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A diagnosis system and ultrasonic vibration energy in plant to quality control

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Abstract. In this paper, the mechanical characteristics of ultrasonic cold forged technology (UCFT) used for the trimming knife and the effects of ultrasonic vibration energy (UVE) into the trimming process on the state of the strip cutting face were studied. And a diagnosis system to quality control for trimming knife and strip cutting face was developed and installed in plant. By the plant application of UCFT, service life of knife was more increased over 100% than that of conventional knife. And using the developed diagnosis system, the knife breakage and saw ear have been perfectly detected and quality control of trimming face is obtained effectively.

1. Introduction

Recently, the usage of high strength steels (HSS) for automotive applications has been drastically increased not only for enhancement of safety and durability of vehicles but also for light weight construction for fuel efficiency. To fulfill the increased demands, therefore, steel-making companies have focused on development of the HSS.

However, the increase of production of HSS incurs overload in the steel-making process. One of examples causing such overload would be a side-trimming process, which cuts out 7 to 10mm from both edges of cold rolled strip in order to meet desired width required by customers and to eliminate cracks existing on edges of hot rolled strips. During the side trimming operation of the HSS and mild steel, knife breakage and burr are frequently occurred. In Addition, such breakage and bad quality of strip cutting face are affected on less yield as well as reduced productivity and reliability on production line. In concern of these problem, various studies on producing severe plastic deformation on the surface of the trimming tools[Toith, 1971; Pyun et al., 2001; Pyun et al., 2002], advanced heat treatment technology[Pye, 1997] and improving quality of strip cutting face[Horisawa, 1997] have been made to prevent knife breakage and decrease burr damage.

In this paper, the characteristics in mechanical properties of ultrasonic cold forged technology (UCFT) used for the trimming knife and the effects of ultrasonic vibration energy (UVE) into the trimming process on the state of the strip cutting face were studied. And a diagnosis system to quality control for trimming knife and strip cutting face was developed and installed in plant. Using this system, its effectiveness and reliability was successfully verified through the field test.

2. Effects of UVE on mechanical properties

2.1 Ultrasonic cold forging device

UCFT uses ultrasonic vibration energy (UVE) as a source, and tens of thousand times per second are struck on the material surface as constant pressure is applied. These strikes bring severe plastic deformation to surface layers and induce a nano-scale crystal structure. Configuration of the UCF device is shown in Fig. 1. It consists of several components such as the ultrasonic generator(a) generating electric ultrasonic frequency, the air compressor(b) pushing ultrasonic generator unit with constant pressure, the piezo-transducer [(c), $Pb(Zr,Ti)O_3$], the booster(d) amplifying the ultrasonic vibration, the horn(e) transmitting the ultrasonic vibration and ball tip [(f), tungsten carbide].

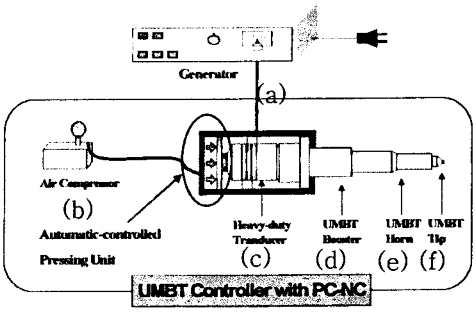

Fig. 1 Configuration of the UCF device

2.2 Effects of UCFT on residual stress, fatigue strength and field test

To verify the feasibility of the UCFT, various experiments were carried out with SKD-61 which is the material of the trimming knife used in the cold rolling mill. Specimens were fabricated by help of the UCF device shown Fig.1. 20 kHz of frequency was applied to the ball tip, and the applied static force was 10kgf.

Fig.2 shows the change of residual stress along the depth direction both before and after the UCFT. Compressive residual stress is the most crucial factor in shock resistance. The residual stress measured every 20μm depth using a X-ray residual stress measurement equipment. Electrolysis-polishing was used to cut out the constant depth. As shown in Fig.3, compressive residual stress after the UCFT remains to 150μm depth. Its magnitude is 2 times higher than that of before the UCFT. It was also observed that the effective depth by the UCFT was about 350μm. These results demonstrate the increment of compressive residual stress and depth by the shock resistance.

