Study on heat transfer performance of water-borne and oily graphene coatings using anti-/de-icing component

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Abstract. A graphene coating anti-/de-icing experiment was proposed by employing water-borne and oily graphene coatings on the composite material anti-/de-icing component. Considering the characteristics of helicopter rotor sensitivity to icing, a new graphene coating enhancing thermal conductivity of anti-/de-icing component was proposed. The anti-/de-icing experiment was conducted to validate the effectiveness of graphene coating. The results of the experiment show that the graphene coatings play a prominent role in controlling the heat transfer of anti-/de-icing component. The anti-/de-icing effect of oily graphene coating is superior to water-borne graphene.

1. Introduction
The helicopter will encounter cold water droplets in the air when it is in the cold area or passing through the cloud, and the rotor surface is easy to freeze [1-3]. The icing on the rotor surface will lead to decreasing in flight lift and imbalance of rotor weight. At this stage, the main mean of protection is to prevent ice and deicing by installing and controlling the anti-/de-icing components on the rotor [4-5]. However, this method is more expensive for airborne energy, so it is necessary to improve this method.

Graphene, as a single layer graphite material, has been widely used in aviation and aerospace because of its excellent thermal conductivity and electrical conductivity [6-9]. A large number of studies have shown that graphene coating has good thermal conductivity and mechanical stability. Grzegorz [6], Prolongo [7] and Raji [8] studied the thermal conductivity of graphite coating respectively. The researches focus on the Joule heat produced by the graphene coating. Wang [9] proposed a graphene nanoribbon film that take advantage of both the low polarizability and conductive.

In this paper, we mainly focus on the thermal conductivity of graphene itself. Due to the heat conduction structure of graphene, the generated heat of the heating pad in the anti-/de-icing component is transferred to the surface by graphene coating, which accelerating the rotor surface ice melting, and improving the anti-icing and de-icing efficiency of helicopter rotor. The thermal conductivity of graphene coating was studied by preparing anti-/de-icing component and surface sprayed graphene coating, and conducting the anti-/de-icing experiment.

2. Heat transfer mathematical model
The heat transfer mathematical model mainly consists of the internal heat transfer model and surface heat transfer model. The internal heat transfer model can be written as follows [10]:

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\[ T_{ni} = T_{w1} - \phi \sum_{j=1}^{\delta_i} \frac{\delta_j}{A\lambda_j} = T_{w1} - \phi \sum_{j=1}^{\delta_i} \frac{\delta_j}{A(\lambda_{ji} \sin^2 \beta + \lambda_{j2} \cos^2 \beta)} \]

At ambient temperature, Balandin \cite{11} measured thermal conductivity of single layer graphene prepared by mechanical peeling. The test result range from 4840 to 5300 W m K\(^{-1}\), and the deduced thermal conductivity formula can be written as follows:

\[ k = \chi_G \left( \frac{L}{2hW} \right) \left( \frac{\delta w}{\delta p} \right)^{-1} \]

Where \( L \) denotes the length of Graphene film; \( W \) stands for graphene width; \( h \) denotes the thickness of graphene; \( \chi_G \) is temperature coefficient: \( \chi_G = \delta w / \Delta T \).

3. Experiment setup

The anti-/de-icing experiment was set up in the refrigeration environment under -15 °C. As shown in Figure 1, the graphene coating samples were prepared by using the standard spray process and the composite material were paved and cured under high temperature of 120 °C.

![Figure 1. Schematic of the graphene sample.](image)

Figure 2 shows the anti-/de-icing device in de-icing experiment, the pulling force is used, which is equivalent to centrifugal force generated by rotor rotating at high speed. The surface temperature was measured by thermocouples. The accuracy of the thermocouple is 0.5K, and the measuring range is 243.15K-353.15K.

In this paper, water-soluble graphene coating and oily graphene coating tests were carried out. By comparing the heat transfer effect of these two kinds of graphene coating, different characters of graphene were analyzed. Two kinds of graphene have the same content of carbon, and are provided by Jiangsu Graphene Company.
Figure 2. Anti-/de-icing experiment device.

4. Result and discuss
Through conducting the de-icing experiments, the de-icing performance of the graphene coating on the anti-/de-icing component was verified by recording the de-icing time in each de-icing experiment.

Firstly, the effect of thermal conductivity of graphene coating on the surface temperature distribution of anti-/de-icing components was tested under the same experimental conditions. Plot the maximum temperature value as shown in Figure 3.

Figure 3. Comparison of maximum temperature of coating sample and uncoated sample.

By comparing the experimental data, the graphene coating surface temperature controlling ice components increased significantly, indicating that the graphene sheet coating can change the thermal conductivity of ice on the surface of the rotor assembly, improve the anti icing and de-icing efficiency.

The de-icing performance of graphene coating with different properties was compared by de-icing experiments. The water-soluble graphene and the oily graphene were coated on the surface of the anti-/de-icing component by the same spraying process. Under the same heating scheme, the rotor surface temperature is measured and the de-icing test is carried out under the same icing condition.

Figure 4 shows the temperature distribution of different kinds of graphene. From the figure we can know that water-soluble graphene has better heat transfer performance, which indicating the de-icing time is shorter than that of oily graphene.
Figure 4. Temperature distribution of different kinds of graphene.

At the same time, the de-icing tests were taken three times to measuring the de-icing time. The experiment results verify that the heat transfer performance of the oily graphene coating is better than that of the water-soluble graphene coating. The data listed in Table 1 are experimental results. Analyzing experiment results show that with the change of water graphene coating to oily graphene coating, the de-icing time is obviously shortened, and the de-icing efficiency is improved obviously.

Table 1. De-icing time of two kinds of graphene.

| De-icing time (s) | Water-soluble Graphene | Oily Graphene |
|-------------------|-------------------------|--------------|
| 1                 | 125                     | 83           |
| 2                 | 137                     | 92           |
| 3                 | 119                     | 78           |

The different spraying process was conducted in the de-icing experiment. By changing the spraying process and changing the spraying thickness of the graphene coating, 4 tests were carried out, and the coating thickness of the four experiments was 2 um, 4.3 um, 5.5 um, and 6.7um respectively. The maximum temperature of the anti-/de-icing surface was shown in Figure 5.

Figure 5. Maximum temperature of different spray layers.

From the data, it is obvious that the thickness can change the heat transfer performance of the graphene. With the increase of graphene coating thickness, the thermal conductivity of coating decreases gradually. The results also verify the thermal transfer mathematic model referred in Section 2.

5. Conclusions
Through the experiments of de-icing on the graphene coated on the anti-/de-icing component, the improvement of graphene coatings on the heat transfer performance is studied, which providing a basis for the use of graphene coating in the anti-/de-icing for helicopter rotor.

The experimental results show that the graphene coating can improve the thermal conductivity of the helicopter rotor anti-/de-icing component to prevent icing. When the graphene coating is employed, the de-icing time of the rotor anti-/de-icing component is shortened obviously. Moreover, the results show that the thermal conductivity of the oily graphene coating is better than the thermal conductivity of the water-soluble graphene coating. When increasing the thickness of graphene coating, the heat transfer capacity of anti-/de-icing component decreased.

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