Improvement in Wear Characteristics of Electric Hair Clipper Blade Using High Hardness Material

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Making the angle of a hair clipper blade edge acute improves its cutting ability but causes the edge to be susceptible to wear, resulting in decreased cutting service life. When we used an electric hair clipper with a movable blade having a 45° acute angle on its edge, the edge caused significant wear and thus shortened its cutting service life. In this research, we conducted experiments on the cutting service life by cutting artificial hairs and, according to the experiment results, verified that using a high-hardness blade would suppress the wear of the blade edge to increase the cutting service life. Furthermore, assuming that “degradation in blade sharpness is subject to the wear loss of the blade edge and the wear loss depends on the distance at which the blade edge slides on the cross section of the hair; in other words, on the total number of strands of hair cut and the hardness of the blade materials”, we estimated the cutting service life from the blade hardness, and obtained excellent agreement between the estimated and test results. When using blades having different initial edge angles and radii, the concept of this cutting service life estimation enables us to facilitate estimation of their cutting service life. [doi:10.2320/matertrans.48.1131]

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1. Introduction

Sharpening the edge of a cutting blade reduces the reaction force that the blade receives from the object being cut, thus upgrading the cutting ability. However, a sharp blade edge wears out more quickly, decreasing its cutting service life.¹) Cutting blades that provide upgraded initial cutting ability but decreased cutting service life are not cost effective for industrial use.

As materials of cutting blades for razors and hair clippers, quenched SUS420J2Mo or similar is conventionally used. However, if the blade edge of the said material is made to a 45° acute angle, it decreases the cutting service life. This research used materials having a higher degree of hardness than that of quenched SUS420J2Mo to verify the upgrading effect of the cutting service life on continuous artificial hair cutting tests. Assuming that “degradation in blade sharpness is subject to the wear loss of the blade edge and the wear loss depends on the distance at which the blade edge slides on the cross sections of the hair; in other words, on the total number of strands of hair cut and the hardness of the blade materials”, we estimated the hardness of the blade material to provide the targeted cutting service life, and obtained excellent agreement between the estimated and test results.

2. Shape of Hair Clipper Blade and the Cutting Mechanism

Figure 1 shows close-up photographs of the edge part of an electric hair clipper blade unit, which consists of movable and fixed blades. We profiled these blades by machining and formed their cutting faces by shaving the edges with a grinding stone, and then formed flank faces by surface grinding to finish the blade edges. The movable blade makes a reciprocating movement sliding on the fixed blade in contact with it. For actual hair cutting, a bunch of hair is introduced into the fixed blade slots and nipped with the movable and fixed blade edges to cut one by one only with the movable blade. While cutting hair, the fixed blade just guides the hair.

3. Experimental Procedure

3.1 Experiment samples

To evaluate the wear characteristics, we used the same system including the electric hair clipper (ER151 from Matsushita Electric Works, Ltd.), except for the movable blade. We used a movable blade having a 45° edge angle and 0.5 μm radius and a fixed blade having a 78° edge angle and 2.0 μm radius. Figure 2 shows SEM photographs of a movable blade made of SUS420J2Mo and finished to a 45° edge angle.

As described later in this paper, this blade material has a short cutting service life. Materials having a higher degree of
hardness present increasingly better wear resistance. Consequently, in addition to quenched SUS420J2Mo, which is commonly used as the material of cutting blades for razors and hair clippers, we chose high-hardness stainless steel (C: 0.49%, Si: 0.1%, Mn: 0.2%, Cr: 10.5%, and Fe: Remainder, in weight) having HV770 hardness and powder high-speed tool steel (JIS G 4403: 2000) having HV810 hardness. Table 1 lists the specifications (i.e., hardness, edge radius, curvature, and initial cutting ability) of all movable blade samples used on the cutting service life tests.

### 3.2 Evaluation on cutting ability

For the practical use of electric hair clippers, the hair clippers need to cut more hairs in a short period of time. For our evaluation, we defined the “number of strands of acrylic artificial hair that can be cut per unit time” as the indicator of the cutting ability of electric hair clippers. We measured the cutting ability using the cutting ability testing equipment shown in Fig. 3. The following section describes the measurement in detail.

