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カーボンブラック含有ポリ塩化ビニルマイクロプラスチックテクスチャによる着霜防止表面の創製

Creation of Anti-Frost Surfaces with Carbon Black Containing Polyvinyl Chloride Microplastic Textures

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1. Introduction

Nowadays, the world is facing the problem of energy consumption. According to a report by the Japanese Ministry of Economy, Trade and Industry 2021, the refrigerator is an important appliance that works 24 hours a day, 7 days a week in the home and consumes 120-550 kWh of electricity, depending on its size. All refrigerators have a defrost system, which consists mainly of heaters on the surface of the heat exchanger [1]. Although defrost heaters are necessary to remove frost from the heat exchange ducts and fins of the freezer, their operation causes an increase in the temperature of the freezer and uses additional power consumption. Therefore, it is necessary to reduce the working time and cycle/day of such heaters to reduce the power consumption. To solve this problem, hydrophobic surfaces are needed to prevent ice adhesion on the heat exchanger. In recent years, the use of superhydrophobic surfaces for corrosion protection has generated extensive attention, and the preparation of superhydrophobic coatings on steel surfaces is one of the effective ways to improve the corrosion resistance of steel. By constructing a superhydrophobic structure on the metal surface, the adhesion of H_2O can be reduced, and the self-cleaning effect can be achieved, thus reducing the chance of electrochemical corrosion. With the increasing understanding of the formation mechanism of superhydrophobicity, various methods and techniques for preparing superhydrophobic surfaces have been developed, such as printing, molding, femtosecond laser pulsing, etching, sol-gel technology, chemical vapor deposition, and electrochemical processes. Some of these methods and techniques have the disadvantage of being expensive or limited in their application scenarios, which prevents them from being used on a large scale to prepare the desired superhydrophobic surfaces. Previously, we developed a relatively simple, low-cost preparation method using a microplastic texture construction procedure in which polyvinyl chloride (PVC) is dissolved in an acetone solution, placed between a pair of parallel electrodes and an alternative voltage is applied [2]. Approximately 10 μm spherical microplastic textures were successfully generated, however, the contact angle of water remained less than 100˚ [3]. In addition, high heat transfer capability is important for the application of heat exchangers. Therefore, in this study, we added carbon black (CB) to the PVC acetone solution to achieve a contact angle higher than 100˚ and to obtain a surface with high heat transfer capacity.

We established microplastic textures with CB in 0, 0.9, 1.6 and 2.1 vol.% solutions and compared the applied/non-applied voltages. In addition, to obtain a high water contact angle surface by microplastic texturing, we applied AC voltages of different frequencies between the electrodes. Then, the surface morphology was observed by field emission scanning electron microscopy (FESEM) and contact angle measurements were performed. Time-temperature experiments were also performed to clarify the effect of adding/not adding carbon black powder on the surface thermal conductivity.

2. Experimental procedure

A high voltage power supply was applied to a pair of electrodes with 5 mm gap. A 10×10×5 mm aluminum alloy test piece was put between the electrode plates. A PVC-acetone with CB solution was dropped onto the test piece by a syringe. The solution was prepared with different CB amount, such as 0, 0.9, 1.6, and 2.1 vol.%. The applied voltage and frequency were 2 kV and 0,2,4,6,8,10, and 11 Hz. The instruments of a 677B power supply (Trek Japan) were used as a quadrature high voltage power supply, a function generator AD-8623 (A&D) was used to control the electric field. An oscilloscope (Tektronix TBS2000) and a high voltage probe (P6015A) were prepared to measure the output voltage. The distribution of the surface such as the surface density and the height of microplastic texture is represented by laser microscopy. And the infrared camera is used to obtain temperature data The surface morphology of microplastic textures on specimens were observed by FESEM. The specimen surface was observed as a plane view and a front view to know microplastic texture shape clearly.

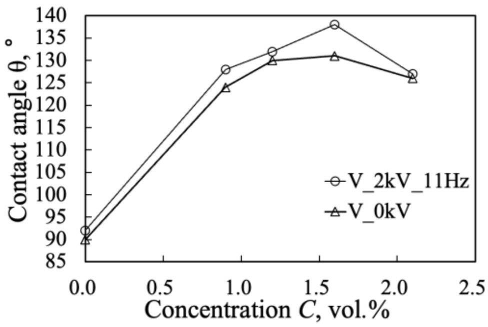

Fig. 1 The relationship between carbon black concentration and contact angle

3. Results and discussion

Figure 1 shows the relationship between carbon black concentration and contact angle, where a carbon black concentration of 1.6% vol% surface water contact angle of 138° was reached at an applied high voltage of 2 kV and a frequency of 11 Hz. To clarify achieving the high contact angle, the surface morphologies were observed by FESEM. The distribution of the protruding surface on the specimens are shown in Fig. 2(a)-(d). The difference between Fig. 2(a) and (b) is only with or without addition of carbon black, and it can be seen from the figure that there is an obvious spherical structure after the addition of carbon black. While Fig. 2(c) and (d) show the shape of the microplastic texture when the concentration of carbon black which amount is ~2.1 vol%, and this sharp shape of the microplastic establishment of the texture is expected to be a high contact angle surface.

