Debonding Failure Analysis of Honeycomb Sandwich Composite Radome

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Abstract. The radome made of C sandwich structure failed after different service time. The failure causes were analyzed by ultrasonic C-scan inspection, fracture surface inspection, section metallographic inspection, bonding strength test, manufacturing process analysis and viscosity testing of film. The results show that: The debonding position of honeycomb composite radome is between honeycomb and outer skin. That is caused by the weak adhesive strength between honeycomb and skin. The main cause of weak adhesion is that the film loses fluidity and viscosity due to the overlong holding time. Weak adhesion is not related to the heating temperature, compressive stress and local honeycomb contamination. The holding time should be controlled to be less than 6h in later manufacture of the radome to keep fluidity and viscosity of film.

Keywords: Debonding failure; honeycomb sandwich composite; radome; weak adhesion.

1. Introduction

Radome is a kind of shell used to protect the antenna or the whole microwave system from external harmful effects. Radome is located in the head of aircrafts, which is an important part of normal flight, navigation and guidance [1-3]. Many radomes are made of honeycomb sandwich composite structures, such as A-sandwich structure and C-sandwich structure [4-6], because honeycomb sandwich Composites have excellent electromagnetic property, high stiffness, high strength and low density.

Radome is often damaged by lighting and impacts such as bird impact, sand impact and hail impact. In addition, the sandwich composites are sensitive to hot and humid environments [6-8]. Thus, the failure of radome such as cracking, debonding, delamination and accumulating water often occurs, which affect the normal operation of the antenna or the microwave system. The Boeing company and Airbus investigated the failure modes of delamination and lighting damage [7,8]. Sun analyzed the cause of water accumulation in radomes and the effect of water on the delamination [9]. Guo researched nondestructive testing methods of C-sandwich radomes [10]. Li investigated the inspection and repair methods of radome failure zone, but didn’t analyzed the causes of delamination of radomes[11].
In this article, the radome, made of C sandwich structure, worked abnormally after different service time. Radomes are ellipse and their size are 9m×2m×3m. The C sandwich structure was made by 3-step same bonding process. First, the inner skin and the inner honeycomb were adhered together, and then the media skin was adhered to the inner honeycomb and outer honeycomb. At last, the outer skin is adhered to the outer honeycomb, as shown in Figure1. All the skins were made of glass fiber reinforced composite, and the honeycomb was made of paper. The adhesive film is used in the adhesive process.

![Fig.1 Sketch map of C sandwich structure](image)

And the plump-up of outer skin of the radomes were found by visual inspection after service. The failure causes of radomes were analyzed, which providing technical support for radome structure improvement to avoid the recurrence of similar failure.

2. Experimental Materials and Procedure
The failed radome was inspected by ultrasonic C-scan inspection to confirm the failure area. The detailed position of debonding zone and the state of abnormal zone were cut perpendicular to the outer skin. Then the fracture surface inspection and adhesive interface analysis were carried out by metallographic microscope. The bond strength tests were carried out for normal and abnormal zones. The manufacturing processes were analyzed to look for the influencing factors of radome failure. At last, the viscidity testing of film was tested to find out the debonding reasons of radome.

3. Results and Discussions

3.1. Ultrasonic c-scan inspection
The ultrasonic c-scan inspection show that there are three kinds of states on the radome, debonding zone, abnormal zone and normal zone. The size and shape of each zone was shown in Fig.2. In the abnormal zone, the signals of non destructive testing are abnormal, but what kind of damages were in this zone couldn’t be confirmed by nondestructive testing.

![Fig.2 The result of ultrasonic c-scan inspection](image)
3.2. Fracture surface inspection
The debonding zone, abnormal zone and normal zone was cut perpendicular to the outer skin. After cutting, the outer skin fall from the outer honeycomb. And the film lay on the outer skin in the debonding zone. There is no honeycomb in the film, as shown in Fig.3. In the abnormal area, the outer skin could be tore lightly from outer skin. The failure characteristics of the abnormal area are the same with that of the debonding area, as shown in Fig.4. The above inspection results show that the abnormal areas are weakly adhesive areas, and the debonding of honeycomb structures is due to weak adhesion between honeycomb and outer skin.

3.3. Bonding strength test
The bond strength tests of normal zone and abnormal zone were carried out. The results show that adhesive strength of the normal is higher than that of abnormal zone, as shown in table1, which further prove that the radome failure is caused by weak adhesion between honeycomb and outer skin.

| Table 1. Adhesive strength (MPa) |
|---------------------------------|
| Position & Position2 | Position3 | Average |
|---------------------|-----------|---------|
| Abnormal zone       | 0.78      | 0.42    | 0.51    | 0.57     |
| Normal zone         | 2.7       | 3.2     | 2.8     | 2.9      |

In the normal radome, the failure position lay on the honeycomb, and small honeycombs are left in the film (as shown in Fig.5), which is different from the debonding and abnormal area. This is the normal failure mode for honeycomb sandwich structure. At the same time, the adhesive strength is much higher.