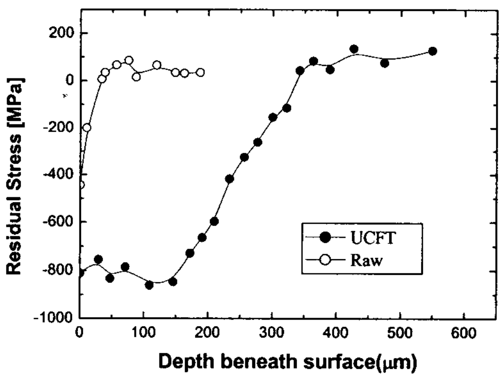

Fig. 2 Variation of compressive residual stress before and after the UCFT

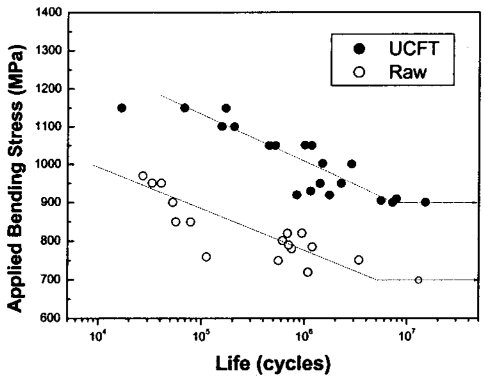

Fig. 3 S-N curves of SKD61 before and after the UCFT

Fatigue test was conducted using Ono type rotary bending machine (H5 type, 98Nm, Shimadzu Co.) at 3400rpm of revolution under room temperature, and the specimens were prepared under the JIS Z2274 standard. The fatigue characteristics before and after the UCFT were shown in Fig. 4. The 107 cycles fatigue strength before the UCFT was 719MPa, whereas that after UCFT was 899MPa, which is 25% higher.

Pilot test at a Cold Strip Mill, POSCO was made to verify the effect of the UCFT on service life of the trimming knife in Recoiling line (RCL). RCL is the final process producing the cold rolled steel sheet, and plays an important role in correcting the quality of the strip shape. It also trims 7 to 10mm of both edges on the strip in order to meet the desired width required by customers. The trimming knife was made of SKD-61. The UCFT process in the knife is shown in Fig. 4. TRIP80 (Transformation induced Plasticity), which is one of HSS and its tensile strength is 780MPa, was used as a trimmed material. Table 1 summarizes the test and its results. When 16 coils were trimmed with the UCFT knife, the knife breakage was not observed and the amount of the wear on the knife was very small in comparison with that of before the UCF T. When the conventional knife trims off strips, the knife was broken at the 3rd coil and the knife was replaced with a new one when the 8th coil is trimmed. The field test confirmed results in replacement with the UCFT knife for the side trimmer in the cold rolling mill and 100% more increment in the service life.

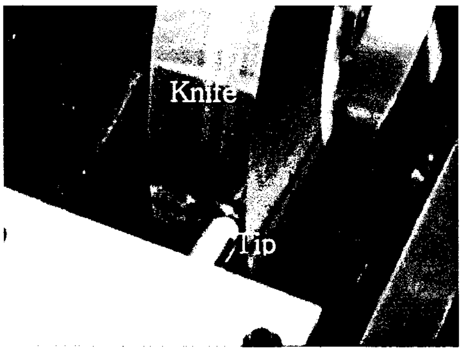

Fig. 4 Appearance of UCFT process for trimming knife

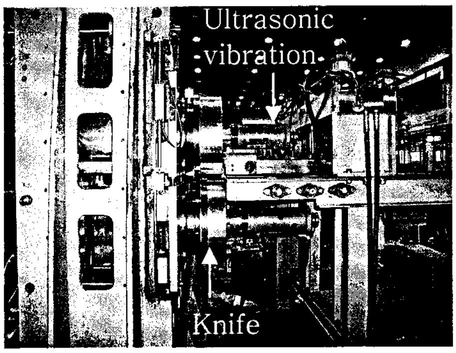

Fig. 5 Configuration of side trimming simulator

Table 1 Summary of field test results

	Steel grade	Strip size (mm)	Amount of test	Result
UCFT knife	80TRIP	1.8t x 1049	230Ton (16 Coils)	Unoccurrence of knife breakage
conventional knife	80TRIP	1.6t x 1303	207Ton (13 Coils)	Occurrence of knife breakage and knife replacement (8th coil)

3. Effect of UVE on Quality Control of Strip Cutting Face

3.1 Side Trimming Simulator and Ultrasonic Vibration Device

Fig. 5 shows a side trimming simulator in the field (POSCO cold rolling process) and a laboratory one. On major difference between two is the knife block. This is rotating and moving in the laboratory one while the knife is not rotating and strip is moving in the field one.

