Dust Adhesion Suppression Effect by Meta-material Structure

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Techniques have been developed for measuring orbital deviation by image measurement. In this method, the trajectory distortion is measured by measuring the coordinates of the center of gravity of the circle with a digital camera. However, due to the repeated train running, the surface of the recursive target for measurement becomes black due to dirt, and the position of the center of gravity of the circle cannot be accurately measured on the image. When the target becomes black, the center of gravity of the circle cannot be accurately measured on the image, so currently it needs to be cleaned about twice a month. Dirt due to the deposits is an important issue, and a technique for protecting the surface of the target from dirt is desired. In this study, we evaluated the surface effect of hydrophilic, water-repellent and metamaterial sheets on water and muddy water. Prevention is possible due to the oil repellency and dustproof effect, which leads to a reduction in maintenance work. In the near future, it aims to develop an oil-repellent and dust-proof metamaterial sheet for maintenance-free technology.

Keywords: Maintenance-free technology, Antifouling technology, Infrastructure technology, Image measurement, Dustproof effect

1. Introduction
The control of the track irregularity is important from the viewpoints of safe and comfortable running of train. Especially, in case of an excavation work having a risk of subgrade depression, the track irregularity is controlled by an image measurement for 24 hours (Fig. 1).

In recent years, the measurement technology of the track irregularity has been developed [1-4]. In this technology, the recursive target is attached on the railroad track, and the centroid displacement of the white circle is measured by the digital camera.

However, by cyclic train loading, the extraneous stuffs are attached on the measurement target, and the target becomes black. In the black target, the centroid displacement cannot be measured exactly, the measurement target must be cleaned twice a month.

Consider the environment in which track rails are currently installed. In rainy weather, ballast debris and rolled-up soil beneath them will adhere to the target. In addition, it is considered that iron oxide
and like that materials generated by shaving the rails and wheels adhere to the target.

Much research has been done on polymer surfaces and water droplets [5-13]. We need to discuss the balance of forces at the nano surface. Surface contact angles and surface energy in air have been discussed for a long time [14-17].

However, there is no study on polymer surfaces and sediments given muddy soils. By grasping the actual condition of the deposits, countermeasures and prevention can be taken, leading to a reduction in maintenance work. To solve this problem, there is a metamaterial technology that mimics the shell of a snail, one of the biomimetics [18-22], and has an oil-repellent effect.

From these backgrounds, we have been developing the antifouling technology [23-29] of the measurement target used by metamaterial effect. In this study, in preparation of the antifouling technology development, we stuck some kinds of sheets and evaluate the effect against to the water and the muddy water.

2. Evaluation of dustproof effect of targets with dustproof sheet

In order to evaluate the effects on water and muddy water, we stuck seven types of water-repellent and hydrophilic sheets on the target suppressing adhesive material on the target.

These following seven types sheet were evaluated as types of the sheet. Normal (N) that is currently used in the field, fluorine sheet (F), Teflon sheet (T), acrylic (A), imprinted acrylic (AI), imprinted and blasted acrylic (AIB), there are seven types of photocatalysts (P).

Figure 1 shows the N sheet as one example of the target with sheet attached.

In this study, three experiments were conducted to confirm the hydrophilic and water-repellent tendency and the antifouling effect of the sheet.

Firstly, contact angle measurement experiment of the JIS standard. Secondly, we conducted the water vapor experiment assuming drizzle. Drizzle is defined as water droplets of 0.5 mm or less. In this experiment, the steam generated by the heating humidifier was regarded as drizzle. Thirdly, we conducted the dripping experiment of muddy water to clarify the antifouling effect of each sheet on mud.

3. Evaluation method for targets

3.1. Water vapor experiment (water droplet behavior)

To evaluate the behavior of water droplets on each sheet, a water vapor experiment was performed using a heated humidifier. Figure 2 shows the schematic of the experiment environment and photograph took from the upper side of the experiment conditions.

