A NEW METHOD FOR MEASURING VERTICAL ICE ADHESION STRENGTH

Wang Guogang*, Mu Jingjing, Zhou Hongwei, Liu Zhenqiang
Beijng Guodian Futong Science and Technology Development Co., Ltd, China Electric Power Research Institute, Beijing, China
*Email: wanggg@epri.sgcc.com.cn

Abstract: Serious accidents or disasters could be induced by ice that covered on structures. The comprehensive understanding of the special physical properties of ice, especially, the low-temperature phase transition process, and the ice adhesion on structures is crucial to reduce the accidents and disasters. In this work, the vertical ice adhesion strength (VIAS) on different material surface had been measured by the novel designed device. And the effect of VIAS on same material surface had been discussed, such as the material surface roughness, freezing time, ice thickness, icing temperature, and so on.

1. INTRODUCTION

The natural water (snow, sleet and dew etc) is easily frozen on the structures surface and formed ice in low-temperature and damp environment, such as snow ice on road, ice on plane flanks and transmission wires, and so on. Serious problems can be caused by the ice, such as the inconvenience to the human life, the serious threat on safety of production and transportation, and even huge economic losses[1,2]. Therefore, in the past several decades, many scientists focused their efforts on preventing ice disasters. The ice adhesion between ice and material surface, which plays key role on studying the ice damage, is evaluated by the ice adhesion strength. In recent years, some methods have been carried out to measure the ice adhesion strength[3-7], such as lap method, stripping method, axial cylindrical shear method, stretching method, inflatable method, laser spallation method, piezoelectric membrane method, disc torsional method and so on. But a more reliable, widely used method for measuring ice adhesion strength is still urgent.

2. RESULTS

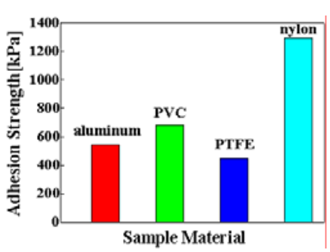
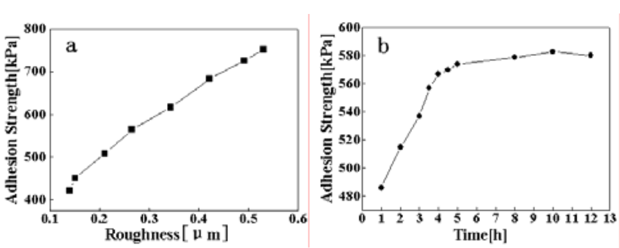


Figure 1: VIAS on different material surface



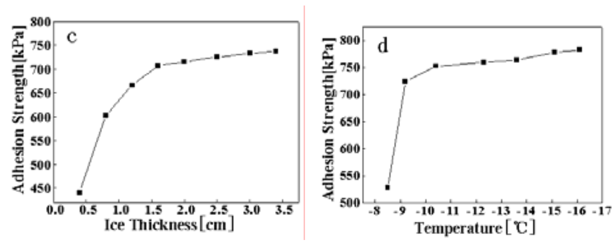


Figure 2: Effects of sample surface roughness (a), frozen time (b), ice thickness (c) and frozen temperature on VIAS

Table 1: Relative Errors (RE) of Measuring VIAS on Different Samples

Sample	Aluminum	PVC	PTFE	Nylon
RE	±6.2%	±5.5%	±5.7%	±5.1%

3. CONCLUSION:

The vertical ice adhesion strength (VIAS) was tested by the novel device and a new method. This method can also be used to accurately measure VIAS on multi-solid materials, such as metal, polymer and variety of coatings on them.