An ultrasonic vibrator makes a repeated oscillation within ultrasonic frequency range. This vibrator oscillates the fitting plate which fixes the knives, and then the vibration transfers to the knives. 15, 18 and 20 kHz of vibrator were selected to find out the optimal frequency in this study. The range was chosen by the most common frequencies for cutting and by considering the adding mass (knife, spindle, etc) from the system. This vibrator is similar with Fig. 1.

3.2 Experiment Results

The strip cut by the simulator is YP20 with 4.0 mm thickness. Gap and lap have set to 0.14 mm and 0.35 mm respectively, just the same dimension as the field ones. Patterns of strip cutting face are shown in Figs. 6. As shown in these figures, the cutting face (b) using the UVE is more uniformed rather than that (a) of not using UVE. This result revealed that shear force of the trimming knife of (b) is transmitted equally when UVE is applied to the knife.

Figs. 7 show the comparison of burr shape. A shorter burr of (b) can be found when applying UVE. The length and width of burr of (b) are shorter rather than that of (a); without applying UVE.

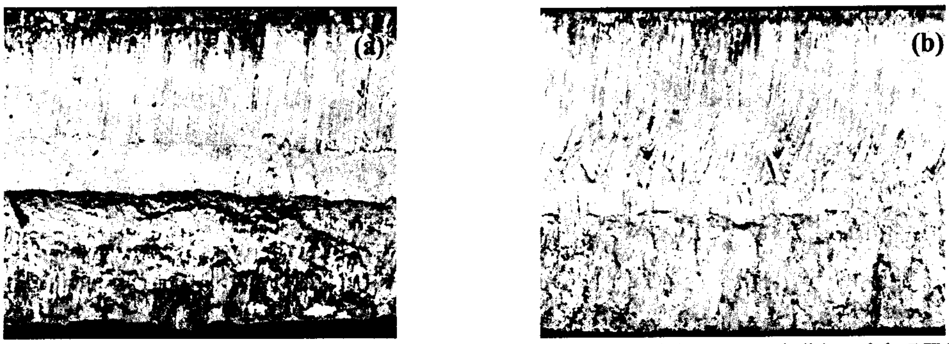

Fig.6 Comparison of strip cutting face between (a) without and (b) with UVE

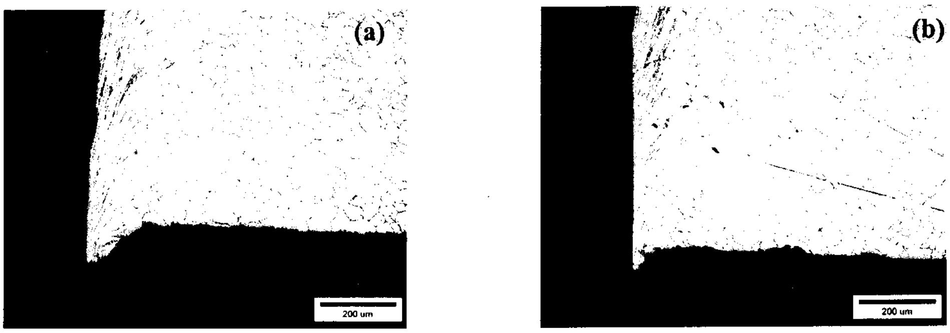

Fig.7 Comparison of burr shape between (a) without and with (b) UVE

4. Diagnosis System for monitoring the knife and the cutting face

4.1 Configuration and Function of Diagnosis System

The component and layout of the diagnosis system is shown in Fig. 8. Two CCD cameras facing each other are mounted at the delivery side (the entry of the burr masher roll) of the side trimmer. Images obtained from the cameras are inputted to the frame grabber converts the image from analog to digital signal. Then, the numeric values determining the state of the knives and cutting faces are calculated based on the level of digital image signal at the camera PC. The camera PC has a special function; saving raw images.

A HMI (Human-Man Interface) PC is used to determine the state of the cutting faces base on the values calculated at the camera PC, which is done by means of a internet protocol, namely TCP/IP communication with the camera PC. It also guides operators with the diagnosis results of the state of knives and faces. The HMI PC has a function that operators can easily monitor the trimming states by the periodically displayed images of strip cutting face on the screen. Light is generated from the light source in the control panel and transferred to the light guide which is installed in front of camera through the fiber optic cable.

