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Analysis on anti-ice properties of aero aluminum alloy with weak wettability

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Abstract. Aero aluminum alloy skin of airframe and aerofoil is easy to freeze at low temperature, and endangering flight safety. Therefore, it is of great importance to improve the anti-ice ability of aero aluminum alloy. In this paper, the contact characteristics of a single water droplet with aero aluminum alloy with different wettability is analyzed as well as the freeze of aluminum alloy at low temperature, and study the anti-ice properties of aero aluminum alloy with different wettability. The results indicate that the anti-ice capability of aero aluminum alloy is gradually enhanced with the weakening of surface wettability. And also the ice area is reduced, and the ice distribution is changed from facet to point gradually. When aero aluminum alloy becoming super hydrophobic surface, there are only few micro ice grains on the edge of surface.

1. Introduction

Skin of airframe and aerofoil is easy to freeze when cold rain and snow weather happened, which result in the increase of airframe weight and flight resistance, causing uneven distribution of velocity field on aerofoil and lift decreasing [1]. The icing of key parts even causing the aircraft rudder to jam, endangering the flight safety [2]. At present, the skin of civil aviation passenger aircraft is usually made of aero-aluminum alloy, methods of engine bleeding, electric heating and deicing fluid are used to prevent skin from freezing [3]. However, both engine bleeding and electric heating will consume engine power, result in poor acceleration of aircraft and poor economy. In addition, a large number of electric heating components make the aircraft structure more complex and difficult to maintain. Moreover the polyols contained in deicing fluid will also cause environmental pollution [4,5]. Therefore, it is of great importance to improve the anti-ice ability of aero aluminum alloy skin.

The development of bionic technology [6] in recent years, hydrophobic coating[7,8] on metal and metalloid surface is easy to prepare based on lotus effect [9]. Applications of hydrophobic coating in corrosion prevention [10], antiseptis[11] and drag reduction [12,13]are researched also. Hermelin [14] obtained superhydrophobic coating on the surface of titanium alloy by ultra-fast laser treatment, and adhesions of two pathogenic bacteria on surface were also studied. The result showed that superhydrophobic surface could control the type of bacteria attached to it. On one hand, this surface promoted the adhesion of staphylococcus aureus, but on the other hand completely inhibited the attachment of pseudomonas aeruginosa.

Although the researches on weak wettability coating are extensive [15-17], it is seldom reported in anti-icing field. Previously, Thibaut [18] had dripped super cooler water onto the surface of 304 stainless steel, freezing it by lowering temperature gradually. It showed that the freezing temperature of droplet on the surface of hydrophobic stainless steel was 7 °C lower than that of untreated stainless



steel. Accordingly, weak wettability had anti-ice capability to some extent. Therefore, a range of surface treatments are used in this paper to obtain aero aluminum alloys with different wettability. Contact characteristics of single droplets with aero aluminum alloy with different wettability are analyzed. Comparing and studying anti-ice properties of aero aluminum alloy with different wettability.

2. Experiment

2.1. Sample preparation

The length and width of samples made by 7075 aero aluminum alloy are 30 mm and 15 mm, a range of surface treatments are used to obtain different surface wettability. Detailed treatments and surface contact angles are shown in table 1 and Figure 1.

Table 1. Detailed treatments and surface contact angles of samples.

Sample	Contact angles	Detailed treatments
S1	151°	Sanding by 300 [#] 、600 [#] 、1000 [#] emery paper→Processing mesh texture on surface with spacing of 0.05 mm by laser (with current of 15A and focal length of 120 mm→Uv irradiation for 1 h for hydroxylation treatment→Depositing FDTs (Chemical formula: CF ₃ -(CF ₂) ₇ (CH ₂) ₂ - (C _n , n=10)) self-assembled molecular membranes on sample surface
S2	108°	Sanding by 300 [#] 、600 [#] 、1000 [#] emery paper→Processing mesh texture on surface with spacing of 0.15 mm by laser (the same with S1)→Uv irradiation for 1 h for hydroxylation treatment→Depositing FDTs self-assembled molecular membranes on sample surface
S3	62°	Sanding by 300 [#] 、600 [#] 、1000 [#] emery paper → Polishing
S4	30°	Sanding by 300 [#] 、600 [#] 、1000 [#] emery paper → Polishing

