Technical paper

Study on Cutting Edge Wear and Excavation Resistance of Motor Grader

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Motor graders used for such purposes as earthwork and snow removal work have excellent capacity of cutting road surfaces. Therefore, the cutting edges mounted on their blade tips are used under extremely severe conditions in the works such as road maintenance (levelling a hard earth/sand road surface by cutting its unevenness) and removal of compacted snow (removing the compacted snow and/or ice trodden down and hardened). Thus cutting edges are expected to be improved to higher efficiency in terms of enhanced abrasion resistance and reduction of excavation resistance.

This report presents our study in which we verified the relations of a cutting edge's shape with the wear rate and excavation resistance by simulation and test.

***Key Words**: Cutting edge, Abrasion resistance, Excavation resistance, Ground contact area, Simulation, Test*

1. Introduction

Cutting edges mounted on the blade tips of motor graders (refer to **Fig. 1**) wear more severely when working with a hard earth/sand road surface or compacted snow. According to the condition of the road surface for snow removal, the wear allowance of the cutting edge can be lost and require replacement during only a single mobilization for snow removal.

Moreover, if the edge's wear progresses, the ground contact area with the road surface will increase, which will cause an increase in excavation resistance, resulting in worse penetration performance and work fuel consumption of the cutting edge. Therefore, against such a hard road surface as requires removal of compacted snow, the operator often uses the power tilt function (tilting the blades back and forth) so as to sharpen the edge tip while working.

Hence, if the abrasion resistance and excavation resistance of cutting edges can be improved, such effects as improvement of excavating workability and fuel consumption can be expected in addition to reduction of the edge replacement cost. On the other hand, improvement of the cutting edge shape has been hardly reviewed though their materials have been improved. The shape of the initial graders conforming to the Japanese Industrial Standards (JIS) has not been changed.

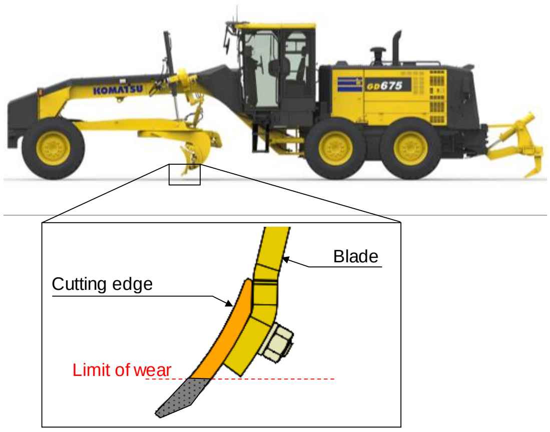


Fig.1 Cutting edge

Under the circumstance, this study was aimed at raising the efficiency (extending the service life and reducing the excavation resistance) of cutting edges by improving their shapes. The authors verified the relations between the shapes of cutting edges and wear rates and excavation resistances, by simulation and test from the standpoint of metal cutting work by industry-university joint research with Kanazawa University.

2. Progress of Actual Wear

Fig. 2 shows the wear progress of the cutting edge mounted on the actual motor grader. The wear progresses almost vertically from the edge's tip to the flank, and the service life comes to an end just before the main body of the blade wears. Wear of the cutting face is hardly seen.

3. Analysis by Cutting Simulation

Quantitative comparative evaluation is difficult to review the shapes of cutting edges because verification by mounting on the actual motor grader will require much cost and time, and besides, their results are largely dependent upon the components and densities of earth/sand and compacted snow and the test conditions. Therefore, this research employed the "Cutting Simulation", which was used for metal working, to analyze an excavation phenomenon.

3.1 Simulation Model

For the cutting simulation, we used general-purpose software DEFORM® which allowed relatively easy simulation of a material removal phenomenon by plastic deformation. **Fig. 3** shows an analytical model created using DEFORM®.