Fig. 9 shows the CCD cameras installed at the location of 3 meters away from the delivery side of the side trimmer, just right before the bur masher roll which is decreased the magnitude of the bur created in trimming process. The distance between the camera and the strip edge should always remain constant in order to obtain vivid images from the CCD camera. Even though the strip width changes, the camera position should be controlled according to the strip width. To adjust the position precisely, a mechanical structure used for installation of the camera housing is attached to the structural frame on the bur masher roll, and the frame transports the bur masher roll to keep the constant distance.

Light generated from the light source is coupled with the trimming speed by the trigger converter used to measure the trimming speed, and it is generated 45 times at the maximum trimming speed of 250mpm. Since F.O.V (Field of View) of the camera is 30mm, if one image can be grabbed with 45 frames per second, the traveled strip length is about 1350mm. Therefore, the strip cutting face can be monitored every 1318mm distance (knife diameter is 420mm) which is the circumference of the knife at the maximum trimming speed.

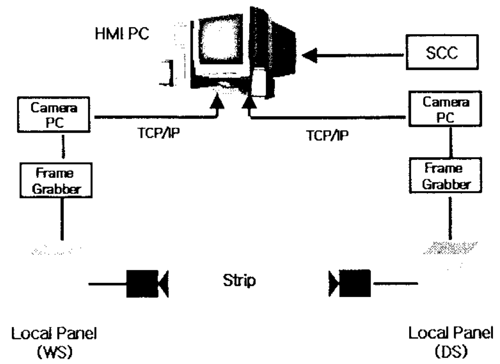

Fig. 8 Layout of the diagnosis system

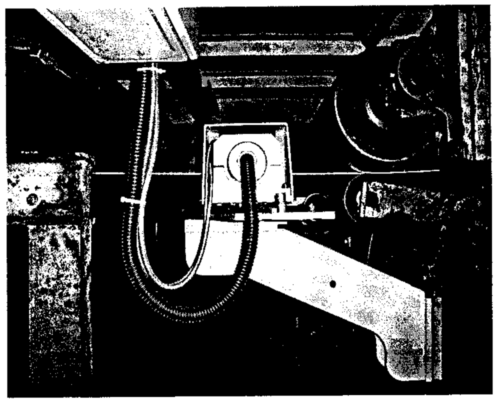

Fig. 9 Installation of CCD camera in plant

Images from the work-side(WS) and the drive-side(DS) are displayed every 100 frames. Abnormal images of strip and knife which detected by the diagnosis system are also displayed at the bottom with alarm signal. Once the alarm is given, the operator can confirm the state of the strip trimming face through the screen on MMI(Man-Machine Interface), and takes proper measures for the knife and the trimming faces. Consequently, the counting number of abnormal images at each coil is displayed as "ABN(Abnormal) count" on the screen. And more the time of normal images are updated and displayed on screen so that the operator can verify working status of the diagnosis system. A period of saving the images and related information is about 3 months.

4.2 Results of the Diagnosis System

Fig. 10 represents some examples of the on-line diagnosis result for the knife breakage. Information of the strip cutting face obtained continuously is very useful to confirming of the knife breakage. Time taken from Fig. 10(a) to (c) is within 1 sec. When the knife breakage happens, the diagnosis system gives the alarm. Then, one of operators can stop operation to replace a new knife. Therefore, the diagnosis system can control the products to keep aloof from bad quality. The condemned goods in trimming may occur consecutively in 6 ~ 7 coils can be prevented. Recently, the knife breakage has been occurred about 10 times a month in average. By the service of the diagnosis system, the knife breakage has been detected 100%, and the occurrence rate of the defect of the saw ears has been decreased remarkably.

Fig. 10 Example of the on-line diagnosis result of the knife breakage

5. Conclusions

1) Compressive residual stress after the UCFT remains to 150μm depth and its magnitude is 2 times higher than that of before the UCFT. It was also observed that the effective depth by the UCFT was about 350μm. These results demonstrate the increment of fatigue strength and the life of trimming knife.
2) Applying ultrasonic vibration energy (UVE) gives the better quality of strip cutting face due to smaller and uniform shear force of knife. The magnitude of burr and the depth of grain deformation range are also all decreased with the UVE during trimming process.
3) The on-line diagnosis system which can determine the knife breakage and badness of trimming on real time is developed in trimming process. By the service of the diagnosis system, the knife breakage has been detected 100%, and the occurrence rate of the defect of the saw ears has been decreased remarkably.

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