Effect of Wedge Tip Thickness of Nail Clipper on Cutting Characteristics of Polystyrene Ribbon

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Abstract. This research was aiming to investigate cutting characteristics of Polystyrene ribbon that were cut by nail clippers. A pair of rotational-linked fixture of recent designed JIG was developed for measuring the cutting load and displacement of nail clipper arm. Nail clippers had the upper apex angle of $\alpha_U = 13^\circ$, $\alpha_U' = 45^\circ$ and lower apex angle of $\alpha_L = 20^\circ$ and the lower biting edge thickness $w_L$ was chosen 0.06 and 0.25 mm. A 2-mm-width and 1-mm-thickness polystyrene ribbon was cut using the nail-clipper and the load response and the cut trace of sheared zone were investigated under the indentation velocity at $V = 0.01 \text{ mm} \cdot \text{s}^{-1}$. A large force dropped and unstable crack was detected when using $w_L = 0.06 \text{ mm}$, while the force drop was disappeared without any large crack when $w_L = 0.25 \text{ mm}$ due to the frictional restriction for fastening the work piece. While the peak line force was direct variation with tip thickness. When considered to vibration during cutting process by using AE sensor, nail clipper that have lower anvil thickness at 0.25 mm have lowest amplitude. Moreover, the cut traces were detected by microscope CCD camera.

1. Introduction
At the presents, nail clipper is almost fundamental equipment for every household. The most popular nail clipper type use nowadays is compound lever type. Typically, ordinary compound lever nail clipper consists of at least three separate rigid parts. Actuator arm that transmits finger force to the jaw and a pin acts as a pivot. Sometimes, there is a file, which assembles to file nail [1]. Many makers of nail clipper try to manufacture a new model of nail clipper blade that can cut a natural nail off with a low resistant load and a smooth sheared profile.

However, such the load response that be gotten from any prototype loading system was insufficient to check for consistency and openness. Therefore, appropriate measurement system of cutting load of developed nail clipper should be verified through a specified condition based experiment.

In the past, Ruchirabha et al. have designed a rotational-linked fixture JIG for using with nipper handle. Through this development of fixture JIG, it was clarified that the capability of designed fixture JIG was consistent for measuring and comparing the cutting response of several nippers [2]. Regarding the relationship between the cutting load (or the cutting moment) and the displacement at the pushing point of nail clipper actuator arm, appropriate theoretical estimation of cutting characteristics of the nail clipper is necessary for understanding the effects of mechanical parameters such as the apex angle of blade, the tip thickness of upper/lower blade.
As for the wedge cutting resistance, since there are several fundamental theories [3-5], the cutting resistance is characterized with the apex angle of wedge and the indentation depth against the thickness of worksheet. One of primary mechanical factors that characterize the cutting resistance is the shear stress. Canakci et al. reported that the shear stress increased with the compressed density of modified expanded polystyrene [6]. Nagasawa et al. reported about the effects of two-line wedge blade on the cutting characteristics of several resin materials [7-9]. The cutting line force and deformation of specimens were affected by the geometry of the blade edge such as the tip radius, the primary height of wedge and the apex angle of blade [10,11].

In a wedge cutting, unstable (multiple deformation modes) shear edge trace (sheared profile) of resin specimen seems to be observed. The multiple deformation modes of shear edge trace were appeared to be caused by the frictional instability or adhesion of wedge surface when choosing a Polycarbonate (PC) and a Polyethylene terephthalate (PET) sheet [12-15]. That provides unstable cracking, bent up necking, large inclination and burred of lower zone.

Baden [16] measured the natural nail stiffness using the speed of sound through nail, the result found that the Young’s modulus was approximate twice as high (4.3±0.3·GPa) transversely as longitudinally (2.1±0.3·GPa).