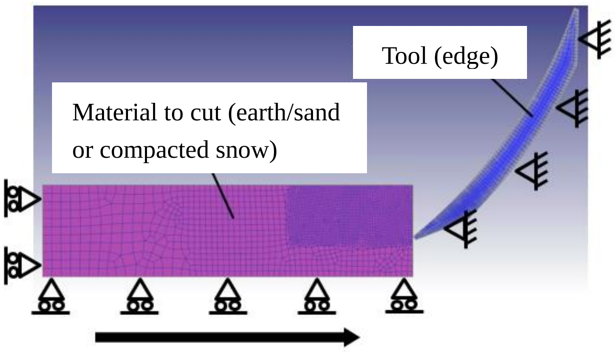


Fig. 3 Simulation model

However, the physical properties of the earth/sand and compacted snow are not constant values and difficult to identify though the data about the mechanical and physical properties of the tool (edge) and materials to be cut (earth/sand and compacted snow) are indispensable to reproduce the actual excavation phenomenon by simulation. Hence, we have decided not to adjust or match the physical properties in this simulation and focused on qualitative evaluation (how the depth of wear changes according to the tool shape), instead of aiming at difficult quantitative evaluation (calculation of wear depths).

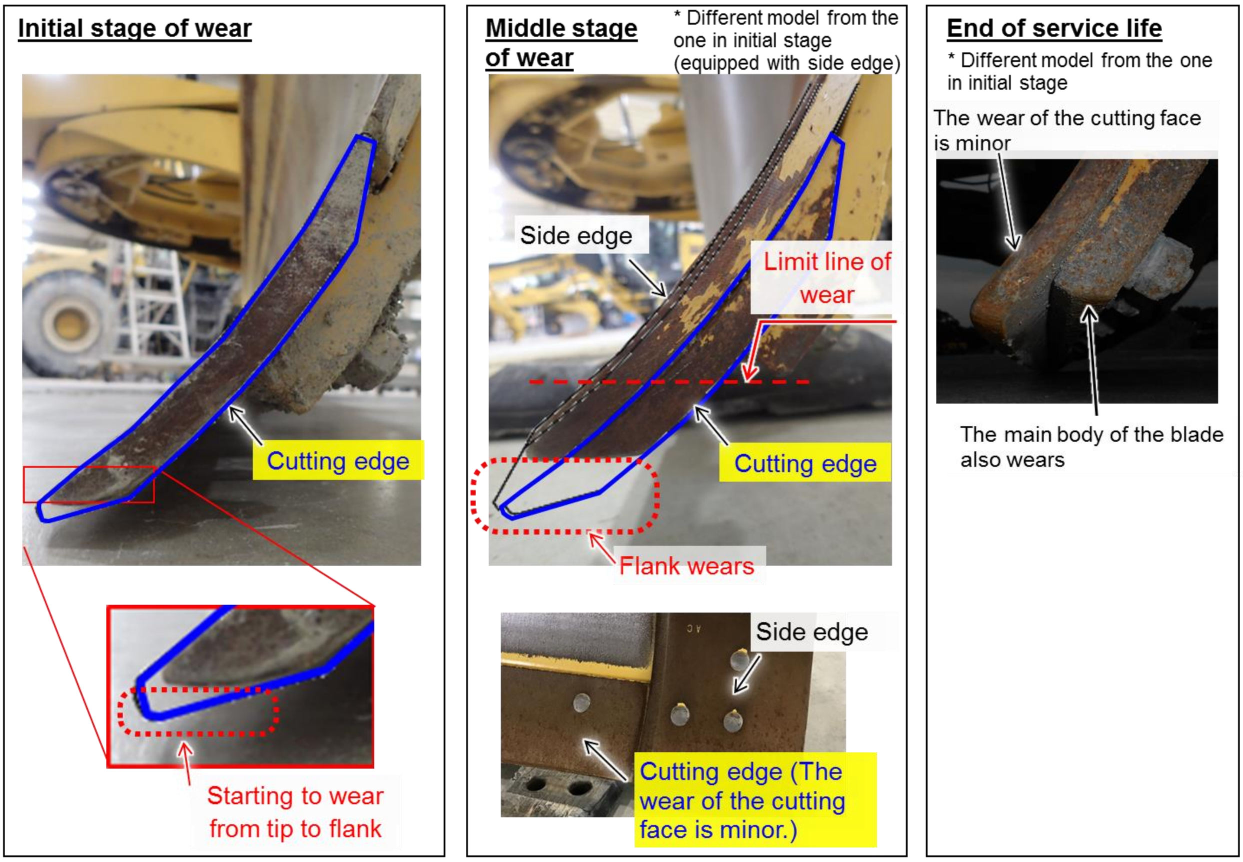


Fig. 2 Edge wear progress

3.2 Modification of Deviation between Cutting Simulation and Actual Excavation

While metal chips greatly affect the wear of the cutting face in metal cutting work, wear on the cutting face is hardly seen in the actual excavation as described in section 2., where wear progresses only on the flank, which is a difference from metal cutting work.

