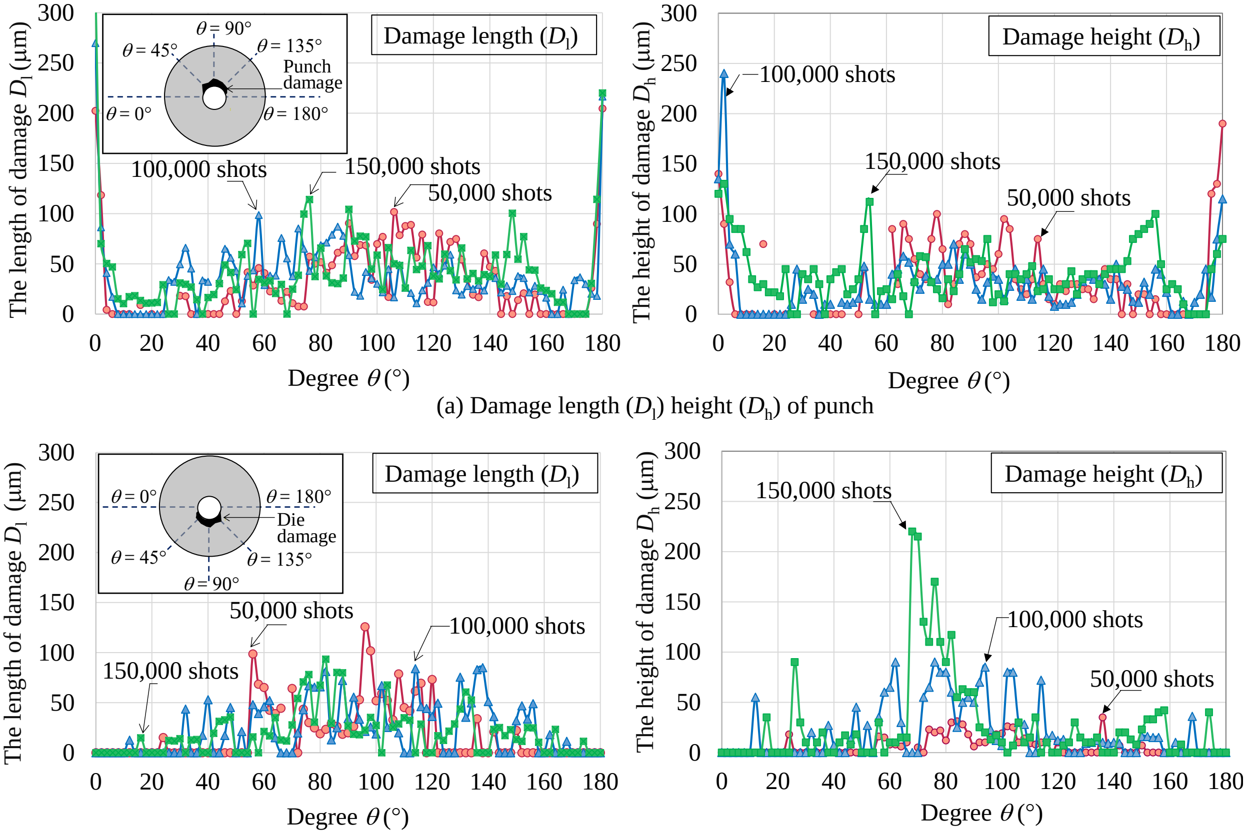


Fig. 5. Measurement of damage distances on replica using 3-Dim laser scanning microscope.

Figure 6 represents the damage length and height measured along the circumferences of the punch and the die cutting edges. As shown in such figure, the 90° angle corresponds to the highest cutting edge of the punch while it corresponds to the lowest cutting edge in the case of the die. From this figure, the following tool damage characteristics were revealed: first, at the edges of the punches (at 0 and 180°), the damage was fairly severe and similar in all cases of the cutting shots. This corresponded to the metal loss at the punch edges, as explained above. Second, seeing the damage distances, D_l and D_h, the chipping of the punches and died was drastic at the highest cutting edges of the punches and the lowest cutting edges of the dies (at 90°) and tended to decrease for the faraway positions along the circumferences of the punches and the dies. Third, comparing the damage of the tools under different cutting shots, the chipping of the tool cutting edges except the damage height of the punch (D_h) was not significantly different. Finally, seeing D_h in Fig. 6 (b), the damage height of the die near the lowest edge tended to increase with increasing the tool cutting shots. Here, it was confirmed that when the cutting shots increased, there was the progression of the damage, i.e. at the cutting edge of the die.



