Development of Quick Repair Method for Aircraft Composite Structures

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This paper presents a quick repair method for composite structures mainly developed for aircraft. Existing repair methods use uncured prepreg for repair patches and it takes a long time to form and cure the repair patches. The developed method uses pre-cured thin repair patches between which glue is applied. To perform repairs, these patches are formed to fit the area to be repaired, attached to the area and are then pressurized under atmospheric pressure. Next, the glue is heated and cured using a heater mat. For verification of the feasibility of the developed method, a bonding quality confirmation test, an inspectability confirmation test and a strength test were implemented and the validity of the developed method was confirmed. This technology reduces the repair time of a composite structure by approximately 70% in comparison to existing methods, and therefore allows damaged aircraft to return to operation more quickly.

1. Introduction

Composite materials with high specific strength, excellent fatigue characteristics and great corrosion resistance have been increasingly used for aircraft structures, etc. When struck by lightning or damaged by an impact, a composite material structure may lose its strength and thus require repair. It is anticipated that such repair cases will increase as the use of composite materials expands. When damage to an aircraft occurs, the aircraft must be returned to operation as soon as possible after recovering the necessary quality. However, existing repair methods have the following problems(1).

Prepreg scarf repair, which is one of the typical repair methods for composite structures, requires the removal of the damaged area, cutting and laminating uncured prepreg so that it fits the area to be repaired and the application of heat under a vacuum to facilitate curing. However, this method takes a long time for the preparation of the area to be repaired, the fabrication of the repair patch and for heating and curing.

Wet lay-up repair is another widely-used repair method. However, this method requires the lamination of resin-impregnated fibers at the work site and therefore tends to generate variations in quality, such as the presence of unfilled voids, depending on the skill of the worker. As a result, problems with difficulty in the management of repair quality occur.

There is also a repair method that uses pre-cured repair patches. When using this method, the shape of the repair patch is generally required to conform to the shape of the area to be repaired to achieve good bonding quality. Because the shape of the area to be repaired varies, however, it is difficult to prepare repair patches in all shapes in advance.

As such, Mitsubishi Heavy Industries, Ltd. (MHI) developed a repair method that uses

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pre-cured thin repair patches to facilitate the improvement of both the quality and the repair time. This paper presents the development of the new method, confirmation of its quality and strength and the results of the verification of its validity.

In this paper, a method using multiple thin pre-cured patches that provides a short repair time and stable quality has been proposed, and the feasibility of the method is presented.

2. Developed repair method

Figure 1 shows a summary of the developed repair method. First, thin pre-cured repair patches are prepared in advance.

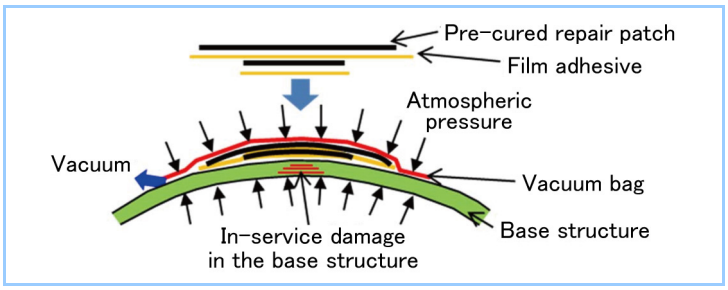

Figure 1 Concept of the proposing repair

When a structural repair is needed, these patches are piled up on the repair area with the insertion of adhesive films between them and the structure to be repaired. Then the area is covered with a bag film and the air in the bag is removed using a vacuum pump to pressurize the repair area under atmospheric pressure. Next, the area is heated using a heater mat, etc., in order to cure the glue.

This method can reduce the time necessary for the fabrication of repair patches that need to fit the repair area, heating and curing. As shown in **Figure 2**, the repair time of composite structures for identical damage is reduced by approximately 70% in comparison to existing methods (prepreg scarf repair). The thin repair patches easily follow the shape of the area to be repaired, due to the atmospheric pressure, even when there is a difference in shape. After the glue is cured, the repair patches unite into a single structure that has enough flexural rigidity to resist buckling. In addition, the repair patches can be fabricated in a well-equipped factory and therefore the fabrication of high-quality repair patches can be expected.

The repair time of this method is calculated on the assumption that the removal of the damage to be repaired is unnecessary. For this assumption, it is necessary that the damage can be left unremoved by confirming that the damage does not progress during the service.

