Utilization of High-strength Steel Wire for Blade of Grass Cutters

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We assessed the application of high-strength steel wires (spring wires) for creating safe and efficient blades for grass cutters. Utilizing our specially shaped wires, blades were produced and tested in the fields of the National Agriculture and Food Research Organization (NARO) using both grass trimmers and remote-controlled grass mower. By changing the steel wire's cross-sectional shape from a simple square to a pentagon with sharp apexes, we achieved cutting performance comparable to traditional chip saws. The remote-controlled grass mower successfully showed its performance in cutting down bushes and woody plants with diameters over 10 mm, which was impossible with nylon cords. Introducing a freely rotating attachment for the cutting blade prevented fatigue failure of the steel wire blade and eliminated the risk of "kickbacks." However, during stone skipping tests, significant stone scattering occurred, and the attachment part showed weakness in impact resistance against hard objects, prompting us to propose solutions for these challenges.

Keywords: grass cutting, cutting blade, steel-wire blade, specially shaped wire, safety

1. Introduction

The Special Steel Wire Division of Sumitomo Electric has primarily focused its business on three product categories: prestressing steel strand, spring wires, and tire cords. However, in applications related to automotive engines, the market is expected to shrink due to the shift towards electric vehicles (EVs), making it imperative to search for new markets. Against this background the division has started to study the possibility of developing new products using special steel wires.

The authors focused on issues in the agricultural field, which will face challenges as the population ages and declines in the future. Based on an investigation into various agricultural issues, we found that grass cutting activities are cost burdening in terms of management and cause frequent injury accidents.(1)-(3) Circular-saw-type cutting blades with cemented carbide tips, commonly called "chip saws" are widely used for grass-trimming work. However, improper handling can lead to serious injuries, or fatal accidents in the worst case scenario, due to the high-speed rotation of the sharp blade.(4) In contrast, nylon trimmer lines (hereinafter referred as "nylon line"), which cut grass using nylon resin strings, are relatively safe; however, they are inferior in terms of cutting capability because they cannot cut tough grass. To address this issue, we considered that both cutting capability and safety could be ensured by replacing nylon lines with piano wires or hard drawn steel wires, which are among our products. These considerations served as the incentive for conducting this study.

Based on literature and intellectual property surveys, we found that the idea of using piano wires as cutting blades*1 had been proposed a long time ago(5), and that many patents had been filed as intellectual property.(6)-(8) However, actual products are rarely seen. We conducted this study to investigate the reasons behind this, determine the requirements for cutting blades, and evaluate the feasibility of meeting these requirements and launching a business using our steel wires.

2. Types of Cutting Blades

For the representative cutting blade types, refer to the references.(9) Chip saws with cemented carbide tips account for 90% of the cutting blades used for grass trimmers due to their high cutting capability, but they pose significant hazards, as mentioned above. Notably, a phenomenon called "kickback" presents a significant safety risk. When a specific area of a cutting blade comes into contact with an obstacle or the ground, the blade bounces backward in the opposite direction to its rotation. This is very dangerous for the worker, because the cutting blade moves unpredictably. When a cutting blade strikes a hard object, such as concrete or large stones, the cemented carbide tips of the blade may break off and scatter. This makes it difficult to perform so-called "edge trimming"—cutting near concrete walls and gutters—using chip saws. In contrast, nylon lines enable edge trimming and do not cause kickback because they use resin cords. Even if nylon lines hit a person, this does not cause significant injury as long as the person is wearing protective equipment. However, nylon lines are only suitable for cutting soft grass due to their limited cutting capability. Additionally, the rotating cords tend to hit and scatter small stones. There are also metal blades without tips (e.g., two-teeth, four-teeth, and eight-teeth blades) and flexible blades, whose attachment parts are designed to rotate freely. Two-edged blades and free blades are inferior to chip saws in terms of cutting capability. However, because they do not cause tooth chipping, they are mainly used in applications where contact with the ground cannot be controlled, such as self-propelled or remote-controlled mower. Flexible blades are considered safer because they mitigate the impact of hitting stones and hard objects. However, metal blades require regular sharpening. As discussed above, there is no perfect cutting blade in terms of cutting capability, safety, and maintenance.