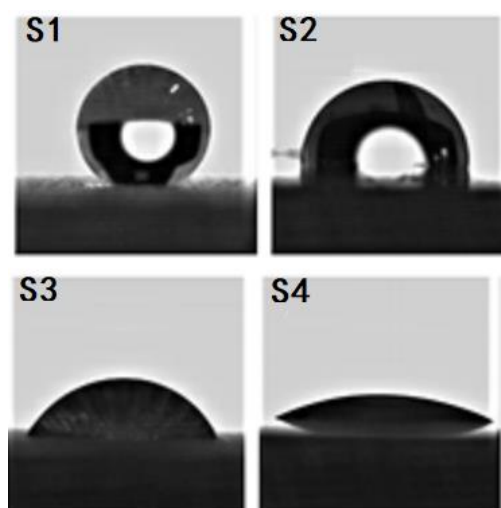


Figure 1. Surface contact angles of samples by contact angle measurement.

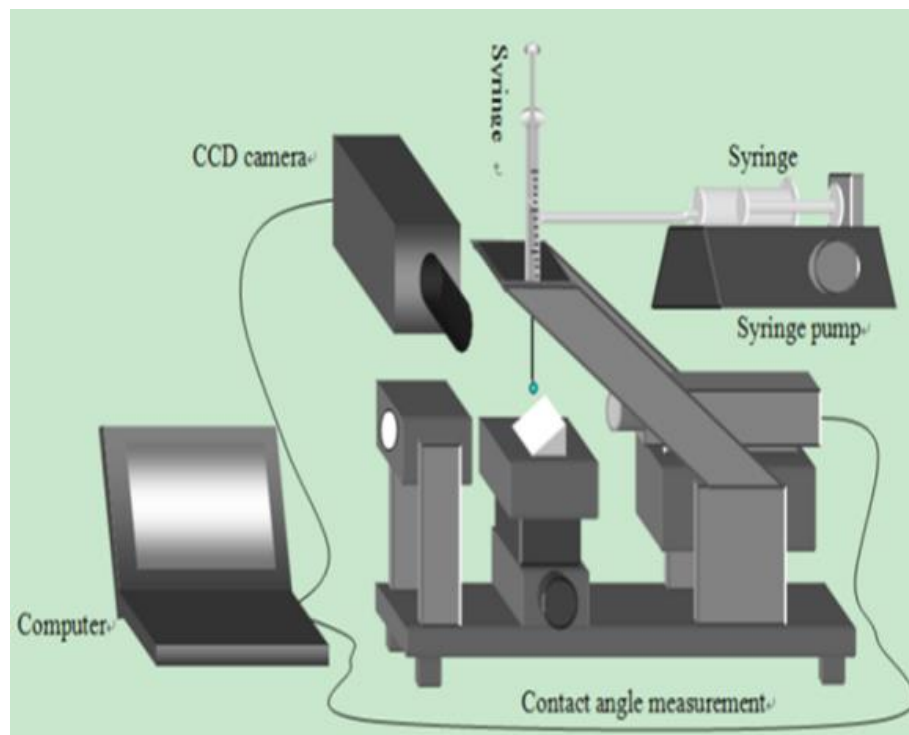


Figure 2. Schematic diagram of the devices.

2.2. Experiment process

Experiment devices are shown in Figure 2. The syringe needle is vertically downward at an angle α to the surface of sample. A single drop of water with volume V is dropped by a quantitative injection and hit the sample surface with velocity v for all samples, changing angle α , water volume V and velocity v to analysis the contact characteristics of water droplets of different volumes against samples with different surface wettability at different speeds and directions. High speed camera is used to record the process by which a single water drop hits the surface of samples. Resolution and frame frequency of camera are set as 512×512 dpi and 4000 fps respectively. After each experiment, acetone, anhydrous ethanol and deionized water are used to clean the surface of sample successively. Then, 99% nitrogen is used to dry the surface of sample to make sure the surface wettability always the same.