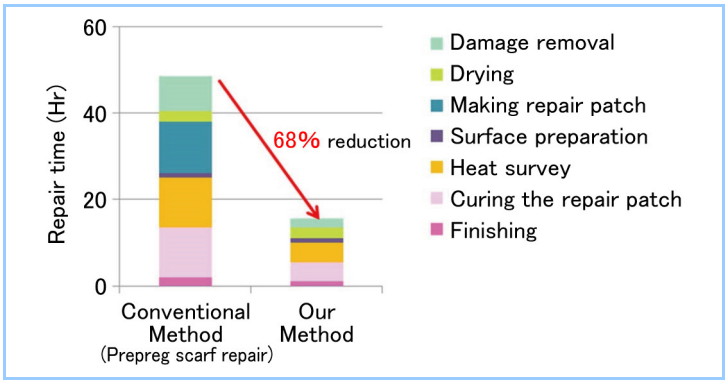

Figure 2 Comparison of repair times

3. Quality confirmation test

To confirm the bonding quality of a repair area, a repaired CFRP panel was prepared and microscopic observation of its cross section was performed.

3.1 Test conditions

The material used for the repair patches was TR6821H106FMA (produced by Mitsubishi

Rayon Co., Ltd.), which was semi-cured prepreg made by impregnating medium-elasticity carbon fiber five-harness satin with epoxy resin. The pre-cured patches used were fabricated in an autoclave by curing two laminated products, each of which was made by laminating four layers of the prepreg on a flat forming tool. The glue used was FM300-2M film glue (produced by Cytec Industries.), and was applied between the two pre-cured repair patches and between the patches and the structure to be repaired.

The structure to be repaired was a CFRP panel with a curvature radius of 1600 mm. As shown in **Figure 3**, the area to be repaired was covered with a bag film and the air was removed from the bag using a vacuum pump to pressurize the repair area under atmospheric pressure. Next, heat was applied using a heater mat, etc., in order to cure the glue.

After the glue was cured, the panel was cut and polished and then its cross section was observed using a microscope.

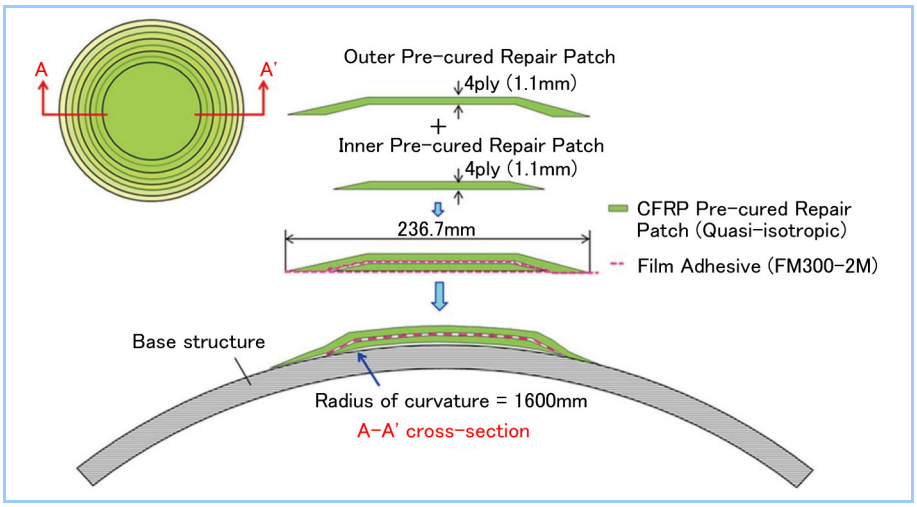

Figure 3 Condition of quality check test

3.2 Test results

Two cross sections, one of which was the area with the minimum curvature radius, were observed. As a result, the unfilled void rate of the bonding layer was 0.3% or less. This is far smaller than the 1% to 2%, which is generally considered as the threshold for the deterioration of shear strength, and therefore it was confirmed that the bonding quality was good (**Figure 4**).