3. Requirements of Cutting Blades

We interviewed grass cutting experts about their requirements for cutting blades and summarized their opinions, as shown in Table 1. First, they required cutting capability equivalent to those of chip saws. They stated that safety was important, but a decrease in cutting capability was not desirable. A decrease in cutting capability leads to lower fuel efficiency or higher power consumption. This is particularly important for electric grass trimmers, which are difficult to charge in outdoor environments. The second point was the prevention of flying stones. Business owners were especially concerned about this point because they are held liable for damages if a person or object is struck by flying stones. We asked why the use of steel wire blades had not become more widespread, but there was no definitive answer. Nevertheless, some expressed concerns about the fear of broken cutting blades flying around. Other points included ease of on-site blade replacement in the event of wear, lightweight design, and edge-trimming capabilities. There was tendency to minimize the time spent on grass cutting because the task was not directly related to agricultural production. Based on these findings, we decided to fabricate a cutting blade by focusing on high-priority functions: high cutting capability, prevention of flying stones, ease of replacement, prevention of kickback, and prevention of breakage and scattering of steel wire blades when striking hard objects. These were expected as essential components of safety and quality.

Table 1. Requirements of grass cutting blades

Requirement	Reason
Cutting performance equivalent to that of chip saws	No decrease in work efficiency
No scattering stones	To prevent scattering stone accidents
Low power consumption	Difficult to charge in an outdoor environment
Ease of replacement	To eliminate waste of time
Capable of edge trimming	To eliminate the time required to replace with an edge trimming blade
Long service life	To eliminate the time required for replacement
No kickback	To prevent fatal accidents and injuries to operators
No breakage	Expected quality

4. Product Design

4-1 Cross-sectional shape of a blade

We can fabricate steel wire blades of various cross-sectional shapes, including round shapes, by harnessing our specially shaped wires processing technology. First, we prepared a shaped wire with a rectangular cross-section (2.3 mm × 3.6 mm), whose cutting capability were expected to be higher than those of round wires due to its edges. We also prepared wires with a pentagonal cross-section featuring an sharp apex angle, as shown in Fig. 1 (hereinafter referred to as “pentagonal wire”). Both cutting capability and safety were ensured by forming an acute angle at the tip while providing appropriate roundness. Two variations of the pentagonal cross-section were prepared: symmetrical and asymmetrical. The asymmetrical shape was designed to enhance aerodynamic stability during rotation. This cross-sectional shape was fabricated using our shape rolling process. However, rolling the pentagonal wire incurred additional costs such as roll fee. Thus, in this study, we confirmed the feasibility of manufacturing these shapes by rolling, and then fabricated steel wire blades by machining for following tests.

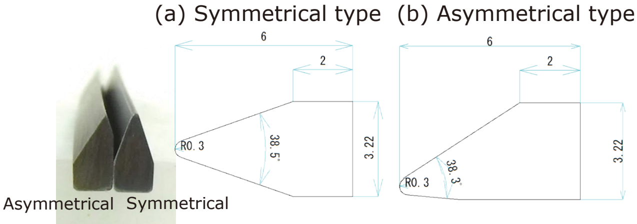

Fig. 1. Cross-section of pentagonal steel wire blades

4-2 Method of installing a steel wire blade

A flexible blade structure, whose attachment part was designed to rotate freely, was employed for the steel wire blade to prevent fatigue failure. Photo 1 shows a cutting blade equipped with pentagonal wires, a magnified view of the attachment part, and the installation condition of rectangular wires. A through hole was drilled in a pentagonal wire, which was installed onto a pin extended from the resin board. The pin was secured by a clip, which was designed for ease of insertion and removal, as well as