4. REFERENCES:

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Abstract: **Serious accidents or disasters could be induced by ice that covered on structures. The comprehensive understanding of the special physical properties of ice, especially, the low-temperature phase transition process, and the ice adhesion on structures is crucial to reduce the accidents and disasters. In this work, the vertical ice adhesion strength (VIAS) on different material surface had been measured by the novel designed device. And the effect of VIAS on same material surface had been discussed, such as the material surface roughness, freezing time, ice thickness, icing temperature, and so on.**

Keywords: Vertical Adhesion Strength, Test Device, New Method

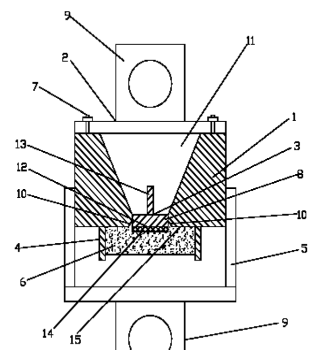
I. INTRODUCTION

The natural water (snow, sleet and dew etc) is easily frozen on the structures surface and formed ice in low-temperature and damp environment, such as snow ice on road, ice on plane flanks and transmission wires, and so on. Serious problems can be caused by the ice, such as the inconvenience to the human life, the serious threat on safety of production and transportation, and even huge economic losses[1,2]. Therefore, in the past several decades, many scientists focused their efforts on preventing ice disasters. The ice adhesion between ice and material surface, which plays key role on studying the ice damage, is evaluated by the ice adhesion strength. In recent years, some methods have been carried out to measure the ice adhesion strength[3-7], such as lap method, stripping method, axial cylindrical shear method, stretching method, inflatable method, laser spallation method, piezoelectric membrane method, disc torsional method and so on. But a more reliable, widely used method for measuring ice adhesion strength is still urgent.

II. DEVICE AND METHOD DESCRIPTION

The vertical ice adhesion strength (VIAS) on material surface had been measured repeatedly by the novel designed device. A complete and effective measuring method had been put forward finally. The method can be applied to measure VIAS on different materials surface. The results measured by this method are repeatable and accurate.

The schematic of the novel designed device is shown in Fig. 1[8]. The VIAS on different material surface can be measured by this device. Fig.2 shows the process of testing VIAS.



1. Support, 2. Sample loading, 3. Sample, 4. Water block, 5. Cover, 6. Ice, 7. Fixed nut, 8. Sample body, 9. Fixed handle, 10. Sample hole, 11. Inserting part, 12. Sample plane, 13. Sample fixed, 14. Coating, 15. Support plane

Figure 1. Device for measuring VIAS

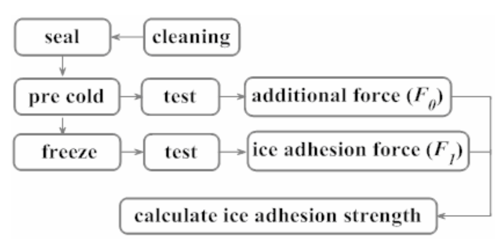


Figure 2. Process of testing VIAS

As shown in Fig. 1, the test device consists of four major parts. They are support (part 1), sample loading (part 2), cover (part 5) and fixed nut (part 7) respectively. The sample loading part contains fixed handle (part 9) and inserting part (part 11). The support part contains water block (part 4), sample hole (part 10) and support plane (part 5). The fixed nut part should be removed before testing. And the wall of sample hole must be daubed by hydrophobic sealing material to prevent generating additional force induced by frozen water infiltrating tapered joint surface process between part 1 and part 11 (combination of surface). The adhesion between sealing material and the wall of sample hole can generate additional shear force, and adding the weight of the top components of the device (contain

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support body, sample loading body, fixed nut and sample), cause the measured vertical ice adhesion force (F_1) to the material contains an additional force (F_0). Therefore, the effective vertical ice adhesion force (F) equal to F_1-F_0, and the VIAS $\sigma = F/S = (F_1 - F_0) / S$. The VIAS is the vertical ice adhesion force on unit area of the material surface. The S is the surface area of the sample plane (part 12).

Fig. 2 shows the experimental process. First, the sample and test device must be cleaned with acetone. Second, the sample must be fixed in sample loading, and hydrophobic sealing material must be daubed on the wall of sample hole. Next, the part 1, part 2 and part 7 should be assembled and refrigerated with part 5 to pre-cold for 2h or longer. Then screw part 5 and remove part 7. The additional force can be tested by computer controlled electronic universal test machine. The experimental process is repeated as the first three steps. Then some distilled water is infused into water block (part 4) after pre-cold for 2h and continued to cold until all of the water has frozen. Subsequently, screw part 5 and remove part 7. The ice adhesion force can be tested by computer controlled electronic universal test machine.