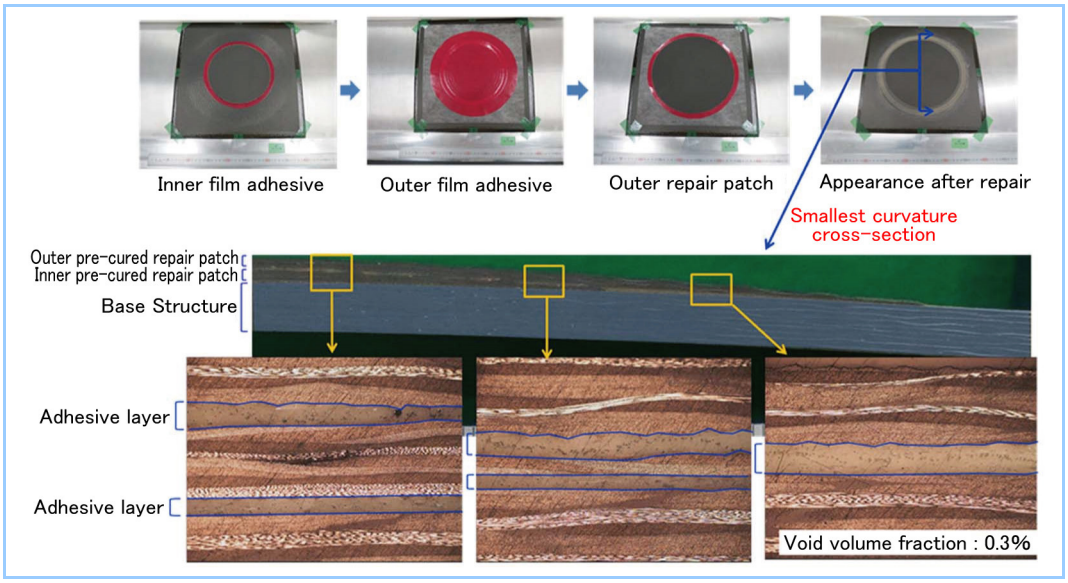

Figure 4 Results of quality check test

4. Inspectability confirmation test

It is necessary to perform a reliable nondestructive inspection in order to inspect the bonding area repaired by the developed method. We confirmed the applicability of a typical ultrasonic flaw detection method.

4.1 Test conditions

A test piece that has the same shape as the test piece used for the quality confirmation test was used for this test and eight artificial flaws inserted into the panel repair bonding area to facilitate the simulation of delamination as shown in **Figure 5**. The inspectability of the artificial flaws in the panel was checked with a pulse reflection method using the typically-used ultrasonic flaw detection device UI-23 manufactured by Ryoden Shonan Electronics Corporation and a probe. **Table 1** shows the test conditions.

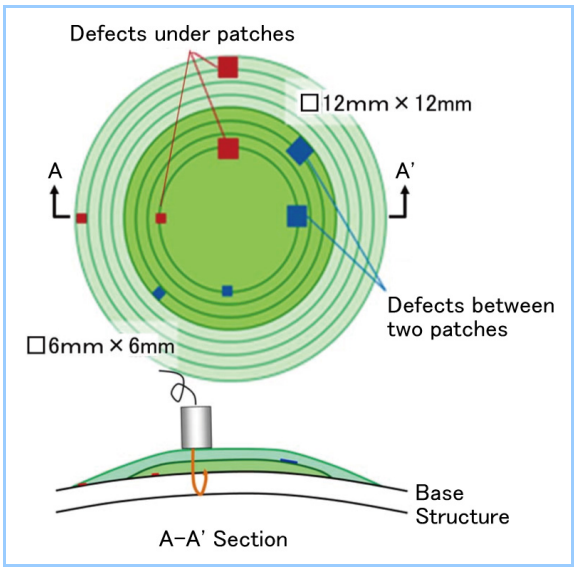

Figure 5 Specimen with artificial defects and ultrasonic inspection method

Table 1 Condition of ultrasonic inspection

UT method		Pulse echo reflection
Coupling medium		Water
UT probe	Frequency	5MHz
	Size	0.25”

4.2 Test results

Figure 6 shows the testing situation and **Figure 7** shows the obtained waveform sample. As shown in these figures, the back wall echo could be identified clearly in the general portion, and the amplitude at reflection pulse on the artificial flaw was less than half of the general portion. In this way, the presence of the flaw could be detected. The same results were obtained for the other flaws, and therefore it was confirmed that flaws in this repair bonding area can be detected with an ultrasonic flaw detection method using a typical device.