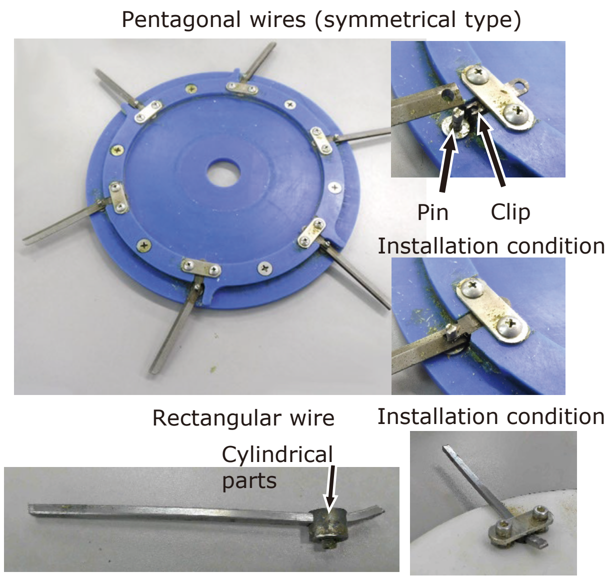

Photo 1. Cutting blade using specially shaped wires

replacement of the steel wire blade by using a tool. This structure allowed the steel wire blades to rotate freely during operation. In contrast, the rectangular wire was found to be too narrow to accommodate a through hole. Thus, it was installed by piercing the wire through a cylindrical parts, with the bent part hooked, the cylindrical parts embedded in the resin board, and a cap used to hold it down. This flexible blade structure prevent fatigue failure caused by the repeated loads encountered during grass cutting, and mitigated the impact when the blade hit hard objects.

5. Demonstration Test

In studying the cutting blade shape, we grew grass on a farm owned by the Western Region Agricultural Research Center (hereinafter referred to as "WARC") of the National Agriculture and Food Research Organization (hereinafter referred to as "NARO"). We then conducted a cutting test to obtain a quantitative evaluation.

5-1 Experimental procedures

A farm owned by WARC/NARO was used for the test. As shown in Fig. 2, we prepared 16 blocks, with each block measuring 1.5 m × 29 m. To reduce variations in vegetation and clearly define the block borders, oat seeds were sown in six rows in each block and grown to a height of approximately 40 cm. To compensate differences in plant growth in each block, we cut the plants within a 50 cm × 50 cm area prior to the test and measured the weight (g) of the plants after drying them at 105°C for 48 h. This measurement served as an index of the plant density on the farm. The dry weight at the WARC farm was 83 to 135 g per 50 cm × 50 cm area. For the power consumption index, we measured the battery voltage drop of the grass trimmer after cutting the plants in one block. The work time per block was measured to evaluate the work efficiency. This process was repeated twice for each cutting blade type, and the mean value was adopted. Two workers with different proficiency levels were engaged, and cutting was performed four times in total (twice per cutting blade type per worker). Makita's MUR012GZ (maximum voltage: 80 V) grass trimmer was used, and the rotation speed was set to 5,000 rpm. For this test, pentagonal wires of a symmetrical shape were used. For comparison, we used Makita's DC chip saw with a diameter of 255 mm (model: A-67321)[9] and nylon lines appurtenant to the Ultra Metal Roller 4 (model: A-58241).[9]

To investigate cutting performance in highly bush-covered slope where operators cannot enter, we performed tests using remote-controlled mower. Sasaki Corporation's "smamo," shown in Photo 2, was used as the remote-controlled mower. An edge-trimming attachment (SSC-30) was installed for the test. Two types of steel wire blades were installed onto the edge trimming attachment to cut grass on a bush-covered slope, also shown in Photo 2. For comparison, a standard cutting blade for the smamo (a four teeth flexible blade), shown in the lower left part of Photo 2, was used. A grass-trimming attachment (M700) was installed for the standard cutting blade, which equipped two set of the blades. The dry weight of the plants covering 50 × 50 cm area of the slope was 250 to 530 g.