Therefore, in this research, in order to reveal the effect of biting edge thickness of nail clipper on the cutting characteristics of a PS ribbon material, the rotational-linked fixture JIG system that developed from [2] was provided for the use of nail clippers that had the represent upper apex angle \( \alpha_U = 13^\circ \) with the upper tip thickness \( w_U = 0.1 \) mm and lower apex angle \( \alpha_L = 20^\circ \) with the lower biting edge thickness \( w_L \) was chosen as 0.06mm and 0.25mm

2. Materials and experiments

2.1. Specifications of fixture JIG of nail clipper actuator arm and PS specimens

The holding JIG that used in this research were the same as JIG from [4]. It was used newly for the nail clipper. By the actuator arm (handle) of the nail clippers were inserted into the upper socket and arms that connected with jaw were inserted into lower socket for clamping respectively, as shown in Figure 1. The attitude of the blade was arranged to be vertical against the PS ribbon. Because the ribbon specimen was set up across to the nail clipper blade in the horizontal attitude.

A width 2 mm and 1 mm thick of polystyrene (PS) ribbons that cut from TAMIYA B4 size plates item 70124-720, which had a longitudinal length of \( L = 40 \) mm, was used for the cutting test. All the specimens of PS ribbons were sufficiently cleaned before cutting. The tensile stress-strain relationship in machine direction (MD) (longitudinal direction of bar) of the polystyrene ribbons was examined with the feed velocity \( V = 0.01 \) mm·s\(^{-1}\). In case of mechanical properties of PS, the dimension of polystyrene specimen that used for found stress-strain relationship refer from JIS K7127. The mechanical properties of the PS specimen were shown in Table 1.

| Symbol   | Thickness \( t/\text{mm} \) | Young’s modulus \( E/\text{GPa} \) | Yield strength \( \sigma_Y/\text{MPa} \) | Tensile strength \( \sigma_B/\text{MPa} \) | Breaking strain \( \varepsilon_B \) |
|----------|-----------------------------|----------------------------------|-----------------------------------|---------------------------------|-----------------------------|
| Tensile mode | 1                     | 2.74 (2.71–2.79) | 16.67 (16.33–16.99) | 21.2 (20.42–21.65) | 0.21 (0.18–0.25) |
| Average (Maximum-Minimum measured) | | | | | |

Table 1. In-plane tensile mechanical properties of polystyrene (PS) in longitudinal direction (the strain rate: 0.000125 s\(^{-1}\) with the span of 80 mm).

Table 2. Out of plane compressive mechanical properties of polystyrene (PS) in the cutting direction (the y direction). The strain rate: 0.33 s⁻¹.

| Symbol                   | Thickness t/mm | Young’s modulus $E_C$/GPa | Yield strength $\sigma_{YC}$/MPa |
|--------------------------|----------------|---------------------------|----------------------------------|
| Compressive mode         | 3.0            | 5.04                      | 71.04                            |

After assembling a nail clipper in the fixture JIG on the cutting test apparatus the applied pushing force at the actuator arm $F_1$ was measured by the load cell when cutting PS ribbon. The cutting force at the blade biting position $F_2$ was calculated by Eq. 1 and $f_2$ (= the ratio of $F_2$ by the width of 2 mm) N/mm. The compressive test of 3 mm square polystyrene bars was measured for $\varepsilon \approx 0.65$ with $V = 1$ mm·s⁻¹. Here, the $\varepsilon$ is the true strain in TD. Figure 3 shows a specimen and the setup of apparatus for compressive test. Through this compressive test, the results were that the compressive Young’s modulus $E_C$ in the y direction (cutting direction) and the yield strength $\sigma_{YC}$ in the y direction (cutting direction) were shown in Table 2. Here, it was noted that this compressive $\sigma_{YC}$ included a sort of frictional restriction.

From the table 1, found that the young’s modulus of PS bar was estimated nearly the young’s modulus from the natural nail[16]. Due to the natural nail was hardly using in an experiment. So, the PS bar was used in experiment instead of natural nail. $f_2$ was the cutting line force. Putting the indentation displacement of the actuator arm $D_1$, that of the blade biting position $D_2$ is principally calculated by Eq. 2. Here, since the full stroke value of $D_2$ is equal to the thickness of specimen, namely $D_2$ (full stroke) $\approx 1$ mm in this work. When $F_1$ was measured during the cutting test, $D_1$ was measured as the upper crosshead displacement as shown in Figure 1 and the arm span length $L_1$ and $L_2$ were 42.91 mm and 5.62 mm on both nail clippers, respectively.

\[
F_2 = F_1 \cdot \frac{L_1}{L_2} \tag{1}
\]

\[
D_2 = D_1 \cdot \frac{L_2}{L_1} \tag{2}
\]

Figure 1. Zoomed up view of a nail clipper and each measured arm span length.