(a) Damage length (D_l) height (D_h) of punch

(b) Damage length (D_l) height (D_h) of die

Fig. 6. Measured damage length and height at punch and die edges.

3.2 Cutting characteristics of wire rod by damaged punch/Die tools

In steel wire rod shearing industry, punch and die are impossible to be replaced, suddenly after their damage. Due to the high productivity of the shear cutting process, a lot of wire rods are cut by the damaged tools. In order to identify the acceptance damage level of the tools to obtain satisfy shear cutting results, the understanding of the cutting characteristics of the wire rod by the damaged tools is crucial. Thus, the authors used the damaged tools (50,000, 100,000 and 150,000 cutting shots) for the wire rod shear cutting test and investigated. Figure 7 shows the cutting load resistance of the 50,000, 100,000 and 150,000 cutting shot tools. Here, it was found that the load resistance of the wire rod was not significantly different when varying the tool cutting shots. In addition, considering the peak point of the load (f_{max}) and the peak position (d_{peak}) which typically correspond to the crack initiation state of wire rod, they were not noticeably affected by the tool damage. Also, the final separation position of the wire rod (d_{sep}) was similar for all cutting shot tools.

After shear cutting, the sheared edges of the wire rods were examined by the Scanning Electron Microscope. Figure 8 represents the sheared edges of the wire rods cut with the 50,000, 100,000 and 150,000 cutting shot tools. From this figure, rollover and burr at the sheared edges were observed. Their size seemed to be increasing with the tool cutting shots. To examine the sheared edge feature in more details, an image analyser software was utilized to measure the dimension of the burr and the rollover.

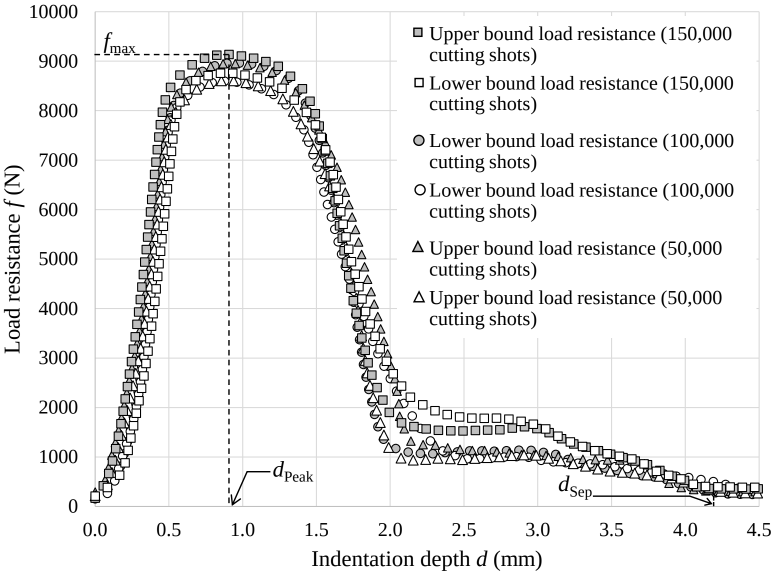


Fig. 7. Relationship between indentation depth of punch and cutting load resistance of wire rod.