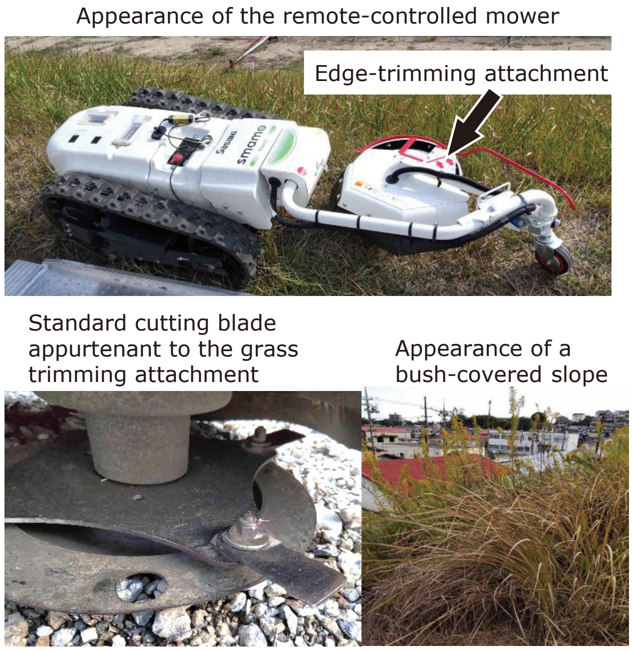

Photo 2. Appearance of a remote-controlled grass mower and a slope to be cleared

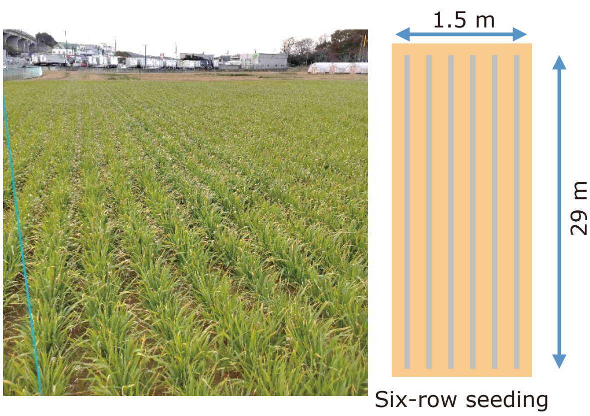

Fig. 2. Appearance of a farm at WARC and image of a block

5-2 Test results

In the grass trimming test, the qualitative usability of the pentagonal wires was close to that of the chip saw, with a strong sense of reaping. In contrast, the qualitative usability of the rectangular wires was closer to that of the nylon lines, giving a sense of tearing off the grass. In fact, as shown in Photo 3, the surface of the stubs cut by the pentagonal wires was flat. In contrast, the surface of the stubs cut by the rectangular wires showed that the grass had been teared off. A large amount of residue was scattered when the rectangular wires were used. The grass became entangled when the cutting amount per one swing was increased for the chip saw, so it was necessary to control the cutting amount. In contrast, the pentagonal wires did not cause grass entanglement, and their cutting capability did not require special attention, which was considered an advantage. Figure 3 shows the quantitative test results. The work time per dry weight is plotted on the vertical axis in Fig. 3 (a). This shows the efficiency with the grass density taken into account. The pentagonal wires attained an work time equivalent to that of the chip saw, followed by the rectangular wires and the nylon lines. This order remained the same when the worker changed. This trend was consistent regardless of the proficiency level. When we tested the asymmetrical pentagonal wires, stability increased without a sense of rotating part floating, and it was possible to reduce the grass height after cutting. Figure 3 (b) shows the voltage drop against work efficiency. The voltage drop of the pentagonal wires was small, second only to that of the chip saw, indicating relatively good battery life. The results of the remote-controlled mower are shown in Fig. 3 (c). For the remote-controlled mower, efficiency per 1set of the blade was indicated. It was difficult to perform cutting on the bush-covered slope along a block. Thus, the area in which cutting was performed during 10 minutes was plotted on the vertical axis as the efficiency. For the remote-controlled mower, the pentagonal wires demonstrated the highest efficiency, exceeding that of the standard cutting blade. As shown in Photo 4, we were able to cut woody Rosa multiflora and shrubs with a diameter of more than 10 mm. Obviously, these plants could not be cut by nylon lines, and they posed the hazard of kickback even when a chip saw is used. After the completion of the work, the steel wire blades were neither bent nor broken, despite some wear. These results showed that the use of steel wire cutting blades with a pentagonal cross-section (based on the round tip shape of our design) attained an efficiency equivalent to that of the chip saw and the standard blade of the remote-controlled mower. We also found that the efficiency varied significantly depending on the cross-sectional shape of the steel wires.