The effective pushing force at the clamped-top position $F_1’$ (N), that excludes the inside-stiffness force of nail clipper from the raw force $F_1$ measured by the load cell, and is estimated using an idle cut calibration test without any work material. Similarly, the effective upper crosshead displacement $D_1’$, that excludes the elastic deformation of fixture JIG, is calibrated from the measured raw displacement $D_1$ using the idle cut calibration test without any work material.

The experiments were carried out under the following conditions: a room temperature of 297 K, and a room humidity of 50%RH.

2.2. Specifications of nail clippers and these profile parameters on cutting process

The cutting experiment of a width 2 mm and 1 mm thick of polystyrene (PS) ribbon was carried out using with nail clippers. Figure 2 shows a nail clipper blade which has the upper apex angle $\alpha_U = 13^\circ$ and the back angle $(\alpha_U’)$ = 45°. While the lower apex angle $(\alpha_L)$ = 20°. In Figure 3, denote “inside” is represent for the side that natural nail is cut off from the finger and “outside” is represent for the side that remains natural nail which attach with the finger.
2.3. Experimental procedure for vibration measurement

In order to know the mechanical vibration during the cutting process, the acoustic emission (AE) system was used for measure the amplitude that occurred. AE transducers were set up at two points: (A) attached with the upper surface of the actuator arm and (B) attached reversed side of the jaw directly.

3. Result and discussions

3.1. Calibration of cutting force with device stiffness at nail clipper’s actuator arm.

Regarding the cutting load diagram using the nail clipper, the indentation velocity of blade \( V = \frac{dD_1}{dt} \) was chosen as 0.01 mm·s\(^{-1}\).

After calibration, it was found that the peak maximum position of raw data was about 49% while that of calibrated data was about 42% of the full stroke. The pushed line force \( f_1' = \text{the ratio of } F_1 \text{ by the width of 2 mm} \) was monotony increased with \( D_1 \) for the first half (less than 25%). This tendency was common for every type of nail clippers. While, in the latter half (larger than 30%), the nail clippers that has the lower biting edge thickness \( w_L \) at 0.06mm had a saturated load response and had a breaking point \( D_1' \approx 92\% \) of 6.5 mm. In the case of the nail clippers that have lower anvil thickness at 0.25mm, it had a stably reducing load response in the latter half (larger than 24% of 8 mm). Then at \( D_1' > 87.5\% \) of 8 mm, the upper and lower blade collided each other but due to work hardening that occur at PS ribbon, the specimen didn’t break down until the \( D_1' \) reach \( \approx 97.5\% \) of 8 mm, the PS ribbon break down.

3.2. Cutting response at biting position

The representative cutting stages were classified in 5 stages, as shown in Figure 3 and 4. The first of cutting stages \( (D_2 \approx 18\% \) of the height of specimen) was classified as upper/lower blade penetrated into specimen. Then, only the upper blade penetrated into specimen at \( D_2 \approx 18\% - 76\% \) of the height of specimen and the peak maximum point occured at near \( D_2 \approx 35\% \) of the height of specimen. Moreover, during the process found that the upper blade penetrated with misalignment of lower anvil as shown in Figure 9 at \( D_2 \approx 50\% - 78\% \) of the height of specimen. Finally, pre- crack was generated \( D_2 \approx 78\% \) of the height of specimen and crack propagated into the uncut area. Then, the specimen was separated.