The 5 mm square sheet was attached to the scale. Water vapor was generated at a position 60 mm away from the scale. As an evaluation method, the number of drops of 3, 5, 7 minutes (1, 1.5, 2 minutes for AIB) as elapsed time was counted from the video. The taken from directly below from the sheet, and the distribution of the number and area was compared. In addition, the contact angles were measured and the results for each sheet were compared to a video taken from the side.

Figure 2 shows a schematic diagram of the experimental environment and a photograph taken from above during the experiment.

3.2. Dripping experiment of muddy water

In order to evaluate the antifouling effect of each sheet, we conducted the dripping experiment of muddy water. Figure 3 shows the schematic of the experiment environment and photograph that took from the front side. Muddy water is made by mixing
the soil (decomposed granite soil) and water in 1:1 mass ratio. The drop was about 0.05 [g], and dropped eight times in total. The muddy water immediately after falling was photographed. Next, in order to make the muddy water conform to the polymer surface, the muddy water was allowed to fall naturally by tilting the target after 10 minutes (elapsed time). The contact angle was measured to evaluate the degree of contamination on the polymer surface.

4. Results and discussion

4.1. Contact angle results (Statically measuring water droplets)

Figures 4 and 5 show the results of JIS standard contact angle measurement.

The acrylic material “A” has a contact angle of less than 90° and can be said to be hydrophilic. Also, “AI” and “Aib”, which are made by nano-processing acrylic material, are super hydrophilic. Further, “F”, “T”, and “P” are hydrophobic because the contact angle exceeds 90°.

4.2. Contact angle results (water vapor experiment)

Figures 4 and 6-11 show the results of the water vapor experiment. Fig. 4 shows the contact angles after 3, 5, 7 minutes. Figures 6-11 are the result of each sheet after 3 and 7 minutes. For “Ai” and “Aib”, a water film was formed immediately after the start of the experiment. Water drops are not shown in these figures because they were difficult to see visually.

Comparing Fig. 7 (“A” sheet) with Fig. 9 (“F” sheet), A sheet has larger water droplets diameter than that of F sheet. It shows the fact that there are many water droplets having large diameter indicates hydrophilicity.

Next, compare the results of the JIS standard with the results of the water vapor experiment. N, A, Ai, F, and T showed the same tendency in both JIS standard and water vapor experiments. As for P, the results of the JIS standard and the water vapor experiment deviated. This factor is considered to be caused by a change in the amount of light during the experiment because P sheet is a photocatalyst. At the time of the JIS standard experiment, the experiment was conducted in a dark room, but the water vapor experiment was conducted in the room with room lights. It causes the change of property of the P sheet. Figure 12 is a graph summarizing the change in the average contact angle with time of each sheet in the water drop experiment. This graph shows that the contact angle of the droplet is almost constant regardless of the size of the droplet.

4.3. Comparative of contact angle between water drop experiment and muddy water experiment

Table 1 shows the values of the contact angles in the JIS standard, water vapor experiments and mud dropping experiments. From this table, it can be

Fig. 3. Schematic and experimental drawing of mud dripping experiment.

Fig. 4. Comparison of contact angles with various sheets (water vapor experiment: Standard: N, Acrylic: A, Acrylic with nanoimprint: Ai, Acrylic material with nanoimprint and blast treatment: Aib, Fluoro-resin: F, Teflon resin: T, Photocatalyst: P).

Fig. 5. Water drop experiment results (Standard: N, Acrylic: A, Acrylic with nanoimprint: Ai, Acrylic material with nanoimprint and blast treatment: Aib, Fluoro-resin: F, Teflon resin: T, Photocatalyst: P).
seen that there is a difference between the contact angle of the water drop of the JIS standard and the contact angle of the muddy water experiment. It can be considered this is because muddy water contains ballast. Therefore, the surface tension is different between the case of only water and the case of containing sand, because the water and sand are sparse on the surface in contact with the sheet surface when the water contains the mud.