Furthermore, we observed how the actual grader excavated the surface of compacted snow and found that the discharged compacted snow was the shear type as shown in **Fig. 4**, which was completely isolated from the compacted snow on the road surface. Therefore, the discharged snow on cutting face can be considered to hardly affect the wear. Excavation of earth and sand can be also considered to be similar to that of compacted snow because the discharged soil is isolated, leaving no continuity. That agrees with the results of checking wear conditions in section 2.

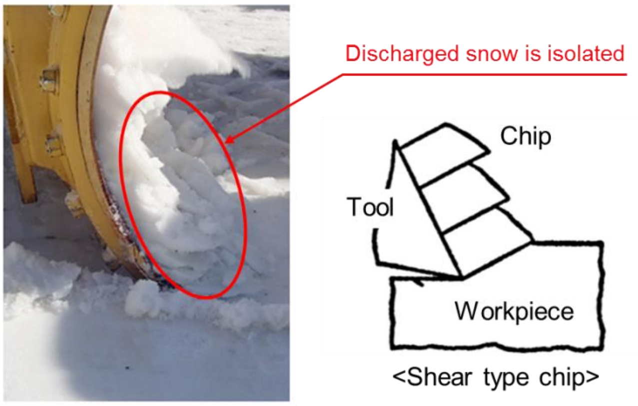


Fig. 4 Excavation of compacted snow

Thus, since the conventional cutting work simulation deviates significantly from the actual excavation in that the wear depth of a cutting face becomes large, the model was modified as follows. (Refer to **Fig. 5**)

First, a cutting analysis was performed with DEFORM® for a short time. After the model was deformed, the node positions of the mesh were output and sent to MATLAB®. The chips (discharged soil or snow) excavated at the tip of the edge and rolled up to the cutting face side were deleted from the model geometry at MATLAB®, and fed back to DEFORM® again. This cycle was automatically repeated while the model geometry continued to be modified successively, by which the effect of a cutting face was eliminated to achieve an analysis method that enabled only the wear of a flank to be evaluated.

