# Development of Garbage Collecting Robot for Marine Microplastics

Mitsuki Uno[1] and Ryo Kurazume[2]

***Abstract*— Marine microplastics originate from plastic products and are crushed as they drift through the ocean, posing a serious threat to marine ecosystems. Nonetheless, collecting these scattered and small microplastics by hand from washed-up beaches is challenging. Consequently, we are working on designing a cleaning robot to automatically gather marine microplastics on beaches. This paper outlines the primary mechanism of the cleaning robot and explores the necessary functions for effective microplastic collection. Two kinds of experiments exploring the behavior of sand in stationary and dynamically states, ”Pseudo-Angle of Repose Measurement Experiment” and ”Claw Excavation Experiment”, are carried out using an experimental model of a cleaning robot.**

## I. INTRODUCTION

Marine microplastics consist of small plastic products like bottles and straws, discarded into the ocean, crushed as they drift, and eventually washed up on beaches and other locations. This garbage poses a significant threat as marine organisms might mistake it for food, disrupting the marine ecosystem. Presently, local residents manually clean up the larger plastic garbage. However, as depicted in Fig.1, dealing with crushed plastic garbage is extremely challenging due to its integration with sand and widespread scattering.

Fig. 1. Marine microplastics on beaches

Presently, we are in the process of developing a cleaning robot capable of automatically collecting marine microplastics on beaches. As a primary step, this paper introduces the fundamental mechanism of the cleaning robot and examines the necessary functions for efficient microplastic collection on beaches.

## II. PREVIOUS RESEARCH

Numerous proposals have been made regarding the use of robots as a solution to marine pollution, leading to the development of various garbage collection robots in previous studies. For example, the small clean robot utilizes tires suitable for rough terrain and employs rotating shovel-shaped claws for garbage collection [1], while the cleaning robot mimics a broom and dustpan mechanism for garbage collection [2]. Additionally, there is a proposed robot that utilizes a conveyor belt for collecting discarded bottles [3]. However, these robots primarily focus on gathering larger garbage items such as plastic bottles, and an efficient cleaning robot specifically designed for collecting small marine microplastics (less than 5 mm) scattered on sandy beaches has not been proposed. As an alternative approach, we have previously developed a robot that collects garbage using a vacuum [4] as shown in Fig.2. This particular robot uses suction force to collect fine garbage, but it faces challenges concerning power efficiency and the separation performance of garbage and sand.

Fig. 2. Vacuum-type marine microplastics cleaning robot [4]

## III. REQUIRED SPECIFICATIONS

The functions essential for collecting garbage on beaches involve ”excavating” sand and garbage, as well as ”separating” sand and garbage. To effectively address these functions, we propose a robot equipped with a conveyor belt featuring a mesh net and claws to efficiently collect small garbage from the beach, as depicted in Fig.3. The claws ensure stable excavation, while the belt conveyor with mesh effectively separates sand and garbage. Furthermore, the garbage is classified by size by squeegees on the conveyor belt. These mechanisms can efficiently collect sandy beach garbage as shown in Fig.4.

This paper primarily focuses on the ”excavating” function of retrieving sand and garbage. To achieve this, the study adopts ”claws” for excavation. By affixing large claws to the

[1]Mitsuki Uno is with Graduate School of Information Science and Electrical Engineering, Kyushu University, Japan. uno@irvs.ait.kyushu-u.ac.jp

[2]Ryo Kurazume is with Faculty of Information Science and Electrical Engineering, Kyushu University, Fukuoka 819-0395, Japan. kurazume@ait.kyushu-u.ac.jp

robot's front, it can simply move forward to dig out sand and garbage. This method was chosen due to its simplicity and reliable performance in achieving the objective.