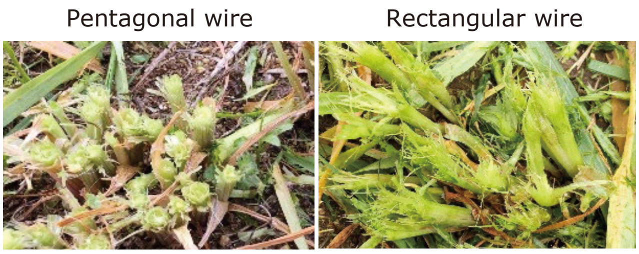

Photo 3. Stubs after cutting

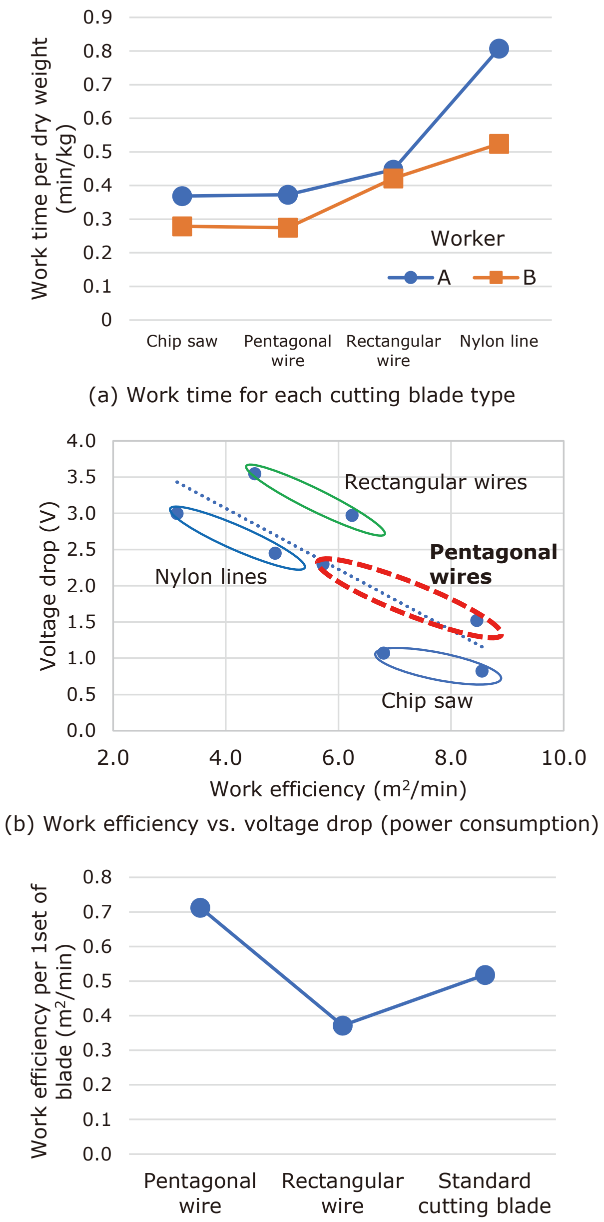

Fig. 3. Test results of steel wire blades

Photo 4. Cutting using a remote-controlled mower with steel wire blades (example)

6. Safety Test

The pentagonal wire demonstrated cutting capability equivalent to those of the chip saw. However, from the standpoint of practical use, it was necessary to verify the existence of kickback when hitting hard objects or flying stones. Thus, we conducted a general performance test regarding safety at the Institute of Agricultural Machinery (hereinafter referred to as "IAM") of NARO.