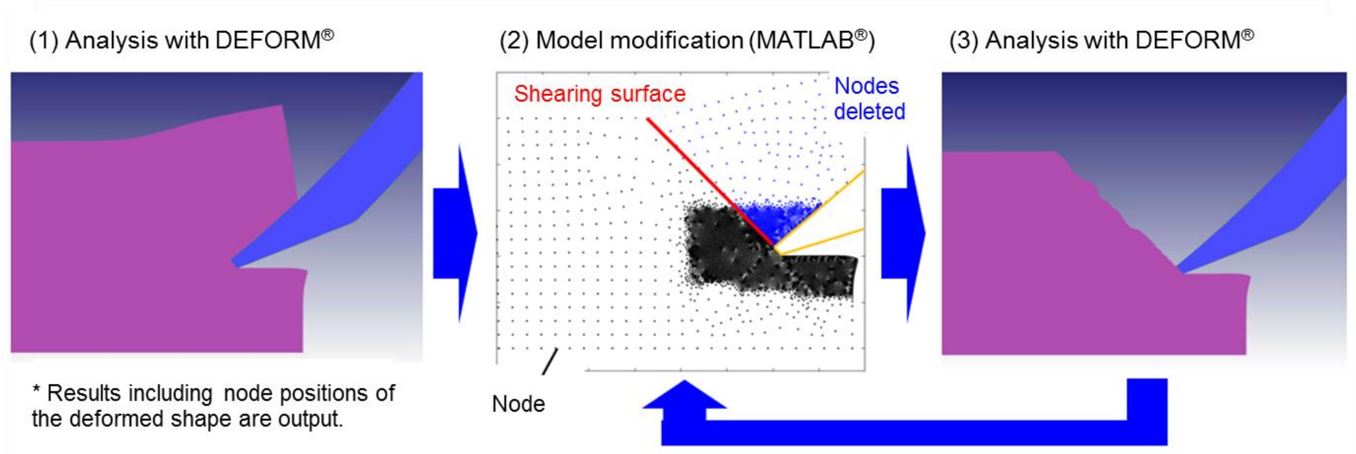


Fig. 5 Cycle of chip removal from cutting face

3.3 Updating of Edge Shape

Since generally in cutting work, the service life is considered to be ended when the tool is worn, there is also no concept in a cutting simulation that a tool shape changes due to wear. Therefore, that cannot apply as it is to an analysis in which the tool continues updating its shape while wearing until the service life comes to an end, like a cutting edge. Hence, we have made improvements so as to update the edge shape as follows:

From the distribution of bearing stress and slipping velocity during excavation, the depth of wear can be found from the equation shown in **Fig. 6**, in accordance with the "Archard model", a model of a wear phenomenon. The edge shape after a given period of time was estimated from the depth of wear so that it could be fed back to the subsequent analysis.