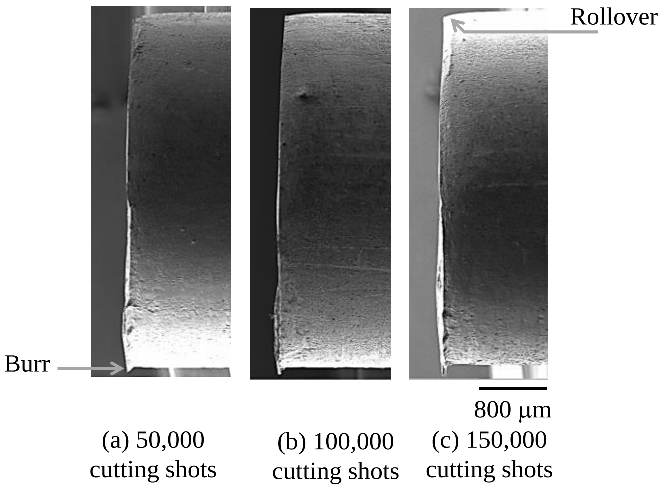
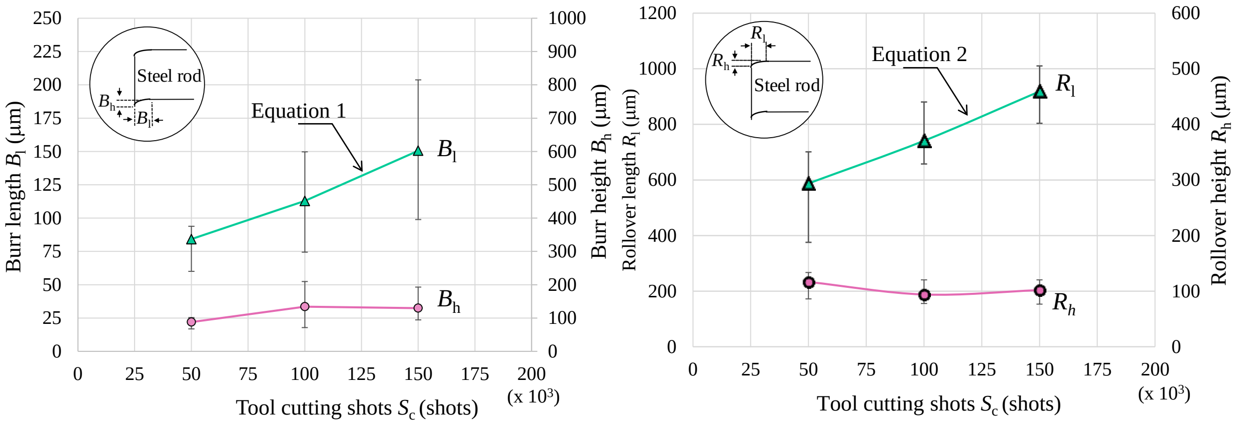


Fig. 8. SEM images of steel wire rod sheared edges.

Figure 9 represents the measured length and the height of the burr and the rollover at the sheared edges. As seen in this figure, the following geometrical features were revealed: (i) for the cutting tool shot ranging from 50,000 to 150,000, the lengths of the burr and the rollover linearly increased when the cutting shot increased. Eqs. (1) and (2) explained the relationships. In these equations, S_c is the numbers of the tool cutting shots. (ii) there were slight variations of the burr and the rollover heights for the investigation range of the cutting shots. When relating the sheared edge geometry with the tool damage explained before, the lengths of the burr and the rollover seemed to be related to the severity of tool damage.

$$B_l = 0.0007S_c + 49.48 \quad (1)$$

$$R_l = 0.0033S_c + 417.9 \quad (2)$$



(a) Length and height of burr (b) Length and height of rollover

Fig. 9. Relationships between cutting shots and dimensions of burr and rollover at sheared edges.

4. CONCLUSIONS

The damage of the punch/die shearing tools and the cutting characteristics of the steel wire rod using the damaged tools were investigated. From the results, the following conclusions were revealed:

(i) The tool (punch and die) damage consisted of the tool surface scratches, the metal loss at the edges of the punch and the chipping of the tool cutting edges at the sheared zone. It was presumed that only the edge chipping was caused by the shear cutting stress.

(ii) Using the replica technique combined with the scanning electron microscopy, the geometrical feature of the tool edge chipping was clearly observed.

(iii) Based on the measured chipping dimension, there was the damage progression of the tool when the cutting shots increased. The progression was observed, especially near the lowest cutting edge of the die.

(iv) The shear cutting with the damaged tools did not significantly affect the cutting load response and the separation position of the steel wire rod.

(v) The use of the damaged tools resulted in the variation of the wire rod sheared edge features, especially the lengths of the burr and the rollover. Also, these lengths increased when the tool damage severity increased.

ACKNOWLEDGMENTS

The authors wishing to acknowledge Prof. Dr.Shigeru Nagasawa, Department of Mechanical Engineering, Nagaoka University of Technology, Niigata, Japan for the huge support of the three-dimension laser scanning microscope for examining the damage of the cutting tools.

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