The uniformity of the microplastic texture is considered as an important parameter from the viewpoint of surface coverage, therefore, we must consider the effect of applied AC voltage and frequency. So, in order to find the best natural frequency, we applied different number of frequencies (0-10 Hz) between the flat plates and observed the density distribution of the surface with laser microscopy, the results are shown in Fig. 3, it can be found that when the applied frequency is 6Hz, the surface density distribution is uniform with high coverage as lotus leaf-like surface. This is due to the fact that when there is only PVC, there is a large amount of acetone solution, and the surface tension σ of acetone solution is 23.3 mN/m and the density ρ is 784 kg/m^3, brought into Equation (1), the natural frequency of acetone is obtained as 12.3 Hz, and after adding carbon black, the surface tension decreases and the density rises, so the natural frequency *f* decreases.

The change of surface heat transfer rate with or without the addition of carbon black is shown in Fig. 4, when carbon black is added, the temperature of the control group with the addition of carbon black decreases faster in the same time 300 s. The surface roughness increases after the addition of carbon black, so we must also consider the effect of surface roughness and elements on the heat transfer rate.

$$f = \frac{1}{2\pi}\sqrt{\frac{3C_1}{2\pi}\frac{\sigma}{R^3\rho}} \qquad (1)$$

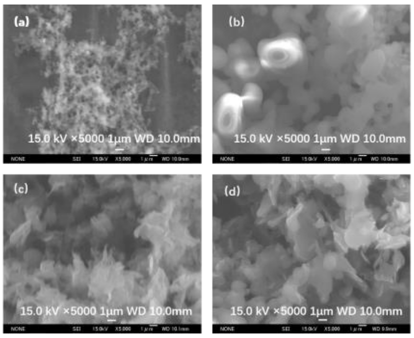

Fig. 2 Plane view FESEM observation for microplastic texture(a) 0, (b) 0.9, (c) 1.6, (d) 2.1 vol.% of CB at 11Hz

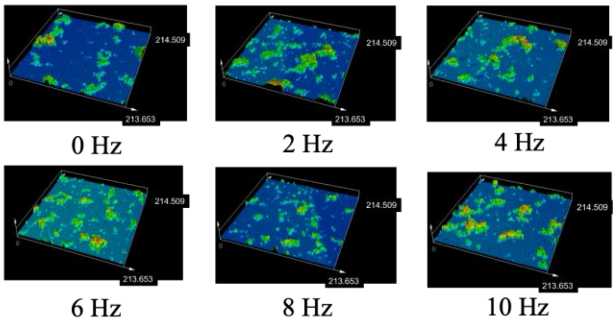

Fig. 3 Density of microplastic surface (from 0-10 Hz) by laser microscopy

4. Conclusion

The aim of this study is to improve the hydrophobicity of the surface and to improve the thermal conductivity of the surface. From the previous exposition, it can be concluded that

1) When the concentration of carbon black was added at 1.6vol% and high voltage was applied at 2 kV and the frequency was 11 Hz, the surface water contact angle increased to 138°.

2) The heat transfer rate of the surface increased after adding carbon black.

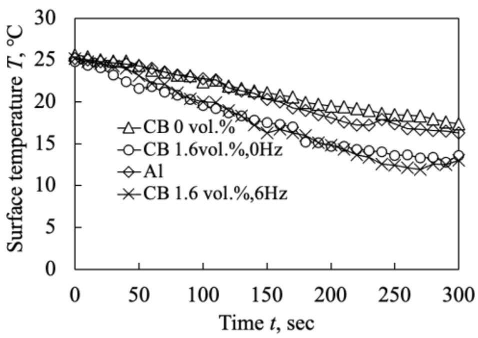

Fig. 4 Relationship between time and temperature

References

1) METI, Resources and project, METI (online), available from, (accessed on 29 May, 2020) (in Japanese).
2) Akagami, Y., Asari, K., Hujita, T., Jayadevan, B., Umeahra, N., Transactions of the JSME, Series C, 66(649), 2000, 3168-3171.
3) Yamada, Y., Tokoroyama, T., Murashima, M., Umehara, N., Transactions of the JSME, 86(892), 2020, 20-00228.