Antifouling Effect on Measurement Target of Track Irregularity by Metamaterial Effect

Risa Matsumoto1, Kenichi Kuribayashi1, Mizuho Okamoto1, Akira Tanida1
Hiroyoshi Tsujii1, Ko Ishibashi1, Ryota Nobuhara3, Sotaro Nishioka3,
Tomohiro Mamiya3, Hiroyuki Mayama2, and Tomoki Nishino3

1JR West Japan Consultants Company,
5-4-20, Nishinakajima, Yodogawa-ku, Osaka 532-0011, Japan
2Department of Chemistry, Asahikawa Medical University,
2-1-1-1 Midorigaoka-Higashi, Asahikawa, Hokkaido 078-8510, Japan
3Department of Mechanical Engineering, Ritsumeikan University,
1-1-1 Nogihigashi, Kusatsu, Shiga 525-8577, Japan
*matsumoto_r@jrnc.co.jp

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. 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 develop a target antifouling sheet using a metamaterial technology that imitates a snail shell and has an oil-repellent effect and verifies the effect.

Keywords: Antifouling technology, Infrastructure technology, Image measurement, Orbital distortion, Snail shell, Oil-repellent 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) [1-4].

In this technology, the displacement of recursive target which is attached on railway track is measured by digital camera. The recursive target follows a movement of railway track. In this method, the centroid displacement of the white circle is measured by the digital camera.

However, this recursive target (white circle) becomes black caused by cyclic train loading, and it becomes difficult to measure the centroid displacement of the white circle exactly.

The contamination due to the attached matter is an important issue. The technique for protecting the surface of the target from dirt is desired. To solve this problem, there is a metamaterial technology that mimics the shell of a snail, one of the biomimetics [5-8], and has an oil-repellent effect. In addition, it was shown that the oil repellent effect was remarkable even in a surface structure having irregularities arranged regularly using semiconductor processing technology. Therefore, it has been shown that the metamaterial structure enables application technology development in the medical field [9-18]. Furthermore, it can be expected to be applied not only to medical technology but also to infrastructure technology. From these backgrounds, in this study, the antifouling technology for the measurement target of the track irregularity used by metamaterial effect is developed.

In this study, we develop a target antifouling sheet using metamaterial technology and verify its effect.

2. Exposure test

2.1. Installation site conditions
The exposure tests were conducted twice. The detail of the tests is shown in Table 1.

The sheet N represents the target which is not covered by an antifouling sheet. The sheet P represents a photocatalyst sheet. The sheet Ai represents an acrylic sheet having moth eye surface. Furthermore, the sheet Ai was blasted to expect dual roughness effect [20], this sheet is Ai+b.

In the first test, the sheet Ai was installed for 81 days. In the second test, the sheets Ai, Ai+b and P were installed for 51 days. As shown in Fig. 2, targets were installed inside and outside a rail.

Figure 3 shows the target after the first exposure test. The target installed inside a rail tend to be fouler than that installed outside a rail.

Figure 4 shows the target after the second exposure test. The sheets Ai and Ai+b installed inside the rail are not shown in Fig. 4, because they were damaged when they were collected.

As shown in Figs. 3 and 4, it can be found that the antifouling sheet prevent from adhering extraneous stuffs to the target.

Table 1. Target status installed on site.

| Installation date | Removal date | Exposure period | Sheet | Target installed inside a rail | Target installed outside a rail |
|-------------------|--------------|-----------------|-------|-------------------------------|--------------------------------|
| 1st test          | 2019/9/26    | 2019/12/23      | 88 days | Ai 2                          | 2                              |
|                   |              |                 |       | N 2                           | 2                              |
| 2nd test          | 2019/12/23   | 2020/2/12       | 51 days | Ai 1                          | 1                              |
|                   |              |                 |       | Ai+b 1                        | 2                              |
|                   |              |                 |       | P 1                           | 1                              |
2.2. Deposits on the target surface

The particle size distribution was measured to determine the amount of dirt on each target. In addition, energy dispersive X-ray analysis (EDX) was performed to examine the deposits on each target.

3. Results and discussion

3.1. Elemental analysis result of target surface

Elemental analysis was performed with a fluorescent X-ray analysis microscope to clarify the deposits on each sheet surface.

Figure 5 shows the results of point analysis using fluorescent X-rays. As can be seen from the Fig. 5, Fe was detected on the target surface regardless of the type of sheet. This suggests that the deposit is iron oxide generated by friction between the rail and the wheel.

Figure 6 shows the results of X-ray fluorescence mapping for each sheet. In all sheets, the distribution of deposits that can be read from the optical image and the distribution of Fe almost agree, so it is considered that the main deposit is iron oxide.

On the other hand, it can be seen that Ca is attached to all sheets. According to the results of elemental analysis, Ca is likely to be derived from sediment.

In sheet, P and Si are detected on the entire surface, but this is the silicon dioxide of the photocatalyst itself.

3.2. Particle size distribution analysis

Figure 7 shows a comparison of the particle size distribution of the deposit on sheet Ai and the existing target exposed for 45 days. The particle size distribution analyzer used was a laser diffraction scattering type particle size analyzer (Beckman Coulter, Inc., model number LS 13 320XR).

