Experiment of ice ball impacting glass fiber laminate

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Abstract. As a solid form of water, ice has brought a lot of technical challenges to aviation, ships, bridges and other related engineering fields, the technical fields such as the impact protection strength of aircraft and the strength design of icebreakers need to consider the influences of ice impact on structural strength and reliability. Therefore, in order to solve such problems, this paper takes the hail disaster as the background, and applies a first-level air gun to use 50.8mm (2inch) and 25.4mm (1inch) diameter ice balls to conduct impact experiments on glass fiber laminates at various speeds (2inch ice ball for 5 speeds, 1inch ice ball for 3 speeds). As the results, the specific support force of the laminated plate and its back plate strain under different working conditions are obtained. It is found that the impact reaction force of the 1 inch ice ball is basically proportional to the impact energy, and the law of the 2 inch ice ball is slightly different due to the fixing method of the laminated plate; in terms of strain caused by impact, it is concluded that the maximum strain at the contact portion of a 1 inch ice ball at an impact speed of 88 m/s is 10300 με; at the same time, a high-speed camera was used to record the process of the ice ball impacting the target plate, and the damage of the ice ball at the instant of impact and the deformation form of the laminated plate were observed and analyzed.

1. Introduction

Decoge [1] and others carried out experiments to simulate the impact of hail on aluminum plates. In the experiments, the quality and speed of ice were changed, and the macro deformation of aluminum plates under different working conditions was observed. Pan and Render [2] [3] changed the curvature of the target surface, and compared the response law and difference between non-planar target and flat target. Finally, the results of the final experiment show that when the hail impacts the non-planar target, the speed of splashing to the surroundings is much lower than that when it hits the flat target, but it has little effect on the size of the fragments formed by the ice ball breaking.
Since the 21st century, Kim [4] [5 used an air gun device to conduct an ice ball impact composite laminate experiment. By changing the speed (30~200m/s) of the ice ball, the contact force on the laminate and the damage form of the laminate under different speeds were measured. Finally, it was found that there was a linear relationship between the kinetic energy of the impact of the ice ball and the impact contact force, regardless of the size of the ice ball. After studying the basic impact force, Qin [5] noticed that when ice can not cause penetration damage to the laminate, the main internal damage form of the laminate is delamination. This view was later confirmed by Hou [7] and others. Subsequently, some scholars [8] [9] analyzed the relationship between different impact speeds and damage areas by C-scan, and concluded that the damage area and the impact energy are linearly related. The damage after the impact of hail is shown in Figure 1.

2. Ice ball impact test

2.1. Ice ball and sabot

2.1.1. Ice ball size

According to the ASTM F320-16 standard [10], there are three standard sizes of ice hockey balls, which are 0.5inch, 1inch, and 2inch, respectively. In this experiment, the reference given in the standard was used, and 2 inch (50.8mm) and 1 inch (25.4mm) ice balls were used for impact test on glass fiber laminates. The ice sample is a non-bubble and crack ice ball prepared by a self-designed mold.

2.1.2. sabot

This experiment uses the form of instantaneous release of compressed gas to directly push the ice ball. The ice ball may be destroyed in the process of instantaneous acceleration, which will cause the experiment to fail. Therefore, it is necessary to find a material with good thermal insulation performance and strong strength as the sabot. The sabot used in this article is polytetrafluoroethylene.

Due to processing errors and other issues, there is no guarantee that all ice balls can be placed in the cartridge without shaking. So, in order to ensure that the ice ball can be fixed and increase the buffering effect when the sabot is separated, the polyurethane foam is selected in the sabot, and a hemispherical space is cut at the center of the foam. The specific situation is shown in Figure 2.
2.2. Introduction of experimental equipment

The schematic diagram of the first-level air gun used in this experiment is shown in Figure 3. The main principle is to compress the gas in the high-pressure gas cylinder through an air compressor, and find the speed corresponding to different air pressure according to multiple tests. Each time the impact speed is changed by changing the compressed air pressure, and the corresponding experiment is completed.

2.3. Experimental procedure

2.3.1. Preparation before experiment

Before this experiment, all target plates need to be pasted with strain gauges. The specific position is shown in Figure 4. Figure 4 shows the engineering drawing of the target plate, where point C is the center of the cover plate (target plate); the inner frame of the target plate is 300mm, H (Horizontal) and V (Vertical) points are the center point to the midpoint of the horizontal and vertical borders, respectively, and Q (Quarter) is the intersection of V and H with the vertical line of the border. An orthogonal strain gauge is attached to each point to measure strain in both horizontal and vertical directions.
2.3.2. Experimental conditions

Before the start of this experiment, the emission pressure of the experimental equipment and the corresponding speed need to be tested. Since this experiment is based on the anti-hail impact of the aeroengine volute, and the aircraft is known to have a take-off and landing speed of about 320 km / h (about 88m/s), this impact experiment uses 88m/s as the basic operating condition to conduct different speed experiments. The specific speed conditions are shown in Tables 1 and 2. The experimental preparation is shown in Figure 5.