6-1 Kickback test

To check for kickback, we conducted a test using the system shown in Fig. 4. A grass trimmer was secured to a stem to allow flexible rotation. Clockwise rotation was triggered by pushing the grass trimmer with an electric cylinder. The cutting blade was adjusted to hit an acrylic plate with a thickness of 15 mm in the area that caused kickback. When kickback occurred, the rotation of the grass trimmer accelerated upon contact with the acrylic plate. In the general performance test, we used asymmetrical pentagonal wires characterized with high stability. For comparison, a chip saw and a chisel blade*2 (Makita's A-72849) were used. The impact speed was 1.5 m/s to simulate the "swing" speed during the grass-trimming work. The depth of cut into the acrylic plate was 10 mm, and the rotation speed of the grass trimmer was 6,150 rpm.

The test results showed that the chisel blade caused significant kickback, while the chip saw caused weak kickback, and the pentagonal wires did not cause any kickback. After the test, the acrylic plate was checked, and it was found that the pentagonal wires reduced kickback by allowing the blades to buffer at the moment of impact.

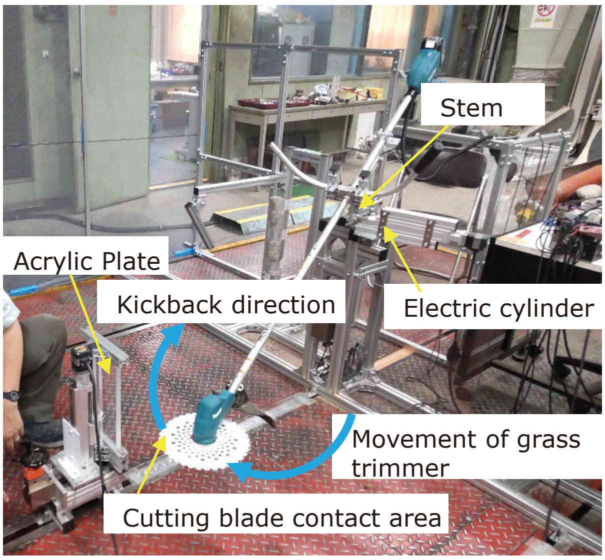

Fig. 4. Configuration of the kickback test

6-2 Stone skipping test

Figure 5 shows the configuration of the Stone skipping test. A grass trimmer was secured to the support frame, and a ceramic ball of φ12 mm (hereinafter referred to as a "ball"), which imitated a small stone, was forced to hit the tip of a rotating cutting blade at a speed of 1 m/s. The ball rebounded in the approach direction, hit the pressure measuring film, and left an indentation mark. The distribution and intensity of scattering stones were estimated based on the positions and colors of the indentation marks. The image at the moment of impact was captured using a high-speed camera to measure the initial velocity of the scattering stones. The process was repeated 100 times.