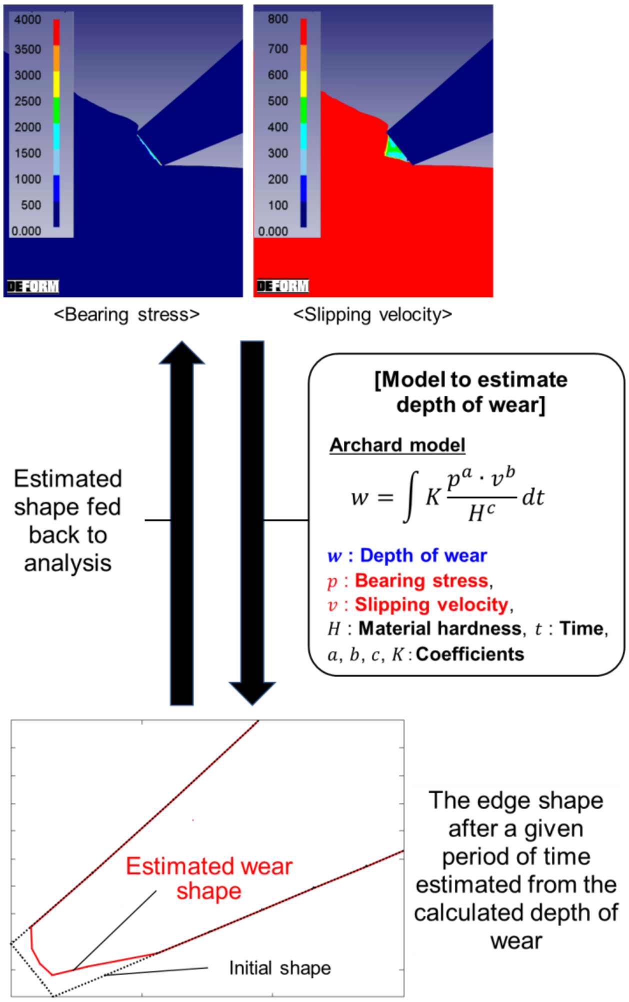


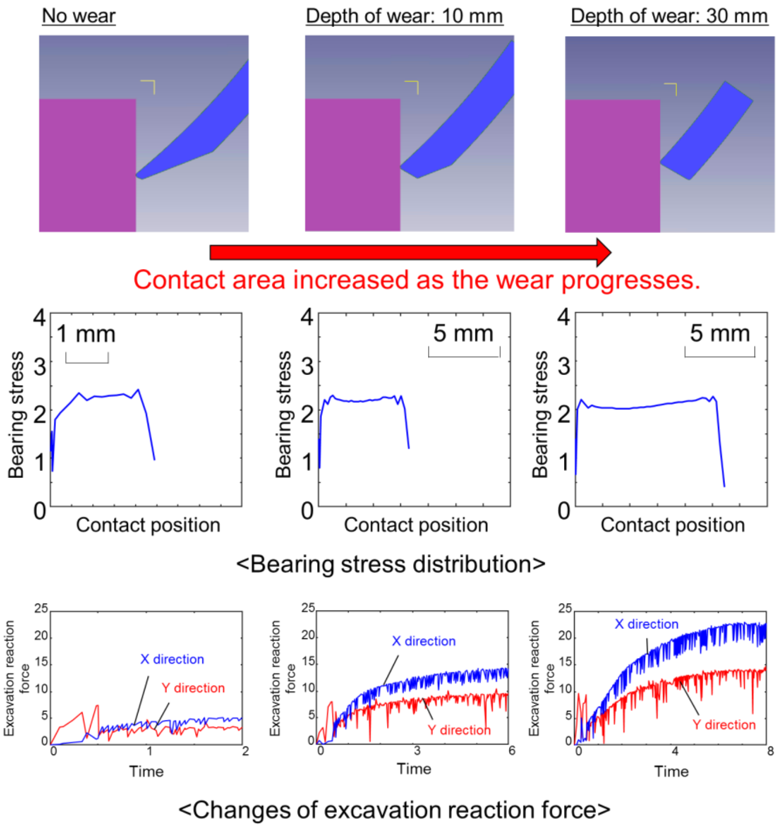
Fig. 6 How to update edge shape

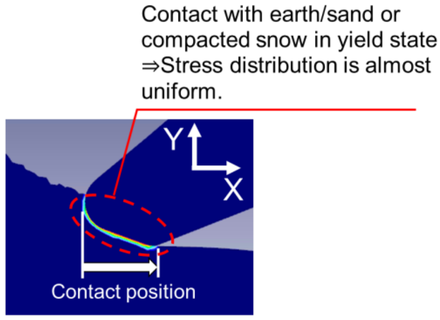
3.4 Simulation Results

Fig. 7 shows the comparison results of the bearing stresses during excavation and excavation reaction forces between at the time of the initial shape of the edge and at the time of wear which were obtained by simulation.

It was initially predicted that if the contact area was large, the force required for excavation would be dispersed, which would cause the bearing stress to be reduced. Though the result contrary to the prediction has been obtained that the bearing stress will remain almost the same even if wear progresses and causes the contact area to increase. Since the bearing stress remains the same, the excavation reaction forces increase both in the X- and Y- directions which affect the required traction force and the required blade pressing force respectively as the contact area increases.

It can be considered from these results that only the tip of the edge actually works in an excavation work, and the part in contact with the flank, which is backward from the tip, only provides resistance and increases the excavating resistance.





Contact area	Required traction force (Reaction force in X direction)	Required pressing force (Reaction force in Y direction)	Contact bearing stress (Effect on wear)
Small	Small	Small	Not affected
Big	Big	Big	Not affected

Fig. 7 Simulation results

4. Verification by Simulation Test

We performed a simulation test on excavation of compacted snow, using a lathe, in order to verify the validity of the cutting simulation results.

4.1 Simulation Test Method

Fig. 8 shows schematic pictures of the test. The cylindrical, simulated compacted snow made of finely crushed ice with abrasive grains dispersedly mixed to accelerate the test, which was compression molded with a press machine, was frozen again and then held with a lathe as the material to cut and provided with a rotary motion. The simulated edge made of polylactic (PLA) resin was fabricated with a 3D printer in imitation of the tip shape of the cutting edge. A compacted snow excavating work was reproduced by pressing the simulated edge onto the end surface of the simulated snow. The test was performed under the conditions where the excavation velocity and cutting depth based on the assumption of the actual snow removal work were converted into the scale of the test.

4.2 Results of Simulation Test

Fig. 9 shows the results of comparative evaluation conducted on the wear depths of the edge tips in the simulation test, with the Standard 1 simulating the shape of the current edge tip and the Standard 2 having a shape with a thick wall flank and an intentionally increased contact area.

The test results verified that the depths of wear after the elapse of a given period of time were almost the same regardless of the contact thickness (contact area) as indicated by the simulation results.