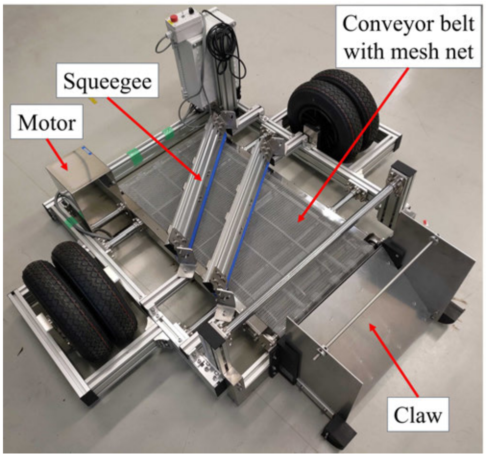


Fig. 3. Conveyor belt-type marine microplastics cleaning robot

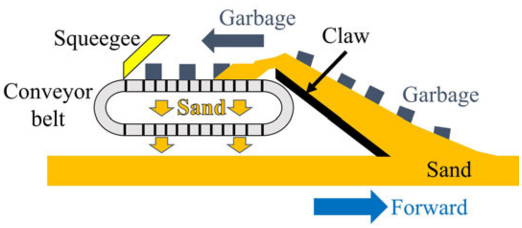


Fig. 4. Garbage collection process

## IV. DESIGN OF CLAW

The excavating claw's parameters encompass the angle and shape of the claw. To elucidate these characteristics, this study conducted three experiments: the "Pseudo-Angle of Repose Measurement Experiment," "Claw Excavation Experiment," and "Sandy Beach Experiment." The "Pseudo-Angle of Repose Measurement Experiment" aims to determine the appropriate angle and shape of the claws under static conditions, where only gravity influences the sand deposited on the claws. The "Claw Excavation Experiment" seeks to identify claws that efficiently collect garbage by utilizing sand piles generated during excavation. Lastly, the "Sandy Beach Experiment" evaluates the garbage collection performance on-site against the actual garbage present.

### *A. Pseudo-Angle of Repose Measurement Experiment*

The angle of repose represents the angle between the slope and horizontal plane of a granular deposit during its formation. Various methods, such as the tilting box method, fixed funnel method, and drum method, are used to measure it [5]. While the general angle of repose for sand is approximately 34°, it can vary based on the shape and size of the grains [6]. Reference paper [7] indicates that sand piles deposited along walls exhibit deformations corresponding to their angle of repose.

In this research, the mechanism under study involves considering the claw as an inclined plane rather than the traditional horizontal plane associated with the angle of repose. To examine this, the experiment modifies the horizontal surface into a slope or step, as shown in Fig.5, to obtain a pseudo-angle of repose. The objective of this experiment is to explore the impact of the angle of repose on the claws used for sand o excavation and determine the optimal angle and shape for the claws.

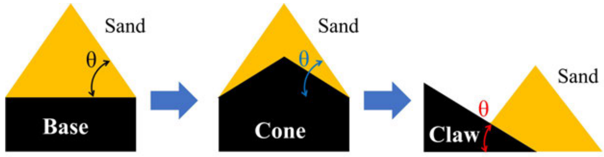


Fig. 5. Application of angle of repose

*1) Procedures:* Fig.6 presents the 3D models of the angle of repose measuring instrument and the conical base used in this experiment. The cone is placed inside the circular cavity at the instrument's center, and sand is poured through the top funnel of the instrument to create a sand pile atop the cone. The pseudo-angle of repose, shown by the red line in Fig.7 is then measured from the formed sand pile using a digital protractor.

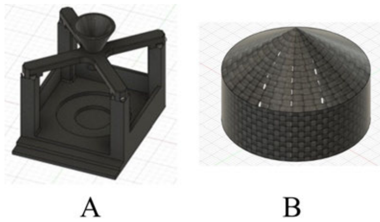


Fig. 6. A : Pseudo-angle of repose measuring instrument, B : Circular truncated cone

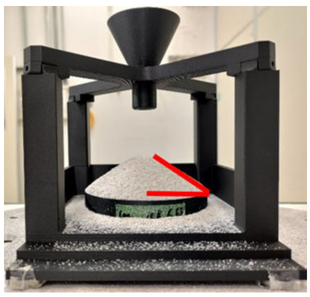

Fig. 7. Pseudo-angle of repose measurement experiment

The measurement items consisted of two types of cones: a 50 mm diameter cone with 0, 1, 2, and 3 steps and a 100 mm diameter cone with 0, 2, 4, and 6 steps as shown in Fig.8. Each cone was made with a slope ranging from 0 to 35° at intervals of 5°. The study examined the impact of changing the slope and surface geometry on sand deposition, as well as the behavior of sand piles at different scales.