Table 1 50.8mm diameter ice ball impact test velocity

| Number | 1   | 2   | 3   | 4   | 5   |
|--------|-----|-----|-----|-----|-----|
| velocity (m/s) | 88  | 110 | 132 | 154 | 198 |

Table 2 25.4mm diameter ice ball impact test velocity

| Number | 1 | 2 | 3 |
|--------|---|---|---|
| velocity (m/s) | 88 | 132 | 177 |
The physical picture of the front and back of the fiberglass laminate before the experiment is shown in Figure 6. The size of the glass fiber laminate used in this experiment was set to 330mm × 330mm, and the laminate was laminated in a [0/90] orthogonal layer with a total thickness of 1.86mm (17 layers).

2.4. Experimental results and analysis

2.4.1. Ice ball impact laminate process

In this experiment, the impact process was recorded with a high-speed camera. The number of shooting frames used by the high-speed camera was 10,000 fps. Figure 7 shows the moment when the part of the video is meaningful. The last frame before the ice ball touches the target is customized as the first frame of the process analysis, which is the 0.1ms moment.

According to the same principle, the video of the ice ball impact laminate with a diameter of 25.4mm was intercepted and integrated, as shown in Figure 8.
2.4.2 Results of impact test data

Due to the small stiffness of the glass fiber, the load-time curve will jitter during the impact process. In this article, only the maximum load at the moment of impact is considered. The specific relationship between the load size and speed is shown in Table 2 and 3.

| No  | Ice ball quality(g) | Actual velocity(m/s) | Peak load(kN) |
|-----|---------------------|----------------------|---------------|
| V88-1 | 63.11  | 79.18  | 12.85         |
| V88-2 | 62.14  | 89.20  | 12.01         |
| V88-3 | 64.31  | 92.80  | 14.58         |
| V110-1 | 63.33  | 119.19 | 22.81         |
| V110-2 | 64.54  | 117.23 | 23.81         |
| V110-3 | 63.12  | 122.39 | 21.99         |
| V132-1 | 62.82  | 135.68 | 28.55         |
| V132-2 | 61.98  | 132.10 | 27.49         |
| V132-3 | 62.66  | 136.33 | 27.25         |
| V154-1 | 64.01  | 159.24 | 35.46         |
| V154-2 | 62.54  | 160.66 | 36.08         |
| V198-1 | 62.65  | 135.68 | 28.55         |
| V198-2 | 61.12  | 208.77 | 45.20         |

| No  | Ice ball quality(g) | Actual velocity(m/s) | Peak load(kN) |
|-----|---------------------|----------------------|---------------|
| V88-1 | 7.96   | 85.25  | 5.00          |
| V88-2 | 8.20   | 87.55  | 6.12          |
| V88-3 | 7.84   | 88.11  | 6.80          |
| V132-1 | 7.99  | 131.06 | 13.03         |
| V132-2 | 7.65  | 132.80 | 13.08         |
| V132-3 | 8.08  | 130.04 | 12.22         |
| V177-1 | 8.11  | 188.16 | 23.33         |
| V177-2 | 7.97  | 185.36 | 22.91         |

This experiment also measured the target plate strain. However, due to the large load and deformation at the moment of impact, many strain gauges have been detackified or out of range without collecting the data completely. Therefore, only the strain data of the 25.8mm ice ball under the impact of 88m/s velocity(V88-2) is more complete.
3. Summary
1. It can be seen from Table 4 that in the experimental results of the 25.4mm ice ball, the impact energy and the impact load show a basically proportional relationship, which is basically consistent with the conclusions obtained in the relevant literature. However, in the results of the 50.8mm ice ball (Table 3), this rule is not obvious and the results are more discrete, mainly because the plate is fixed by the cover plate and the bottom plate, this method works better at low energy. However, it can be seen from the high-speed camera video that the fiberglass laminate will have a "knockback" phenomenon during the impact. When the energy is large and the ice ball is not enough to penetrate it, it will cause the entire laminate to overcome the friction formed by the cover plate and the bottom plate, forming a serious "pumping" phenomenon. This results in a reduction in the contact area between the fiberboard and the bottom plate, and no longer effectively squeezing the bottom plate. So the rule is not obvious.

2. As can be seen from Figure 9 and Figure 10, theoretically the data with the same strain fits well, the error is within the allowable range and can be used as valid data. According to FIG. 11, it can be seen that the maximum strain value of the laminate due to impact is 10,300.

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