Figure 12 shows comparing the contact angles of the JIS, steam and muddy water experiment of each sheet. Figure 13 shows that “Aib”, “Ai”, “F”, and “T” obtained almost the same results in the three experiments. The contact angle in the muddy water experiment deviated from the contact angle in the JIS experiment in some sheets, but generally they
are almost same with the result in the water vapor experiment and JIS experiment.

It is considered that this is because “P” is a photocatalyst and the amount of light during the experiment was different, so that hydrophilization occurred.

4.4. Mud dripping experiment results

Figure 14 shows the state of the target which was leaned 10 minutes after the muddy water was dropped and the result of 24 hours had passed since the dropping. For the evaluation of muddy water, an experiment was conducted at a sliding angle of 90°. Figure 15 shows the state immediately after the dripping of the muddy water.

Table 1. Contact angle results in steam and mud dropping experiments.

|                | JIS experiment | Water vapor experiment | Dropping experiment of muddy water |
|----------------|----------------|------------------------|-----------------------------------|
|                | 3min | 5min | 7min | Avg. | S.D. | Avg. | S.D. | Avg. | S.D. | Avg. | S.D. | Avg. | S.D. | Avg. | S.D. |
| N              | -    | -    | -    | -    | 36.5 | 2.69 | 31.0 | 7.87 | 36.9 | 5.24 | 31.3 | 9.09 | 35.4 | 5.79 |
| A              | 75.9 | 1.39 | 33.2 | 3.66 | 55.0 | 7.48 | 50.2 | 5.78 | 24.2 | 5.55 | 34.7 | 3.59 | 21.4 | 4.55 |
| Ai             | 13.7 | 0.51 | 12.8 | 3.71 | 9.0  | 2.83 | 15.0 | 3.95 | 12.7 | 2.69 | 13.2 | 3.49 | 16.4 | 2.77 |
| Aib            | 22.0 | 0.64 | -    | -    | -    | -    | -    | -    | 10.8 | 2.17 | -    | -    | 13.2 | 1.87 |
| T              | 105.3| 0.70 | 98.4 | 10.3 | 108  | 5.73 | 100  | 3.77 | 78.8 | 11.8 | 98.2 | 5.49 | 80.0 | 7.09 |
| F              | 106.1| 1.48 | 104  | 5.24 | 104  | 4.59 | 111  | 2.97 | 88.1 | 9.78 | 86.3 | 11.0 | 80.3 | 9.75 |
| P              | 111.4| 0.59 | 38.8 | 10.76| 39.2 | 6.52 | 43.2 | 7.63 | 21.2 | 1.47 | 11.7 | 1.25 | 29.2 | 6.10 |

Fig. 13. Comparison of contact angle between water vapor experiment and mud drop experiment.
“F”, “T” showed hydrophobicity in JIS and water vapor experiments. Almost, all dirt was removed by leaning the target. On the other hand, “N”, “A”, “Ai”, “Aib”, and “P”, which showed hydrophilicity in the water vapor experiment, were contaminated. Above all, “Ai” and “Aib”, which have high hydrophilicity, remained almost dirt.

From these results, it can be said that the use of the hydrophobic sheet is more effective for antifouling than the case of using the hydrophilic sheet.

5. Conclusion

In this study, we evaluated the surface effect of hydrophilic, water-repellent and metamaterial sheets on water and muddy water. As a result, the currently used sheet and hydrophilic sheet have low antifouling and dustproof functions. On the other hand, it was proved that the hydrophobic sheet has high antifouling and dustproof effects. Prevention is possible due to the oil repellency and dustproof effect, which leads to a reduction in maintenance work.

In addition, when considering the place where the target is installed, a change in weather is a problem. It is important to evaluate the deposits because it is assumed that the environment of the site changes due to snow, sea, and heavy rain, and that the substances attached to the polymer surface change. It is important to evaluate the great problems of mud in any environment. In the near future, we aim to develop a sheet with an oil-repellent and dust-proof metamaterial structure for a track-correcting recursive target for maintenance-free purposes.

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