In case of the nail clipper that has the lower biting edge thickness \( w_L \) at 0.25 mm, the represent cutting stages were classified in 5 stages too by only upper blade penetrated until \( D_2 \approx 23\% \), as shown in Figure 9. After that during the upper blade penetrated into specimen, the compressive phenomena of lower blade occurred 4 times at 43%, 62% and 83%. After that, any a sort of crack of the specimen didn’t occurred, but received work hardening at \( D_2 \approx 92\% \). So, the biting line force \( f_2 \) increased rapidly. Then, the specimen was cut off at \( D_2 \approx 100\% \) under having the biting collision of upper/lower blades. These figures captured by the CCD camera.
Figure 3. Deformation states of PS ribbon specimen indented by nail clipper that the lower biting edge thickness \( w_L \) at 0.06 mm. (a) Machine press actuator arm at \( D_2 = 0.0 \) mm, (b) Upper blade/lower anvil penetrated into specimen at \( D_2 \approx 0.1 \) mm, (c) Pre-crack occur at \( D_2 \approx 0.8 \) mm, (d) Crack propagated at \( D_2 \approx 0.82 \) mm, and (e) Cut off at \( D_2 \approx 0.87 \) mm.

Figure 4. Deformation states of PS ribbon specimen indented by former nail clipper that the lower biting edge thickness \( w_L \) at 0.25 mm. (a) Upper blade/lower anvil penetrated into specimen at \( D_2 \approx 0.01 \) mm, (b) 1st lower anvil compress at \( D_2 \approx 0.15 \) mm, (c) 2nd lower anvil compress at \( D_2 \approx 0.40 \) mm, (d) 3rd lower anvil compress at \( D_2 \approx 0.63 \) mm, (e) 4th lower anvil compress at \( D_2 \approx 0.85 \) mm and (e) Cut off at \( D_2 \approx 1 \) mm.

After calibrating the cutting force with device stiffness, Eq 1 used to converted the effective pushing response \( f'_1 \) (N·mm\(^{-1}\)) to blade biting force \( f_2 \) (N·mm\(^{-1}\)) and Eq 2 were used to converted the indentation displacement of nail clipper’s actuator arm \( D_1' \) (mm) to the blade biting position \( D_2 \) (mm). The relationship between the blade biting line force \( f_2 \) and the blade displacement at the biting position \( D_2 \) was shown in Figure 5 by each stages refer from Figure 3 and 4.

Figure 5. The blade biting line force \( f_2 \) and blade displacement of nail clipper arm \( D_2 \) under the indentation velocity \( V = 0.01 \) mm·s\(^{-1}\) of the nail clipper that has the lower biting edge thickness \( w_L \) at 0.25 mm.
3.3. Effects of blade structure on sheared profile

After cutting PS ribbon specimens at \( V = 0.01 \text{mm} \cdot \text{s}^{-1} \), the sheared profile of the specimens was observed by a microscope CCD camera. Figures 6(a) and (b) shows the representative side views of sheared zone of PS ribbon specimen. Here, the left of specimen was located in the side that noted as “inside” of Figures 1. The profile parameters of the left sheared edge were defined as \( h_1(\text{mm}) \), \( h_2(\text{mm}) \), \( h_3(\text{mm}) \), and \( \theta (\degree) \). That of the right sheared edge were defined as \( t_1(\text{mm}) \), \( t_2(\text{mm}) \), \( t_3(\text{mm}) \), \( t_4(\text{mm}) \) and \( w(\text{mm}) \). The parameters of sheared edge profile were measured from the photographs of a microscope CCD camera. Seeing Figure 6(a) and (b), the blade profile was asymmetric with the thickness direction. The existence of the torn zone \( t_3 \) seemed to correspond to the stages of propagation of crack.

![Figure 6](image)

Figure 6. Representative sheared profile of PS ribbon specimen that was cut off by using nail clipper that the lower biting edge thickness \( w_L \) at (a) 0.06 mm and (b) 0.25 mm.

When choosing the former nail clippers that has the lower biting edge thickness \( w_L \) at 0.06 mm, the result show that the pre-crack was detected at \( D_2 \approx 0.7 \text{ mm} \) due to low friction force. So, the sheared edge trace has the depth of “\( d \)” without \( t_4 \) zone. In case of the nail clipper that has the lower biting edge thickness \( w_L \) at 0.25 mm, any large pre-crack and dispersion of force drop was not detected during the full stroke as seen from Figure 6. Therefore, the nail clipper that have lower anvil thickness at 0.25 mm seems to have a friction force from the lower blade tip for restricted the crack propagation. This friction restriction of lower blade made the shear profile of specimen smoother than another nail clipper as seen in Figure 7(b) (Namely, they don’t show any “\( d \)”).