3. Result and analysis

3.1. Effect of surface wettability on contact characteristics

Syringe needle with a diameter of 0.9 mm is vertically downward at an angle of 30° to the surface of sample. Needle is 30 mm from sample surface. Individual droplets with volume of $1.62 \mu\text{L}$ impact the surface of S1~S4 samples respectively at a speed of 0.77 m/s. Processes are shown in Figure 3, analyzing the effect of surface wettability on contact characteristics.

It could be found that all of water droplets impacting on surfaces of S1~S4 samples deform obviously, and also slide along sample surfaces. On the surface of S1 sample with the weakest wettability, water droplet restores gradually and leaves the surface during sliding. However, water droplets on other sample surfaces spread during sliding and finally stay on it. Furthermore, with the enhancement of wettability of sample surface, the sliding distance of water droplet is shorter, and also has a lower height and lager spread area.

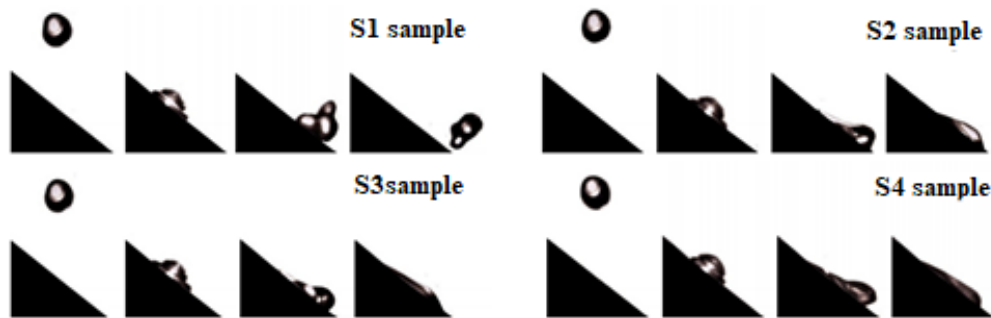


Figure 3. Impact of individual water droplets on surfaces with different wettability.

3.2. Effect of impact direction on contact characteristics

The syringe needle with a diameter of 0.9 mm is 30 mm from sample surface. Individual water droplets with a volume of 1.62 μL impact the surface of S1 and S4 samples respectively at a speed of 0.77 m/s, which are shown in Figure 4 and Figure 5. The angles of needle and sample surface are set as 30°, 40° and 60°, and analyzing the influence of direction in which the water droplets impact sample on contact characteristics.

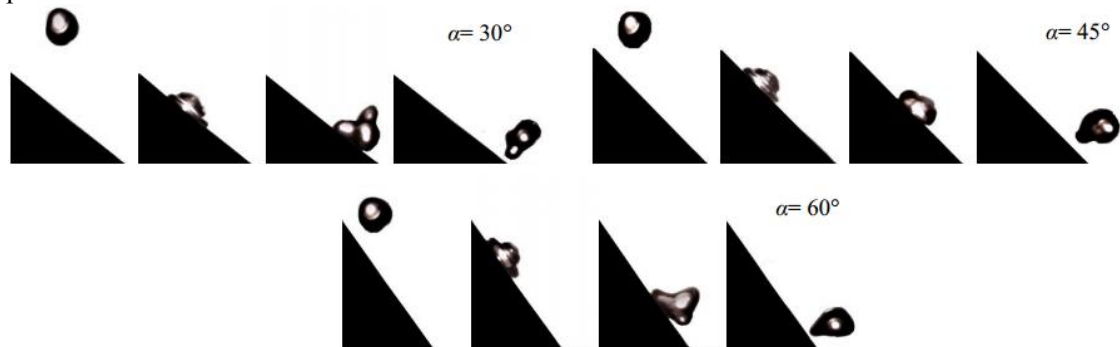


Figure 4. Impact of individual water droplets on surfaces of S1 sample.

In Figure 4, water droplets impact S1 sample surface at different directions, and then all of water droplets leave sample surfaces after deformation, sliding and restoring. But on the surface of S4 sample with strong wettability, the results are completely different.