We used acrylic fibers of 80 µm in diameter that are similar to human hair in mechanical properties and size, as the artificial hair.2-4)

We clamped a bunch of 16,000 strands of artificial hair with the clamp. To bring the strands of hair closer to the practical cutting conditions, we simulated the shape of a bunch of strands of artificial hair in which a barber cuts hair held between his/her fingers to tie up the artificial hair in a bunch of 6 mm × 36 mm × 110 mm long. We clamped the bunch with a clamp positioned 60 mm away from the bunch end and positioned the remaining portion of the bunch out of the clamp. We set the cutting position to 5 mm from the upper end of the clamp opening. Then, we moved the electric hair clipper while operating it toward the bunch of strands of artificial hair at a rate of 18 mm/s together with the clamp. The number of strands of artificial hair cut per unit time is calculated from this moving rate. If the cutting ability is sufficiently high, the bunch of artificial hair will be completely cut with a margin left for the ability. In this case, we slightly increased the moving rate of the electric hair clipper to cut the bunch of artificial hair again. We repeated cutting until the bunch of artificial hair can no longer be cut to find the critical moving rate of the electric hair clipper at which the bunch of artificial hair can be completely cut. According to this critical moving rate, we calculated the maximum number of strands of artificial hair that can be cut per unit time, and then defined the calculated number as the cutting ability.

<table>
<thead>
<tr>
<th>Edge material</th>
<th>Evaluation criteria</th>
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<tbody>
<tr>
<td></td>
<td>Hardness, $H/\text{HV}$ (2.942N)</td>
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<tr>
<td>Quenched SUS420J2Mo</td>
<td>670</td>
</tr>
<tr>
<td>Powder high-speed tool steel</td>
<td>810</td>
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<tr>
<td>High-hardness-stainless-steel</td>
<td>770</td>
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</table>
3.3 Evaluation on cutting service life

We used the continuous artificial hair cutting test equipment shown in Fig. 4 to intermittently cut the artificial hair. The basic cutting operation of this test equipment is the same as that of the cutting ability testing equipment. The test equipment moves the electric hair clipper toward the bunch of 16,000 strands of artificial hair with the transfer unit linearly at a constant rate of 7 mm/s to cut the bunch of hair in a single stroke, thus repeating this basic operation. We recorded the total number of strokes, and then calculated the number of strands of hair cut. We set the cutting width of a bunch of hair to 10 mm to cut it only with 10 blades located in the center. Consequently, the wear of the cutting blade edges is only observed with these 10 blades. Under the conditions aforementioned, we started the test with measurement of the initial cutting ability using blades by which no strands of artificial hair were cut at all. Then, we continuously cut the artificial hair in the cutting service life tests. At the time when the total number strands of hair cut reached the target number, we observed the shapes of the blade edges with a scanning electron microscope to measure the cutting ability at that time. After that, we carried out the service life tests using the same samples again. We repeated the aforementioned sequence, thus recording the cutting ability for the total number of strands of artificial hair and also changes in the wear conditions of the blade edges by sample.

4. Results and Discussion

4.1 Results of cutting service life tests

Figure 5 shows the relationship between the cutting ability of the movable blades and the total number of strands of artificial hair cut per blade edge. Figure 6 shows the shapes of the blade edges while the cutting service life tests are in progress. We measured blade edge radius “R” by using Fig 6. In the case of quenched SUS420J2Mo having hardness of HV670, looking into changes in the relationship from the initial level to that after cutting 2.0 × 10⁷ strands of artificial hair, blade edge “R” showed a significant increase from 0.5 μm to 2.0 μm. In response to such increase, the cutting ability presented a significant drop (by 37%) from 2.55 × 10⁴ strands of artificial hair per second to 1.61 × 10⁴ strands of artificial hair per second. Then, looking into changes in the relationship after cutting 2.0 × 10⁷ strands of artificial hair and after cutting 4.0 × 10⁷ strands of artificial hair, blade edge “R” showed a change from 2.0 μm to 2.5 μm at a low increase rate. In response to such change, the cutting ability presented a slight drop (by 16%) from 1.61 × 10⁴ strands of artificial hair per second to 1.35 × 10⁴ strands of artificial hair per second.