III. APPLICATION RESEARCH ON DEVICE

A. *VIAS on Different Material Surface*

The VIAS had been measured by above test device and method on different samples, which were made from aluminum, polyvinylchloride (PVC), polytetrafluoroethylene (PTFE) and nylon with the temperature from -8℃ to -12℃, the humidity from 80% to 90%, the frozen time 4h, and the thickness of ice about 2.5cm. The results are showed in Fig. 3. The surface of all samples had been polished with the roughness of samples between 0.20μm and 0.22μm.

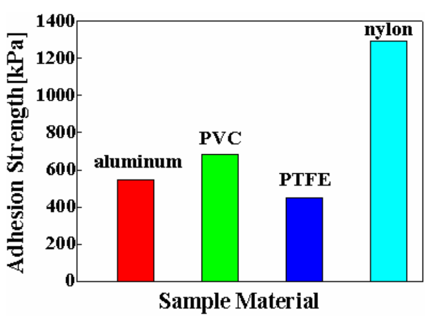

Figure 3. VIAS on different material surface

As shown in Fig 3, the VIAS on the surface of PTFE, aluminum, PVC and nylon increase in file. They are mainly caused by different instinct characteristics and surface energies of different materials. For example, surface energy of PTFE is lower, which causes the water spreading on the surface more slowly, resulting in the slower frozen speed. The results are in accordance with the reference[9].

The accuracy of the measurement of the device and method had been investigated by a lot of repeated experiment. The relative errors of measuring VIAS on different samples are shown in Table 1.

As shown in Table 1, the relative errors of measuring VIAS on the surface of nylon, PVC, PTFE, and aluminum increase in file. The results explain that the measurement values are accurate enough tested by this novel device and new method.

TABLE I. RELATIVE ERRORS (RE) OF MEASURING VIAS ON DIFFERENT SAMPLES

Sample	Aluminum	PVC	PTFE	Nylon
RE	±6.2%	±5.5%	±5.7%	±5.1%

B. *Effect of other Factors on VIAS*

The VIAS is affected by the material character as above description. But the VIAS is also affected by many other factors, such as the surface roughness of the samples, frozen time, frozen temperature, the thickness of ice, and so on. Therefore, we chose the aluminum as sample to investigate the effect of the other factors on the VIAS with the test device and method.

1) *Effect of sample surface roughness*

The experiment condition is as follows: the surface roughness of samples was in the range of 0.13μm to 0.53μm; the frozen temperature was from -9℃ to -10℃; the humidity was from 80% to 90%; the frozen time was 4h; and the thickness of ice was about 2.5cm. The results are showed in Fig. 4.

As shown in Fig. 4, it is evident that the VIAS can be affected by the surface roughness of aluminum. The VIAS is increased with the increasing roughness. It is well known that the tiny flaws and pits are the main factors to ice firmly adhere on sample surface, and the samples surface roughness is increased with the quantities of the flaws and pits. Therefore, it is understandable that the VIAS is increased with the increasing surface roughness.

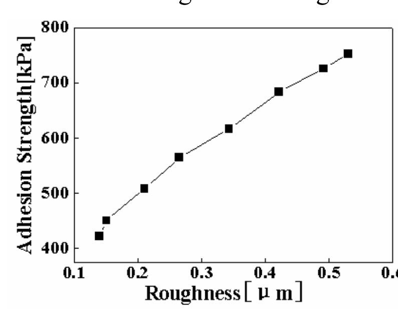

Figure 4. Effect of samples surface roughness on the VIAS

2) *Effect of frozen time on VIAS*

The experiment condition is as follows: the surface roughness of samples was in the range of 0.20μm to 0.22μm; the frozen temperature was between -9℃ and -10℃; the humidity was between 80% and 90%; the thickness of ice was about 2.5cm; the frozen time was changed from 1h to 12h. The results are showed in Fig. 5.