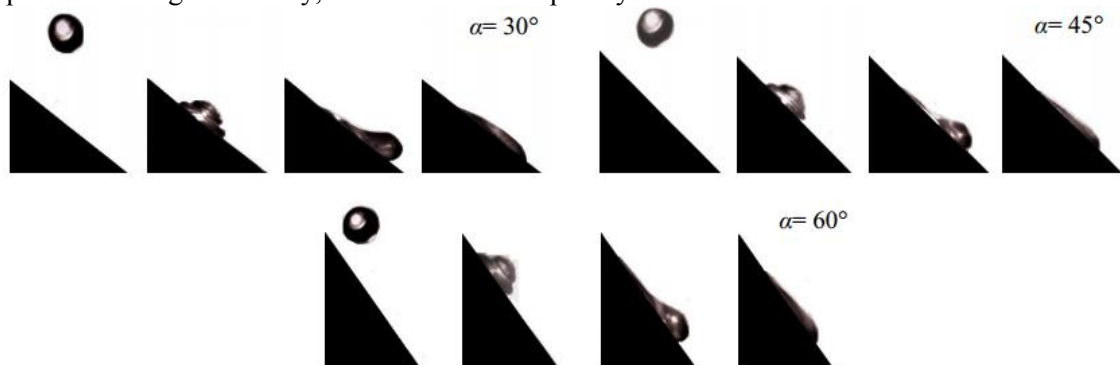


Figure 5. Impact of individual water droplets on surfaces of S4 sample.

It could be seen that all of water droplets impacting from different directions stay on S4 sample surfaces after deformation and sliding. There is no significant difference in height and spread area of water droplets finally. And thus, the impact direction of water droplets has no obvious influence on the contact characteristics of water droplets and sample surface on the same wettability surface. Water droplets will never stay on weak wettability surface no matter what direction it from.

3.3. Effect of impact speed on contact characteristics

The syringe needle with a diameter of 0.9 mm is vertically downward at an angle of 60° to the surface of sample. Needles are 30 mm and 50 mm from sample surface. Individual water droplets with a volume of $1.62 \mu\text{L}$ impact the surface of S1 and S4 samples respectively at a speed of 0.77 m/s. Processes are shown in Figure 6 and Figure 7, analyzing the effect of impact speed on contact characteristics.

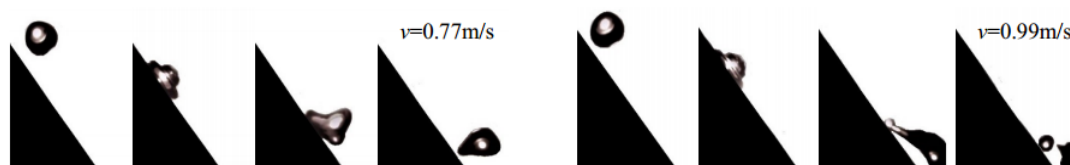


Figure 6. Impact of individual water droplets on surfaces of S1 sample.

In Figure 6, water droplets impact on S1 sample at speed of 0.77 m/s. Then it slides, restores and leaves from sample surface. However, the same water droplets with speed of 0.99 m/s divide into two smaller water droplets when impacting on S1 sample surface and both of two smaller water droplets leave sample surface successively.



Figure 7. Impact of individual water droplets on surfaces of S4 sample.

On the surface of S4 sample, although all of water droplets with different speeds finally stay on the surface, those of higher speeds will have lower height and larger spread area. In addition, the water droplet with a speed of 0.99 m/s does not divide into smaller droplets as it does on the surface of S1 sample. Therefore, the velocity of water droplets has certain influence on contact characteristics. On the surface of weak wettability, water droplets with higher speed are easy to divide into smaller water droplets when impacting on sample surface, and the splitting water droplets will still leave the sample surface. However, on the surface of strong wettability, water droplets will not divide when impacting on the surface of sample, and the faster water droplets will spread out with lower height and larger area.

3.4. Effect of water volume on characteristics

The syringe needles with diameters of 0.6 mm, 0.9 mm and 1.25 mm are vertically downward at an angle of 30° to the surface of sample respectively. Needles are 30 mm from sample surface. Individual water droplets with volumes of $0.83 \mu\text{L}$, $1.62 \mu\text{L}$ and $3.17 \mu\text{L}$ impact the surface of S1 and S4 samples respectively at a speed of 0.77 m/s. Processes are shown in Figure 8 and Figure 9, analyzing the effect of water volume on contact characteristics.