By contrast, in the case of high-hardness stainless steel or powder high-speed tool steel, the blade edges remained nearly unchanged until 4.0 × 10⁷ strands of artificial hair were cut and further blade edge “R” was kept below 0.75 μm. After cutting 6.6 × 10⁷ strands of artificial hair, blade edge “R” shows a sign of slight wear to 1.5 μm on the high-hardness stainless steel and to 1.0 μm on the power high-speed tool steel. The cutting ability was degraded to 2.08 × 10⁴ strands of artificial hair per second on the high-hardness stainless steel and to 2.31 × 10⁴ strands of artificial hair per second on the power high-speed tool steel. In the case of quenched SUS420J2Mo, on the assumption that the cutting ability changed linearly from the initial level to that after cutting 2.0 × 10⁷ strands of artificial hair, estimating from this linear change, the cutting ability will be degraded to 2.08 × 10⁴ strands of artificial hair per second after cutting 1.0 × 10⁷ strands of artificial hair in terms of the ability for a single blade edge. Likewise, after cutting 0.51 × 10⁷ strands of artificial hair, the cutting ability will be degraded to 2.31 × 10⁴ strands of artificial hair per second. As a result, we verified that the cutting service life improved approximately by 6.6 times on the high-hardness stainless steel and approximately 12.9 times on the powder high-speed tool steel compared to that of SUS420J2Mo.

4.2 Blade edge radius “R” and the cutting ability

Figure 7 shows the relationship between blade edge “R” and the cutting ability. We verified that the cutting ability would be more likely to be subject to blade edge “R” in the case of the same blade edge angle even if conditions after the blade edges that were
worn slightly varied with differences in blade materials. In other words, if “R” is the same as that of the initial blade edge, the cutting ability will be determined by the wear loss of the blade edge. The wear loss depends on the distance at which the blade edge slides on the cross sections of the hair; in other words, on the total number of strands of hair cut and the hardness of the blade materials”. Consequently, we assumed that we could estimate the cutting service life as we knew the relationship between the hardness and wear resistance of the blade materials.

4.3 Estimation of cutting service life of high-hardness blade materials

We estimated the cutting service life from the hardness of samples on which the life tests were carried out. The following section describes the details of the estimation. The Ohkoshi type quick wear test is commonly used for evaluating the wear resistance of materials centering on steel products. In this test, two solid bodies come into contact with each other in Area “S”. Assuming that the pressure of this contact is “p”, wear loss “dW” caused when these solid bodies only slide by infinitesimal distance “dl” is represented by eq. (1), where “W” is referred to as specific wear loss, which represents the constant of the proportion representing wear characteristics.

\[ dW = W \cdot p \cdot S \cdot dl \]  

Applying this concept to wear on the edge of a movable blade of a hair clipper, the volume of the worn portion of blade
edge “V” can be regarded as “dW”, the constant of the proportion to be determined by the material of the movable blade as “W”, and the cutting resistance to cut a artificial hair “f” as the product of “p” and “S”. Consequently,

\[ V = dW \]  \hspace{1cm} (2)

\[ f = p \cdot S \]  \hspace{1cm} (3)

Furthermore, assuming that wear is caused on the blade edge by strands of artificial hair scrubbing the edge each time it cuts them, it would appear that sliding distance “dl” is proportional to the total number of artificial hairs cut “N”.

\[ dl = k \cdot N \]  \hspace{1cm} (4)

Hence, deleting “dW”, “p”, “S”, and “dl” from eqs. (1) to (4) gives eq. (5).

\[ V \cdot k^{-1} \cdot f^{-1} = W \cdot N \]  \hspace{1cm} (5)

In addition, as shown in Fig. 7, we assumed that the cutting ability “A” would come to the same figure if the blade edges had the same micro shape, i.e., if these edges had the same wear loss “V” after cutting a given amount of artificial hairs, even though the edges used different materials. Now, if the blade edges composed of materials of low and high hardness are represented by a pattern diagram, they will come to the patterns shown in Fig. 8. If the hair clipper blades 1 and 2 having different hardness and specific wear loss in blade materials are the same in the blade edge wear loss “V” and cutting ability “A” after individual cutting service life tests are conducted on the blades, it is assumed that the left-hand side of the eq. (5) would come to the same on the hair clipper blades 1 and 2. As a result, taking “W1” and “W2” as the specific wear loss and “N1” and “N2” as the total number of cut artificial hairs respectively sets up the eq. (6).