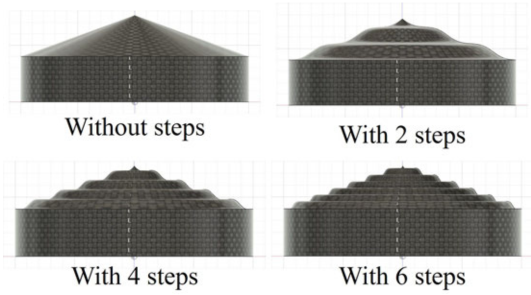


Fig. 8. Shapes of cones with or without steps

*2) Results:* Fig.9 illustrates the measurement results at 50 mm, and Fig.10 at 100 mm. Both graphs present the pseudo-angle of repose on the vertical axis and the slope angle on the horizontal axis, with each line representing the variation in steps. Regions with a pseudo-angle of repose of 0° indicate areas where no sand pile was formed. For cones with a 50 mm diameter, the pseudo-angle of repose remained stable at approximately 30-31°, and sand piles could not form when the slope exceeded 25°. In the case of the 100 mm diameter cone, the pseudo-angle of repose remained stable at about 32°, and sand piles could not form when the slope exceeded 30°. In both instances , the angle of repose showed little influence from the number of steps.

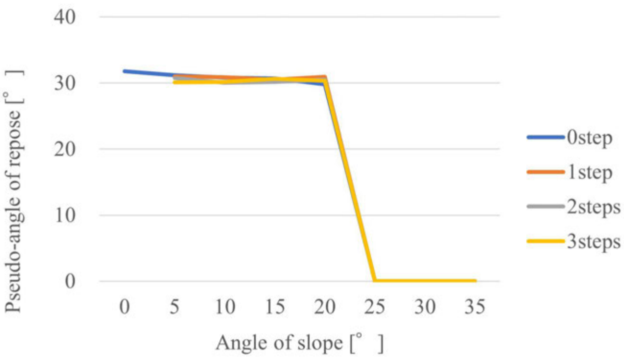


Fig. 9. Results of experiments with a 50 mm diameter cone

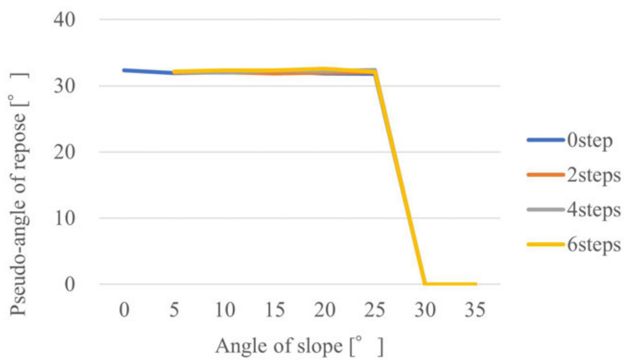


Fig. 10. Results of experiments with a 100 mm diameter cone

*3) Discussion:* Based on the experiment's findings, the pseudo-angle of repose for the sand used in this study is estimated to be approximately 30 to 32°. However, sand piles could not form at slope angles of 25° or higher for the 50 mm diameter cone and 30° or higher for the 100 mm cone. This occurrence is likely attributed to the claws mostly replacing the sand pile, resulting in an insufficient of sand to form a stable pile. The discrepancy in the slope angle limit for forming sand piles between the 50 mm and 100 mm diameter cones can be attributed to the larger slope surface area of the 100 mm diameter cone, enabling it to hold more sand. Given that sand piles cannot form beyond slope angles of 25-30°, it can be assumed that sand can be deposited at a minimum angle of approximately 20° when this slope angle is applied as a claw angle. Nevertheless, it is essential to note that this experiment solely involved sand deposition from above and did not encompass actual sand excavation. Thus, considering lateral forces during excavation, it is conceivable that sand piles could be formed at steeper angles.

## *B. Claw Excavation Experiment*

As shown in Fig.11, for the waste to be conveyed to the separation mechanism situated behind the claw, it must be displaced by the sand flow created during the formation of sand piles during excavation. However, the configuration of this sand pile varies based on factors such as the claw angle, excavation speed, and sand's water content. To explore claws that enable efficient excavation, this experiment (Fig.12) measured the amount of sand required to form a sand pile (amount of sand formation [$cm^3$]), the quantity of sand that displaces the garbage (amount of outflow [$cm^3$]), and the associated garbage collection rate [%] (number of garbage collected per all garbage prepared). To obtain the amount of formation, the difference in volume between the claws and the sand pile was measured using point cloud data acquired through the Azure Kinect depth camera. The amount of outflow and the collection rate were determined from the mass of sand collected in the box (Fig.13) and the number of garbage pieces retrieved. In evaluating the index, superior excavation performance was determined by lower the amount of formation and higher the amount of outflow, as this suggests more efficient garbage excavation through the formation of smaller sand piles and increased sand flow when excavating over the same distance.