Fig.3 Fracture surface of debonding area  
Fig.4 Fracture surface of the abnormal area  
Fig.5 Fracture surface of the normal area
3.4. **Section metallographic inspection**

Weak adhesion of honeycomb structure is related to the heating temperature, compressive stress, holding time and local honeycomb contamination [6-7]. Section metallographic inspection was carried out to determine the main cause leading to the weak adhesion of honeycomb structure. From the section metallographic figures, it could be seen that, for normal zone, honeycombs are inserted into the film, film climbs on the wall of honeycombs, and the adhesive height of film on the honeycomb is about 950µm, as shown in Fig.6. For the abnormal zone, honeycombs are also inserted into the film, but the film don’t climb on the wall of honeycombs, and the adhesive height of film on the honeycomb is only about 500µm. So the adhesive area and adhesive strength between the honeycombs and film are lower in the abnormal zone than that in the normal zone. Whether film climbs on the honeycomb is related to the fluidity and viscosity of film. That the honeycombs have been inserted into the films shows that the compressive stress in the process is appropriate, and that all the honeycomb structures in the abnormal zones are the same states could exclude the possibility of local honeycomb contamination. Thus, it could be concluded that the fluidity and viscosity of film have become bad during adhesion perhaps because of the improper heating temperature and heating time.

![Fig.6 Section metallographic of honeycomb for normal zone](image)

![Fig.7 Section metallographic of honeycomb for abnormal zone](image)
3.5. Manufacturing process analysis and viscosity testing of film

To confirm which process parameters were the main failure causes of radome, the manufacturing process of honeycomb composite radome was analyzed. The size of radome structure is very big, and the temperatures are different at different areas of the radome during heating film to bond, so the honeycomb structure radomes was holding for 5-8h at 70°C to make the temperature become accordant. The samples were cut from the radome of different holding time and the adhesive strength was tested (as shown in table 2). It can be seen that the adhesive strength decrease with the increase of holding time. The adhesive strength is maximal, about 2 MPa when the holding time is 5.4h. The adhesive strength is minimal, about 0.6 MPa when the holding time is 7h, which is about 1/3 of strength when holding time was 5.4h. It could be concluded that holding time have an important effect on adhesive strength between skin and honeycomb.

| Holding time at 70°C | Adhesive strength(MPa) |
|----------------------|------------------------|
| 7h                   | 0.70                   | 0.57 | 0.62 |
| 6.4h                 | 1.84                   | 1.85 | 1.80 |
| 5.4h                 | 1.98                   | 2.04 | 2.03 |

Investigation of radomes that have been used shows that the holding time of failed radome is more than 7h, but the holding time of unfailed radome is less than 6h. There are no other differences but the holding time between the failed and unfailed radome during manufacture. To confirm the effects of the holding time at 70°C on the viscosity and fluidity of film, the viscosity of film was tested at 70°C and the result was shown in Fig. 8. It could be seen from Fig.8 that, when the time of holding time is 6.4h, the viscosity of the film is 3600Pa.s and the film has good fluidity. When the holding time is more than 7h, the viscosity of the film is above 10000Pa.s, and the film begins to solidify and lose viscosity and fluidity. So it can be concluded that the poor fluidity and viscosity of film is not related to the holding temperature (70°C) but is related to the overlong holding time at 70°C. The main cause of weak bonding between honeycomb and outer skin is that the film loses fluidity and viscosity due to the overlong holding time.

![Fig.8 The relationship between viscosity and holding time of film at 70°C](image)

4. Conclusions

Through the Ultrasonic c-scan inspection, fracture surface inspection, bonding strength test, section metallographic inspection, manufacturing process analysis and viscosity testing of film, and comprehensive analysis of failure and normal sandwich composite radomes, the conclusions can be obtained as followed:
1) The debonding position of honeycomb composite radome is between honeycomb and outer skin. The debonding is caused by the weak adhesive strength between honeycomb and skin.

2) The main cause of weak adhesion between honeycomb and outer skin is that the film loses fluidity and viscosity due to the overlong holding time. Weak adhesion is not related to the heating temperature, compressive stress and local honeycomb contamination.

3) The holding time should be controlled to be less than 6h in later manufacture of the radome to keep fluidity and viscosity of film.

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