\[ V \cdot k^{-1} \cdot f^{-1} = W_1 \cdot N_1 = W_2 \cdot N_2 \]  \hspace{1cm} (6)

On the other hand, with consideration given to applications to machine parts and in order to realize wear characteristics, Yamamoto and others\(^7\) conducted Ohkoshi type quick wear tests on a variety of steel products directly and after surface modifications were made to these steel products and then presented the relationship between the hardness of materials and the specific wear loss. Furthermore, Akagaki and others\(^3\) conducted research on the influence of hardness on wear under the lubricated conditions and reported that a linear relationship could be set up between the hardness of materials and the specific wear loss on double logarithmic comparisons for materials having a high level of hardness.

We found the double-logarithmic linear approximation eq. (7) through referring to data only on materials having a surface hardness of HV700 to 900 at a wearing rate of not more than 1.5 m/s from the experiment data of Yamamoto and others,\(^5\) charting a double-logarithmic graph of hardness and specific wear loss, and following the concept of Akagaki and others.\(^7\) When referring to the experiment data, for materials with surface modification made, taking into account the replacement of materials as bulk materials for discussion about the wear of blade edges, we chose material with a sufficiently thick modification layer (i.e., of not less than 55 μm). Furthermore, with regard to the wearing rate, we chose data of 1.5 m per second and below on materials having less influence of heat generation or adhesion.

\[ \log W = -13.68 \log HV + 34.29 \]  \hspace{1cm} (7)

Assuming that the hair clipper is made of SUS420J2Mo and its specific wear loss is “W1” and hardness is “HV670”, and that the hair clipper 2 is made of high-hardness stainless steel and its specific wear loss is “W2” and hardness is “HV770”, the specific wear loss “W1” and “W2” are found by the eq. (7), respectively. Then, deleting the “W1” and “W2” by assigning the specific wear loss found in the eq. (6) makes it possible to set up the eq. (8).

\[ N_2 = 6.7N_1 \]  \hspace{1cm} (8)

As a result, it was estimated that the high-hardness stainless steel had a cutting service life 6.7 times as many as that of SUS420J2Mo, which agrees well with the 6.6 times that was obtained from the experiment. When we performed the same calculation on powder high-speed tool steel having hardness of HV810, we found that the estimated total number of strands of artificial hair until the cutting ability reached 2.31 × 10^4 strands of artificial hair per second came to 13.4 times as many as that of quenched SUS420J2Mo, which agrees well with the 12.4 times that was obtained from the experiment. The concept facilitates estimation of the cutting service life of the blades having different initial edge angles and radii.

5. Conclusions

We reviewed the influence of the wear of electric hair clipper blades on their cutting ability. As a result, we proved the following.

1) As the results of the cutting service life test conducted on the high-hardness stainless steel with a hardness of HV770 and powder high-speed tool steel with a blade material hardness of HV810, we verified that the development of wear on the blade edges was slow to improve the cutting service life approximately by 6 times in the high-hardness stainless steel and approximately 12 times in the powder high-speed tool steel compared to that of SUS420J2Mo.

2) We verified that the cutting ability would be more likely to linearly depend on the blade edge “R” in the case of the same blade edge angle even if the blade materials and blade edge patterns were different. Furthermore, in the case of a 45-degree blade edge angle, we could quantitatively define the relationship between the blade edge “R” and cutting ability.

3) As a result of the estimation of the cutting service life from the hardness of blade edge materials, it was improved approximately by 6 times in the high-hardness stainless steel and approximately 13 times in the powder high-speed tool steel compared to that of SUS420J2Mo, which presented excellent agreement with the results of experiments. When we use blades having different initial edge angles and radii, the concept of this cutting service life estimation enables us to facilitate estimation of their cutting service life.
REFERENCES


2) JIS C9614-1995, Description Table 1.