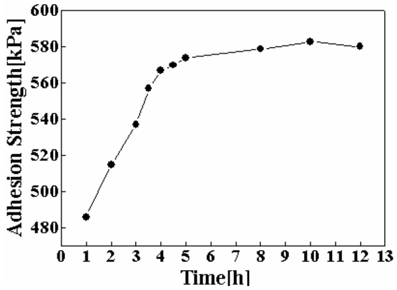

Figure 5. Effec of frozen time on VIAS

As shown in Fig. 5, the VIAS on aluminum surface increases linearly with frozen time from 1h to 4h. Then the VIAS increases slowly when the frozen time is more than 4h. It is well known that the ice formation is the water phase transition process with the heat releasing and icing[10]. The heat is released with the frozen time prolonged at first, and then the system tends to heat balance gradually. Therefore, the VIAS increases quickly with frozen time firstly. Subsequently, the VIAS increases slowly when the system reaches heat balance when the frozen time is more than 4h or longer. Finally, the VIAS reaches maximum when the system reaches the heat balance. Therefore, the frozen time must be long enough before measuring the VIAS.

3) Effect of ice thickness on VIAS

It has been reported the VIAS is irrelevant to the ice thickness[2], but we obtained another conclusion through experiments. The measured values of VIAS are affected by the ice thickness to some extent. The experiment condition is as follows: the surface roughness of samples was between 0.49μm and 0.51μm; the frozen temperature was between -9℃ and -10℃; the humidity was between 80% and 90%; the frozen time was 4h; the thickness of ice was changed from 0.4cm to 3.4cm.

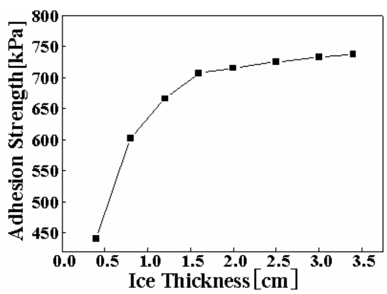

Figure 6. Effec of ice thickness on VIAS

As shown in Fig. 6, the VIAS increases with the increasing ice thickness. It increases quickly when the ice thickness is lower than 2.0cm, but increases slowly when the ice thickness is over 2.0cm. Therefore, the ice thickness must be higher than 2.0cm when we measure the VIAS.

4) Effect of frozen temperature on VIAS

The experiment condition is as follows: the surface roughness of samples was between 0.49μm and 0.51μm; the humidity was between 80% and 90%; the frozen time was 4h; the thickness of ice was 2.5cm; the frozen temperature changed from -16.2℃ to -8.5℃.

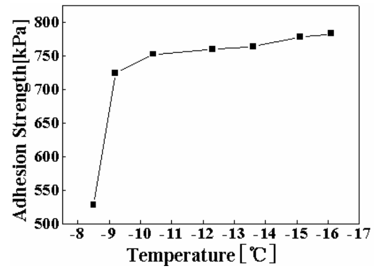

Figure 7. Effect of temperature on VIAS

As shown in Fig. 7, the VIAS increases with the decreasing temperature. The result is in accordance with [2]. The VIAS increases evidently with the temperature in the range of -8.5℃-9℃, but increases slowly when the frozen temperature is lower than -9℃. As reported in [11], the shear force of ice adhesion on solid surface would tend to balance when the frozen temperature reached a certain value. It was due to the structures surface system had reached balance at the temperature. The VIAS would not increase quickly as the frozen temperature above a certain value.

IV. CONCLUSION

- The VIAS, which is affected by the character instincts of material surface, increases with the increasing surface roughness.
- The VIAS increases with the decreasing frozen temperature if the frozen time and ice thickness have been fixed on a certain value. The frozen temperature would not affect the VIAS obviously when it reaches a particular value.
- The frozen time should be long enough and ice thickness should be high enough before measuring the VIAS to minimize measurement errors.

The vertical ice adhesion strength (VIAS) was tested by the novel device and a new method. This method can also be used to accurately measure VIAS on multi-solid materials, such as metal, polymer and variety of coatings on them.

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