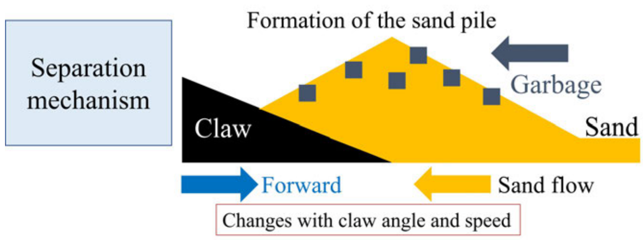


Fig. 11. Sand and garbage flow from excavation

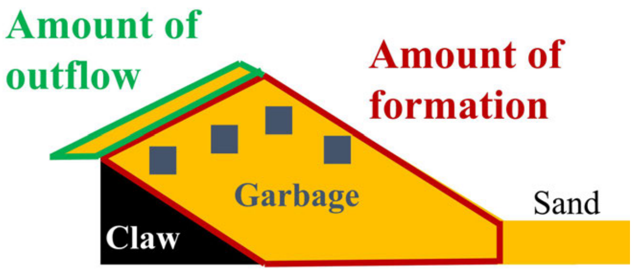


Fig. 12. Evaluation index

*1) Procedures:* The 3D model of the claw used in this experiment is shown in Fig.13. It was fabricated using a 3D printer and a polycarbonate plate. The claw has a height of 5 cm, while the plate has a height of 14 cm and a width of 12 cm. At the rear of the claw, a collection box gathers the sand and garbage that flows out during the process. The claws are efficiently held in place by the polycarbonate plates, ensuring secure retention of the sand for waste removal and facilitating observation of the formed sand pile's condition.

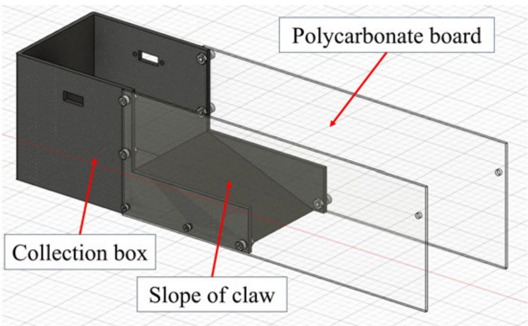


Fig. 13. Claw

The equipment used for continuous excavation in the experiment is presented in Fig.14. It consists of a frame made from polycarbonate sheets and an aluminum frame, designed to collect sand. Two 1-meter-long rails are positioned on the frame, and the claws are mounted between these rails. Additionally, the motor winds the wire shown by the yellow line in the diagram, enabling the claws to be pulled for excavation.

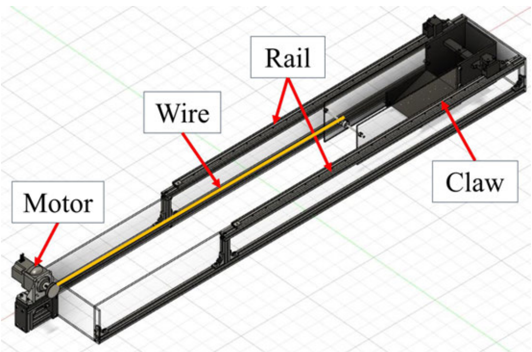


Fig. 14. Excavation test equipment

The experiment is depicted in Fig.15. The excavating claw was inserted into the sand by 2 to 2.5 cm, and then the rail-mounted claw was pulled using a motor and wire for excavation. The excavation distance covered approximately 1 m. The claw slope angle was set to four patterns: 20, 40, 60, and 80°, while the excavation speed had six patterns: 0.05, 0.1, 0.15, 0.2, 0.25, and 0.3 m/s. Additionally, the sand moisture content was tested in three patterns: approximately 0, 8, and 16%.