Figure 7 shows that the particle size distribution of the deposits was almost the same regardless of the presence or absence of the metamaterial.
structure. In the particle size distribution results, small deposits were 300 nm and large deposits were 2 μm.

3.3. Measured value with digital camera rail watcher

The measurement results of the vertical displacement by image measurement are shown in Fig 8. The existing target is not covered by the antifouling sheet and this is cleaned every 2 weeks. The red line in Fig. 8 represents the cleaning date.

Inside the rail, the vertical displacement of the sheet N gradually increased with the lapse of time. The reason for this is that the centroid displacement of the target recognized by image measurement shifted up, because the extraneous matters attached
on the target were washed out by a rainfall and accumulated at the bottom of the target, as shown in Fig. 9.

The vertical displacement of the existing sheet decreased after cleaning. This indicates that the whole circle outline could be recognized by the image measurement and the measured centroid displacement shifted down.

For the sheets Ai and Ai+b, the vertical displacements increased with the lapse of time, however the amounts of the extraneous matters were smaller compared with the sheet N. The vertical displacement of sheet P did not greatly change.

Outside the rail, the vertical displacements of all sheets were almost constant.

From these results, it is clarified that the sheet P is the most effective for antifouling and the antifouling effect of the sheets Ai and Ai+b is smaller than that of the sheet P. However, the sheet P shows the antifouling effect only under sunlight and rain. Thus, the sheets Ai and Ai+b should be used for a target which is installed under the roof, bridge and so on.

4. Conclusion

In this study, we conducted an exposure test to clarify the antifouling effect of the target for measurement of out-of-orbit measurement using the antifouling sheet. As a result of the test, the photocatalyst was the most effective, and acrylic + imprint and acrylic + imprint + blast showed a antifouling effect, but, were not as effective as the photocatalyst. Considering the intended use, the photocatalyst has an antifouling effect in an environment where sunlight and water are supplied. However, it is better to use acrylic + imprint or acrylic + imprint + blast in environments where sunlight does not hit, such as under bridges and roofs.

References
1. K. Kuribayashi, M. Fujigaki, M. Kimura, and Y. Niwa, J. Struct. Eng. A, 62 (2016) 617.
2. Y. Tsubokawa, Proc. SICE, 56 (2017) 105.
3. K. Kuribayashi, M. Kawashita, N. Takeuchi, Y. Tsuno, M. Fujigaki, NEDO Infrastructure Maintenance Technology Symposium, (2018) 30am3-PD-18.
4. K. Kuribayashi, M. Fujigaki, M. Kimura, and Y. Niwa, J. Struct. Eng. A, 62 (2016) 671.
5. M. Yamamoto, N. Nishikawa, H. Mayama, Y. Nonomura, S. Yokojima, S. Nakamura, and K.,
6. C. Neinhuis and W. Barthlott, Ann. Botany, 79 (1997) 667.
7. R. Nishimura, K. Hyodo, H. Mayama, S. Yokojima, S. Nakamura, and K. Uchida, Commun. Chem., 2 (2019) 1.
8. Q. Chen, G. Hubbard, P. A. Shields, C. Liu, D. W. E. Allsopp, W. N. Wang, and S. Abbott, *Appl. Phys. Lett.*, 94 (2009) 263118.

9. T. Nishino, H. Tanigawa, A. Sekiguchi, and H. Mayama, *J. Photopolym. Sci. Technol.*, 32 (2019) 383.

10. H. Mayama, T. Nishino, A. Sekiguchi, R. Nishimura, K. Uchida, S. Yokojima, S. Nakamura, and Y. Nonomura, *J. Photopolym. Sci. Technol.*, 32 (2019) 279.

11. A. Sekiguchi, T. Nishino, M. Aikawa, Y. Matsumoto, H. Minami, K. Tokumaru, F. Tsumori, and H. Tanigawa, *J. Photopolym. Sci. Technol.*, 32 (2019) 373.

12. A. Sekiguchi, Y. Matsumoto, H. Minami, T. Nishino, H. Tanigawa, K. Tokumaru, and F. Tsumori, *J. Photopolym. Sci. Technol.*, 31 (2018) 121.

13. T. Nishino, H. Tanigawa, and A. Sekiguchi, *J. Photopolym. Sci. Technol.*, 32 (2019) 661.

14. T. Nishino, H. Tanigawa, and A. Sekiguchi, *Proc. SPIE*, 10728 (2018) 1072804.

15. T. Nishino, H. Tanigawa, and A. Sekiguchi, *J. Photopolym. Sci. Technol.*, 31 (2018) 129.

16. T. Nishino, H. Tanigawa, and A. Sekiguchi, *J. Photopolym. Sci. Technol.*, 32 (2019) 367.

17. Y. Hirai, H. Mayama, R. Tamura, Y. Matsuo, T. Okamatsu, T. Arita, and M. Shimomura, *Polym. J.*, 51 (2019) 721.

18. H. Mayama, *J. Photopolym. Sci. Technol.*, 31 (2018) 705.

19. R. Nishimura, H. Mayama, Y. Nonomura, S. Yokojima, S. Nakamura, and K. Uchida, *Langmuir*, 35 (2019) 14124.