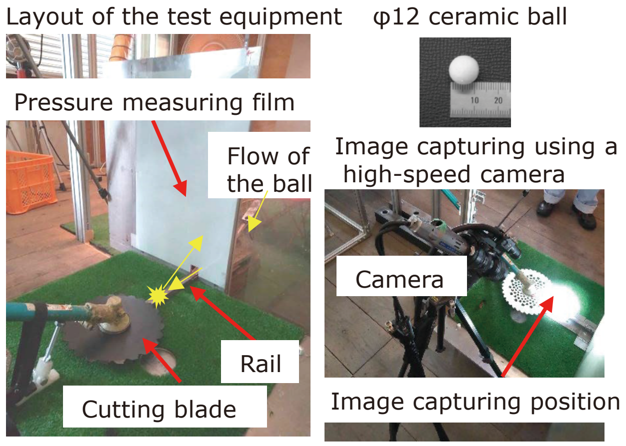

Fig. 5. Stone skipping test

Figure 6 shows the scattering patterns left on the pressure measuring films. The scattering range was the smallest for the chip saw, followed by those of the chisel blade and the pentagonal wires. The initial velocity was the lowest for the chip saw, followed by that of the chisel blade, which was almost equal to that of the pentagonal wires. The results showed that the pentagonal wires were characterized by a high initial velocity and a large scattering range. It should be noted that the balls scattered over a wide range and posed hazards in the test of the pentagonal wires. Thus, the test was discontinued after 18 repetition cycles. This was likely to have been caused by the large gap between the blades in the pentagonal wires, as shown in Fig. 7 (a), resulting in a strong impact on the ball. The asymmetrical-type pentagonal wires presumably lifted the ball as shown in Fig. 7 (b), leading to scattering across a wide

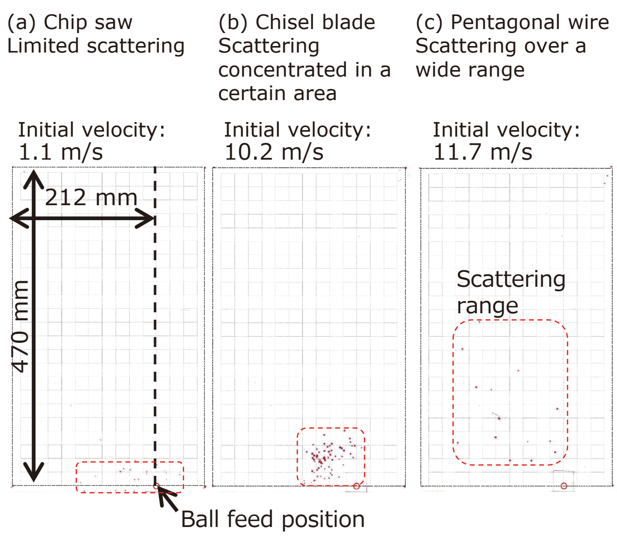

Fig. 6. Ball scattering range

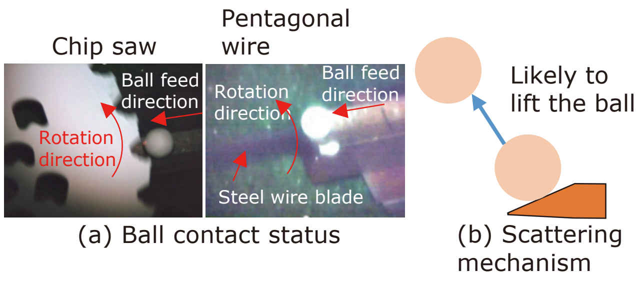

Fig. 7. Discussion about scattering

range.

6-3 Impact test

The configuration of the impact test is shown in Fig. 8. A grass trimmer was suspended from the ceiling and was swung upward by pulling a rope. Upon releasing the rope, the grass trimmer swung down, and the rotating cutting blade impacted a 25 mm diameter S15C steel rod at a speed of 1 m/s. Photo 5 shows the test results. When the pentagonal wires impacted the steel rod, the pin and clip of the attachment part were damaged, resulting in scattering of the steel wire blades. However, the blades themselves only bent but did not break. In comparison, the chip saw lost one of its tips, and the chisel blade was slightly chipped.