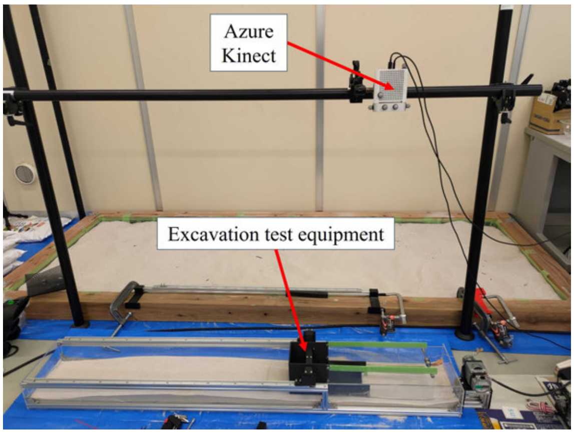


Fig. 15. Claw excavation experiment

Fig.16 illustrates the arrangement of garbage used in the experiment. Plastic plates of approximately 3 mm in size, resembling the secondary microplastics commonly found scattered on beaches, were fabricated and employed. Ten plates were positioned at equal intervals in front of the claws, as indicated by the red circle in the diagram. Although the position of these plates will affect the garbage collection rate, they were placed along the center line in order to compare the basic performance of the claws. For each pattern, five excavations were conducted, and measurements were taken for the amount of formation, the amount of outflow, and the collection rate.

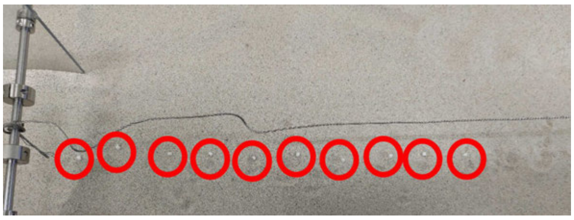

Fig. 16. 10 pieces of plastic garbage

*2) Results:* Each evaluation indicator presents, the amount of formation in Fig.17, the amount of outflow in Fig.18, and the collection rate in Fig.19.

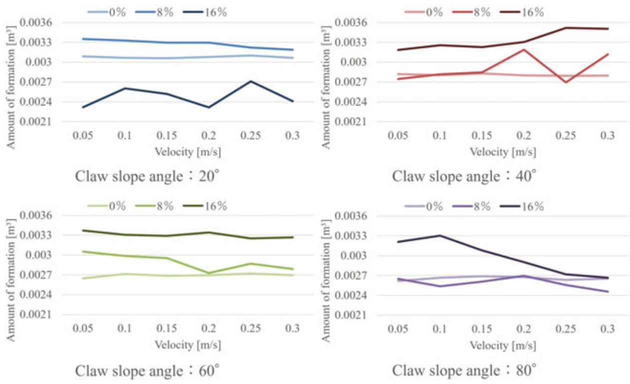


Fig. 17. Amount of formation

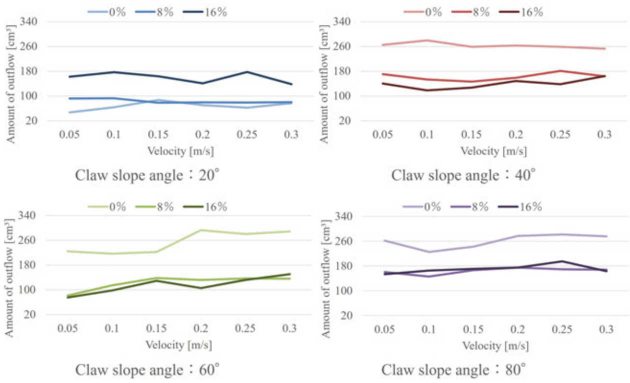


Fig. 18. Amount of outflow

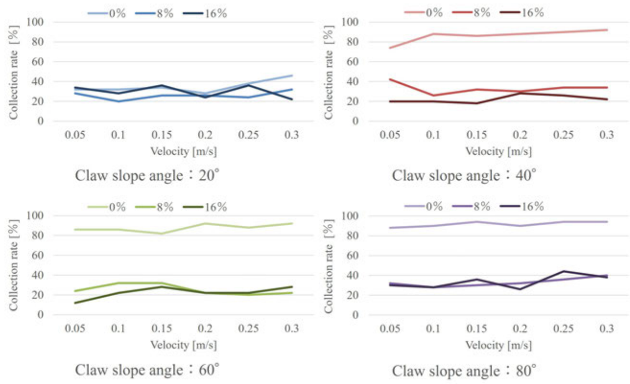


Fig. 19. Collection rate

The vertical axis of each graph represents the amount of formation, the amount of outflow, and the collection rate, while the horizontal axis indicates the velocity. In the graphs, the three blue lines represent claws with slope angles of 20°, red for 40°, green for 60°, and purple for 80°. Each of the three lines indicates an increase in moisture content from 0, 8 and 16% as the colour becomes darker.