Furthermore, the measurement results of the change in shape due to wear every fixed period of time also show, as shown by **Fig. 10**, that the wear rate after initial wear did not decrease but became almost constant, from which we were able to confirm that they were not largely dependent on the contact area.

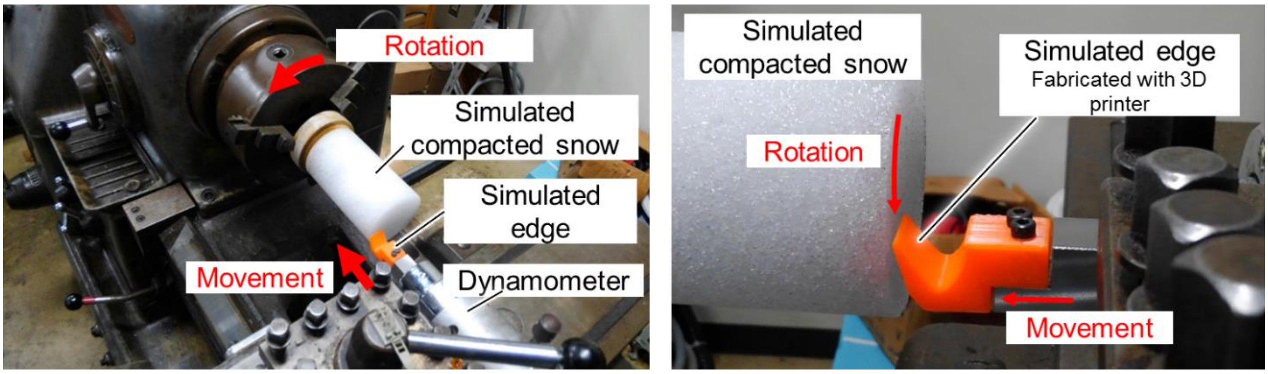


Fig. 8 Simulation test devices

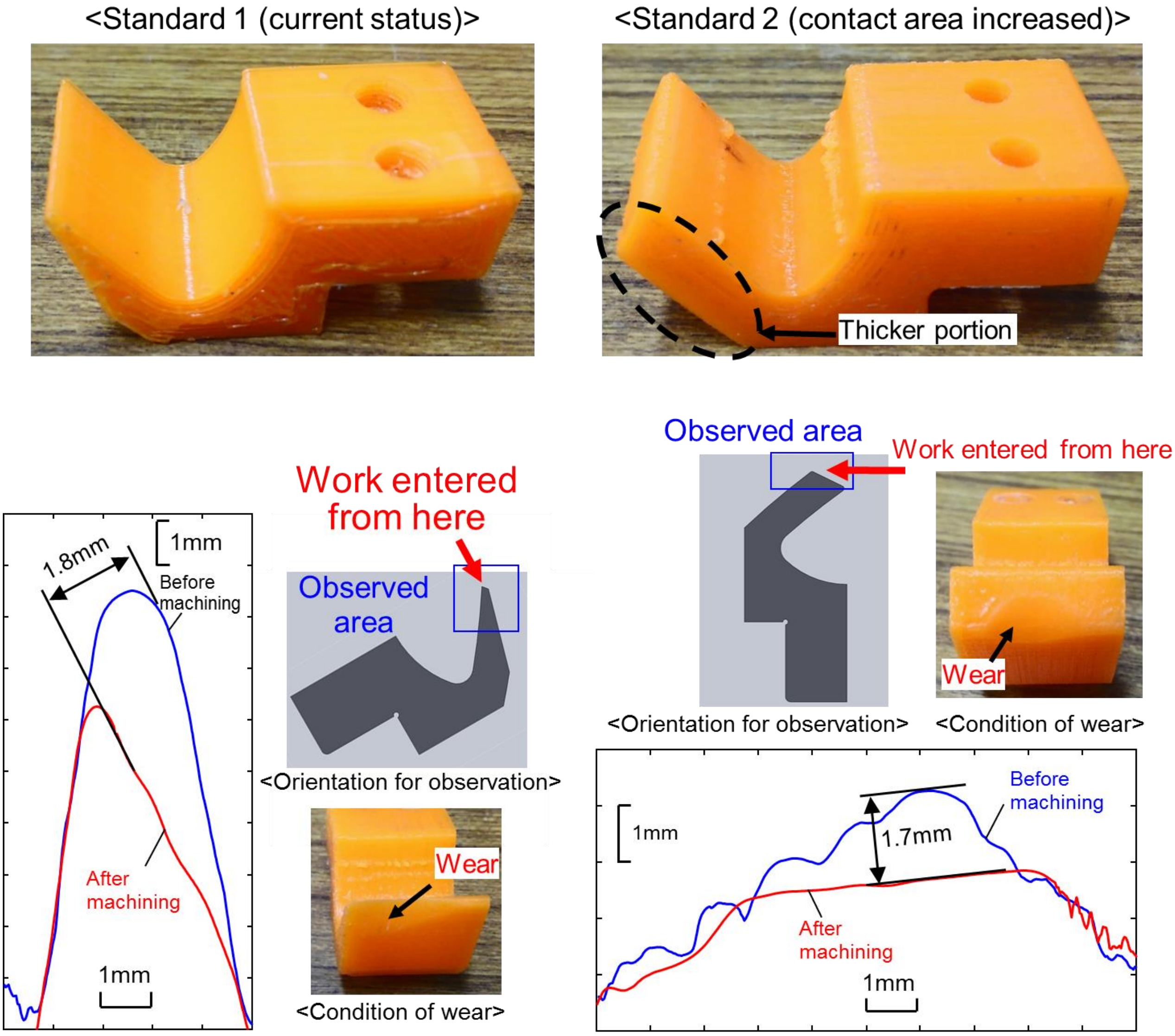


Fig. 9 Results of comparison between depths of wear in simulation test

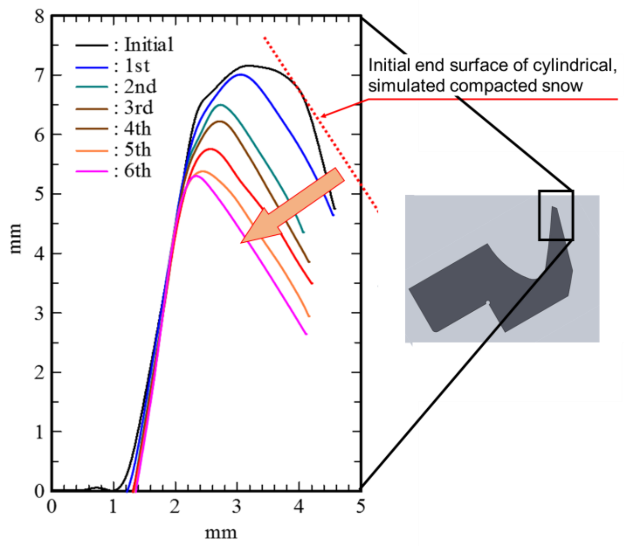


Fig. 10 Changes of edge shapes by time steps

5. Conclusion

The authors were able to confirm by simulation and analysis that the contact surface bearing stress of the tip of the cutting edge in the excavation with a motor grader was not dependent upon the ground contact area of the edge. The result obtained from the above result was that it was difficult to drastically improve the wear life by changing the edge shape including thickness. On the other hand, the authors were also able to confirm that the smaller the contact area, the more reduced the excavation reaction force could be against the cutting depth. Accordingly, we would like to continue our study on cutting edges aiming at reduction of excavation resistance in the future.

Introduction of the authors

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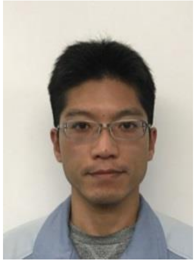

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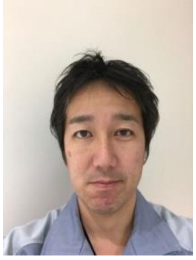

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[A comment from the authors]

Initially, we felt tremendous anxiety about how our study from the perspective of the cutting work field could be applied to the excavation phenomenon with construction machinery. However, we would like to make use of the knowledge obtained in this research and reflect it in further improvements in the future.

Finally, we would like to express our heartfelt thanks to Prof. Hosokawa, Prof. Hashimoto and the students of Kanazawa University for their cooperation through the industry-university joint research.