![Figure 7](image)

Figure 7. SEM micrographs of sheared surfaces of PS ribbon specimen cut by nail clipper by (a) and (b) are front view of sheared specimen that have cut by lower biting edge thickness \( w_L \) at 0.06 mm, (c) and (d) are front view of sheared specimen that have cut by lower biting edge thickness \( w_L \) at 0.25 mm.

The front view of sheared surfaces of specimens cut by the two kinds of nippers were captured by a Scanning Electron Microscope (SEM) and shown in Figure 7(a)-(d). By, the figures 8(a) and (c) were the “outside” and figures 7(b) and (d) were the “inside” of PS ribbon specimen that denoted in Figure 1.

3.4. Effects of blade structure on vibration of nail cutter during cutting process

AE signal could be detected at each set point of the AE transducer. At the setting place of sensors at the actuator arm and jaw, the following AE signals were observed as shown in Figure 8(a) and (b). The result shown that when use the lower blade that has the lower biting edge thickness \( w_L \) at 0.06 mm. The peak amplitude was shown 2 position on both sensors. The first peak was detected at the position of pre-crack occur and the second position was detected at the position that specimen was breaking down. While, the cutting process that has the lower biting edge thickness \( w_L \) at 0.25 mm, the peak amplitude
was detected only one peak amplitude, at the start position of only upper blade indented, as shown in Figure 8. By the peak amplitude was detected at only the jaw due to the indented of upper blade.

**Figure 8.** Results of detected AE signals on cutting process when (a) use nail clipper that has the lower biting edge thickness $w_L$ at (a) 0.06 mm and (b) 0.25 mm. By the black line is AE signal from sensor B and red line was from sensor A.

From Figure 8(a), it was concluded that the pre-crack generated and breaking down of specimen could make the peak amplitude occurred. Moreover, the open of wedged zone was vibrated in high level for generated the peak amplitude also. When considered to the split off specimen, the less vibration (less maximum amplitude) that make specimen split well could be obtained of the nail clipper that have width of lower blade at 0.25 mm due to the peak amplitude didn’t show at the breaking down stage.

4. Conclusion

In order to reveal the effect of blade profile on the cutting line force and the sheared edge profile of a 2mm wide and 1mm thick of polystyrene ribbon, four kinds of nail clippers: the upper/lower asymmetric two-line wedge of angle: $\alpha_U = 13^\circ$, $\alpha_U' = 45^\circ$ against lower side wedge of angle: $\alpha_L = 20^\circ$ that have varied the lower biting edge thickness $w_L$ at 0.06 and 0.25 mm were experimentally investigated. The results were as follow:

1. In order to perform a certain extent of reproducibility in the cutting test of a nail clipper under a constant indentation velocity, the prototype JIG fixture same as [4] was appropriate when considering the discussed calibration method of idle cutting response.
2. In case of nail clipper with large lower anvil thickness, the flow stress appeared to be compressive state and a large resistance, while the flow stress appeared to be tensile state and a small resistance value in the case of small lower anvil thickness.
3. When comparing the sheared edge trace with the nail clippers that varied lower anvil thickness, the nail clipper that have lower anvil thickness at 0.25mm generated a smooth sheared surface without any dynamic large force drop, the pre-crack at the necked stage did not occurred, and also the frictional restriction by the width of tip thickness appeared to fasten the force drop and the dynamic crack propagation.
4. When varying the tip thickness of anvil, the final force drop is controlled to disappeared for the lower biting edge thickness $w_L$ at = 0.25 mm. It seems to be caused from the frictional fastening.
5. When considered to the mechanical vibration of specimen that occurred during the cutting process, the wider of the lower blade provided the less mechanical vibration due to frictional restrain.

Acknowledgements

The authors thank Murayama Taiyo of Godhand company for making the nail clippers for experiment.
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