Across the graphs, there was minimal variation with speed. However, as the moisture content increased, the amount of formation tended to rise, while the amount of outflow and the collection rate tended to decline. Additionally, as the angle increased, the amount of formation tended to decrease, while the amount of outflow and the collection rate tended to increase.

*3) Discussion:* First, we will discuss each of the evaluation indices. The increase in the amount of formation with rising water content can be attributed to the sand becoming lumpy due to increased moisture. Conversely, the decrease in the amount of formation with a higher claw angle is likely due to the reduction in claw size, leading to decreased support force for the sand pile. The reduction in the amount of outflow and the collection rate with increased water content can be attributed to the sand becoming lumpy and less flowable due to higher moisture content. On the other hand, the increase in the amount of outflow and the collection rate with an increased claw angle is likely due to the smaller claws providing reduced support force for the sand pile, thereby enhancing flowability.

In this experiment, the most favorable results were observed when the claw angle was set to 80° for all three evaluation indices. Based on this result, it is considered that a claw angle of 80° is a practical choice for garbage collection.

## *C. Sandy Beach Experiment*

Based on the excavation experiments, it was concluded that the most effective excavation was achieved using 80° claws. In this particular experiment, the performance of excavating claws on an actual sandy beach was evaluated using the crawler robot shown in Fig.20. To make a comparison, claws with a slope angle of 40° were also fabricated using the same method, and their performance was assessed.

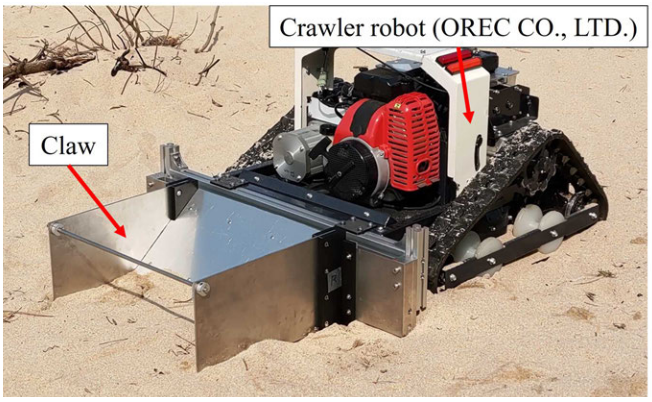


Fig. 20. Crawler robot

*1) Procedures:* The experiments took place on Terayama beach in Fukuoka City, Japan. The sand at the site had a moisture content of 2 to 3% and was interspersed with wood pieces, plastic, seaweed, and other materials. Fig.21 showcases four types of claws used in the experiment: two types with 40° claws and two types with 80° claws. These claws were fabricated from rust-resistant stainless steel plates and measured approximately 200 mm in height and 500 mm in width. The key distinctions among each claw were the slope angle and the length of the side wall: for 40° (1) and

80° (1), the length of the side wall was unified and longer than the horizontal length of the claws; for 40° (2) and 80° (2), the length of the side wall matched the horizontal length of each claw. This design aimed to reduce the amount of excavated sand deposited and enhance excavation efficiency. Unlike in the Claw Excavation Experiment, we didn't mount a large side walls against the claws, because the actual claws are so wide and large that we thought it would be sufficient to just mount a side walls about the same size as the claws. The claws were mounted on a crawler robot (OREC CO., LTD.), which conducted the excavations by moving forward.