Figure 8. Impact of individual water droplets on surfaces of S1 sample.

It could be seen that all of water droplets with different volumes leave from surface of S1 sample after impacting, sliding and restoring. The water droplet with larger volume slide farther across the surface of sample.



Figure 9. Impact of individual water droplets on surfaces of S4 sample.

In Figure 9, all of water droplets with different volumes stay on surface of S4 sample, and water droplet with larger volume has a larger spread area on the surface finally.

In general, water droplets of different volumes, velocities and directions will not stay on the surface of S1 sample with weak wettability after impacting on. Therefore, the surface of S1 sample is not easy to freeze at low temperature. However, on the strong wettability surface of S4 sample, all of water droplets with different volumes, velocities and directions stay on surface finally. In that case, it is especially possible to freeze at low temperature.

3.5. Ice formation on the surface of different wettability samples

Spray water droplets uniformly on the surface of all samples, and then put samples in a CNC thermostat freezer with temperature of -10°C for 10 min. Ice formation on the surface of samples is shown in Figure 10.

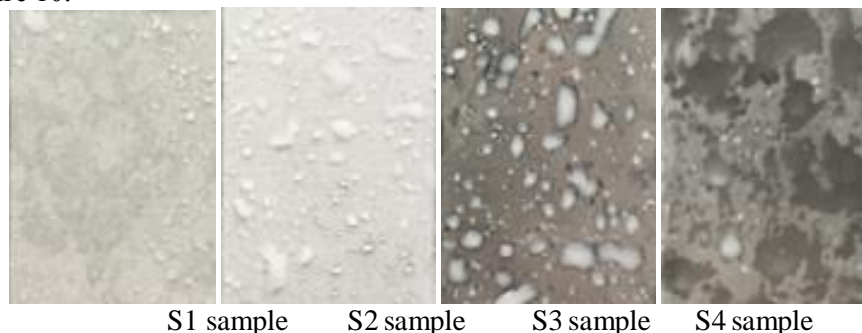


Figure 10. Ice formation on the surface of samples.

In Figure 10, it is especially obvious that ice is forming on the surfaces of S2, S3 and S4 samples. Among them, ice on the surfaces of S2 and S3 samples are relatively small, and distributed as points, while ice on surface of S4 sample is more extensive, and distribute as facet. On the other hand, there is little ice on the surface of S1 sample. Only a small amount of ice grains are distributed as point at the edge of the sample. Thus, the surface of sample with weak wettability can really prevent the formation of ice on surface.

4. Conclusions

In this paper, the contact characteristics of a single water droplet with aero aluminum alloy in different wettability are researched, as well as the anti-ice ability of aero aluminum alloy. The conclusions are as follows.

1. A single water droplet impact on the surfaces of aero aluminum alloy with different wettability, the weaker the wettability of the surface and the larger the volume of droplets, the longer the slip distance of droplets on the surface of aluminum alloy. While on the surface of strong wettability, the

larger the volume and faster the speed of water droplets, the higher of height and the larger the spread area of water droplets on the surface of aero aluminum alloy.

2. When impacting on a surface with weak wettability, all of water droplets will leave the surface of aeroaluminum alloy after deformation, sliding and restoring. But on the surface of aero aluminum alloy with strong wettability, all of water droplets impacting on surface finally stay on it after deformation and sliding. Therefore, the surface of aero aluminum alloy with weak wettability is more likely to freeze.

3. With the weakening of surface wettability, the anti-ice capability of aero-aluminum alloy is gradually enhanced. When the surface of aero aluminum alloy with strong wettability is frozen, the area of ice is relatively wide and distribute as facet. With the decrease of surface wettability, the ice area is reduced, and the ice distribution is changed from facet to point gradually. Once aero aluminum alloy become super hydrophobic surface (surface contact angle is greater than 150°), there are only few micro ice grains on the edge of surface. Thus, the surface with weak wettability can really prevent the formation of ice.

Acknowledgment

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