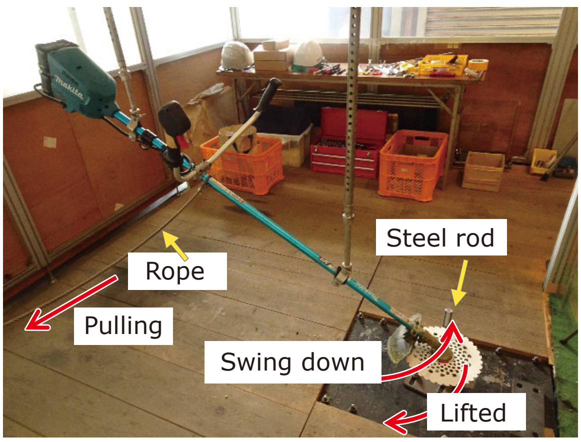

Fig. 8. Configuration of the impact test

Photo 5. Impact test result

7. Overall Evaluation

Table 2 compares the functions of the steel wire blades with those of a conventional cutting blade based on the requirements. The steel wire blades demonstrated cutting capability equivalent to those of the chip saw. In the impact test, there was no scattering of the cutting blades due to breakage, and the steel wire blades did not cause kickback. Both the target cutting capability and basic safety were satisfied. The results also revealed the need to improve the attachment part, and the issue of scattering stones was identified. Additionally, the service life could not be determined in this short-term test. Further verification will be carried out based on tests conducted by a professional services company.

Table 2. Performance of the steel wire blades in contrast to the requirements and comparison with the conventional cutting blades

Requirement	Steel wire blades (newly developed)	Chip saw	Nylon line
Cutting performance	Excellent	Excellent	Poor
Scattering stones	Poor	Good	Poor
Power consumption	Excellent	Excellent	Poor
Replacement time	Good	Excellent	Excellent
Edge trimming	Not confirmed	Poor	Excellent
Service life	Not confirmed	Good	Poor
Kickback	Excellent	Poor	Excellent
Breakage of the cutting blades	Excellent	Poor	Poor

To address the above issues, we plan to forge the tip to improve the strength of the attachment part and redesign it as a type that can be hooked onto the board, as shown in Fig. 9 (a). This structure is expected to make replacement much easier and improve the edge-trimming performance. Regarding the issue of scattering stones, the current structure tends to lift and scatter stones (see Fig. 7 (b)). We believe that stone scattering can be reduced by setting the steel wire blades upside down as shown in Fig. 9 (b), so as to cast stones toward the ground.

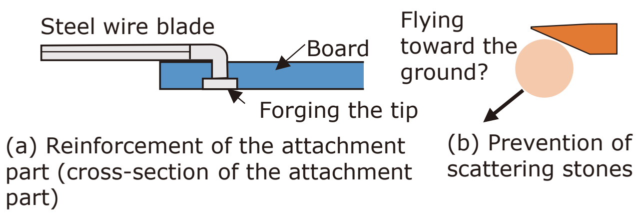

Fig. 9. Measures against the issues

8. Conclusion

We fabricated grass-cutting blades using our specially shaped wires and conducted tests on their cutting performance using a grass trimmer and a remote-controlled mower. The results showed that the steel wires with a pentagonal cross-section with a sharp apex angle attained a cutting performance equivalent to that of the chip saw. The voltage drop was low, second only to that of the chip saw. Breakage, which had been a concern for the steel wire blades, did not occur, and no kickback was observed, either. Thus, we were able to ensure a certain degree of safety. However, two issues remained unresolved: scattering stones and the method of installing the steel wire blades. We will investigate the possibility of changing the blade shape to address the former issue, and consider forging the tip of the steel wire blades and employing a structure to hook the blades onto the board to resolve the latter issue.

9. Acknowledgement

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Technical Terms

*1 Cutting blade: In this paper, a cutting blade refers to a circular blade installed on a grass trimmer. Wire blades are referred to as "steel wire blades."

*2 Chisel blade: A cutting blade that can cut hard wood, including shrubs. A metal blade without a cemented carbide tip was used for comparison.

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