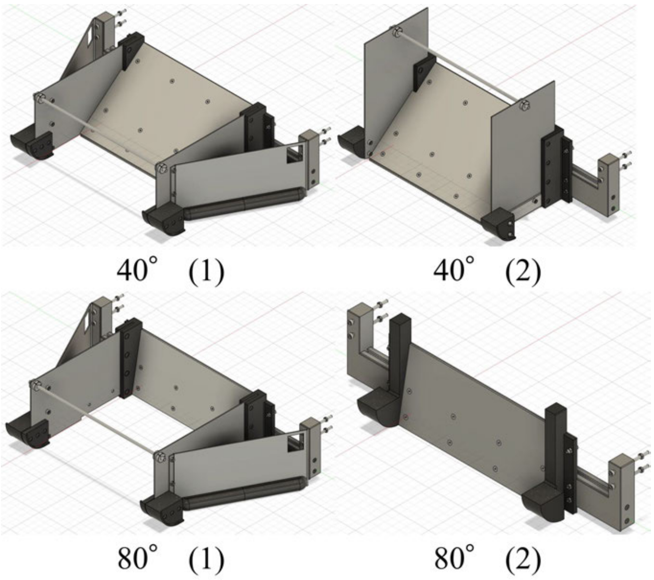


Fig. 21. 4 types of claws

*2) Results:* Excavation was successfully carried out using three types of claws, with the exception of 80° (2). However, in both 40° (1) and 80° (1), the robot encountered difficulty moving forward due to the weight of sand accumulated in front of the claw. Only with 40° (2) was continuous operation achieved through digging and moving forward. Fig.22 shows the excavation carried out using 40° (2). On the left is the robot, and on the right is the view of the claw from above. The areas circled in red indicate the formation of a sand pile within the claw as a result of the excavation.

Fig. 22. Sand piles by excavation

*3) Discussion:* In 40° (1) and 80° (1), the long side wall resulted in a substantial accumulation of sand in front of the claws, hindering forward movement despite successful excavation due to the driving power limitation of the crawler robot. In addition, in 80° (2), sand did not accumulate in front of the claw because it flowed outward from the short side wall, and thus preventing excavation. On the other hand, the 40° claw with the short side wall was more effective than the 80° claw for excavating sand while reducing sand retention. As a result, under conditions of limited drive force, the 40° claw with shorter side wall proved superior to the 80° claw in this experiment.

## V. CONCLUSIONS

This paper focuses on defining the required specifications for a robot capable of collecting marine shredded plastic garbage, which is challenging for humans to collect. It conducts experiments to investigate the necessary functions and trends, primarily focusing on the ”excavation” aspect. The ”Pseudo-Angle of Repose Measurement Experiment” explored the behavior of sand in a stationary state, confirming that the pseudo-angle of repose remained consistent across different shapes and sizes of slopes, with sand being deposited minimally at an approximate slope of 20°. Building on this, the ”Claw Excavation Experiment ” set the claw angle at 20° as the baseline and investigated claws with angles of 40, 60, and 80° to determine the optimal claw angle. In the ”Sandy Beach Experiment,” actual excavating claws were manufactured, and it was demonstrated that claws with a 40° angle outperformed those with an 80° angle. Going forward, the aim is to develop a more efficient garbage collection robot based on the improvement proposals derived from these experiments.

## ACKNOWLEDGMENT


This work was partially supported by JSPS Grant-in-Aid for Scientific Research JP20H00230.


## REFERENCES


[1] M. Kulshreshtha, S. S. Chandra, P. Randhawa, G. Tsaramirsis, A. Khadidos, and A. O. Khadidos, “Oatcr: Outdoor autonomous trash-collecting robot design using yolov4-tiny,” *Electronics*, vol. 10, no. 18, 2021.

[2] T. Ichimura and S.-I. Nakajima, “Performance evaluation of a beach cleaning robot “hirottaro 3” in an actual working environment,” *2018 18th International Conference on Control, Automation and Systems (ICCAS)*, pp. 825–828, 2018.

[3] J. S. Priya, K. Balaji, S. Thangappan, and G. Yuva Sudhakaran, “Beach cleaning bot based on region monitoring,” in *2019 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*, pp. 1–4, 2019.

[4] M. Uno and R. Kurazume, “Development of garbage collecting robot for marine microplastics,” *22th SICE System Integration Division Annual Conference (SI 2021)*, pp. 1054–1057, 2021, (in Japanese).

[5] H. M. Beakawi Al-Hashemi and O. S. Baghabra Al-Amoudi, “A review on the angle of repose of granular materials,” *Powder Technology*, vol. 330, pp. 397–417, 2018.

[6] T. Glover, *Pocket Ref.* Sequoia Publishing, 1995.

[7] K. A. Holsapple, “Modeling granular material flows: The angle of repose, fluidization and the cliff collapse problem,” *Planetary and Space Science*, vol. 82-83, pp. 11–26, 2013.