Figure 6 Setup of ultrasonic inspection of specimen

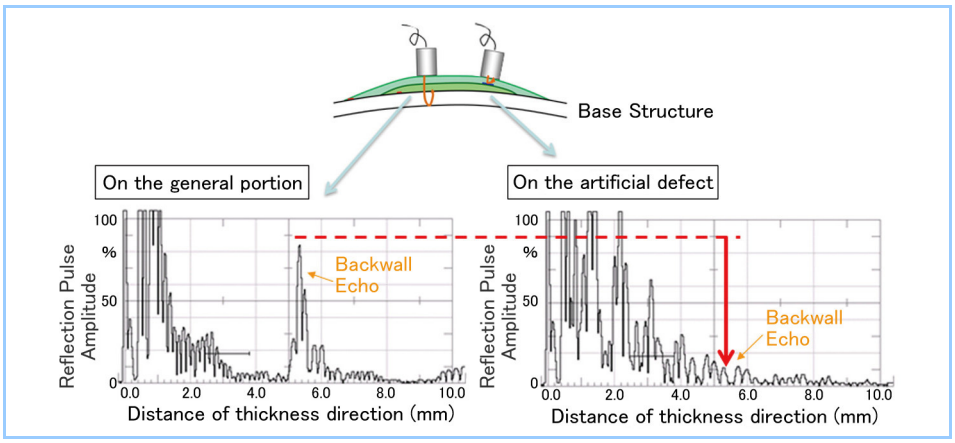

Figure 7 Results of ultrasonic inspection

5. Strength test

Tensile tests were implemented in order to confirm that the repair bonding area had sufficient strength.

5.1 Test piece

Figure 8 shows the shape of the test piece used for this test. The tests were actually performed to simulate a curved area repaired by attaching flat patches, but a strength test of a curved structure is difficult to carry out. Therefore the repair patches were formed to the shape curved oppositely to the simulated repair area as shown in **Figure 9** in advance, and then attached on the both sides of a flat repair panel in a similar process to that described in section 2. In this way, residual stress on the repaired area unique to a repair in which this repair method is used under the condition where the shape of the repair patches differs from that of the area to be repaired was applied to a straight test piece, which can be easily strength tested.

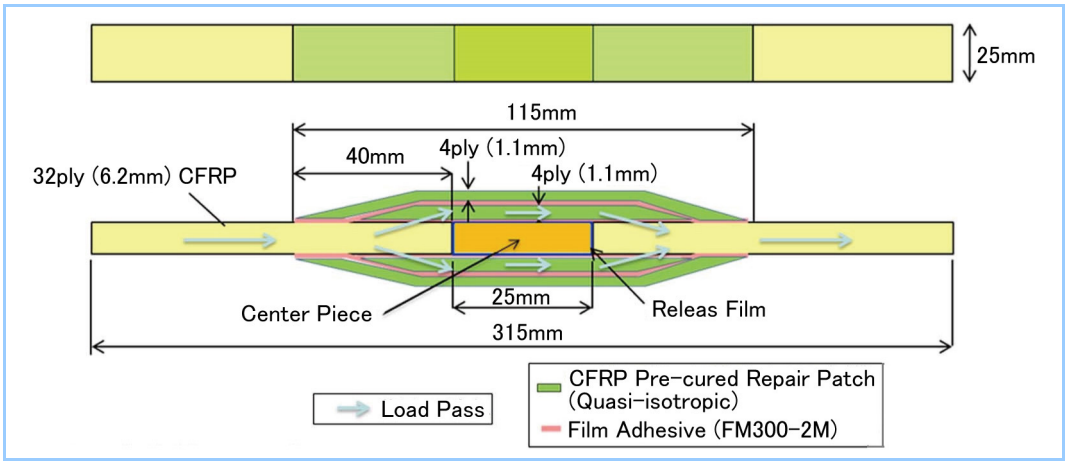

Figure 8 Tensile strength test specimen

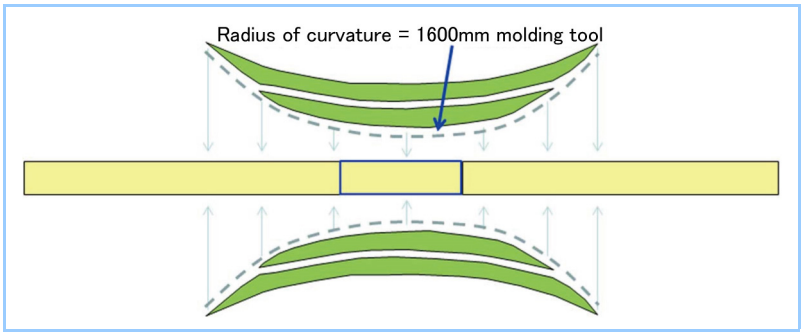

Figure 9 Fabrication of the test specimen with residual stress

5.2 Test conditions

Figure 10 shows the testing situation. The tests were conducted with displacement control using an INSTRON5889 test machine. In this test, a single-axis tensile load was applied at the speed of 2 mm/min under the test environment of normal temperature and normal humidity until destruction occurred. Three test pieces were tested under the same conditions.

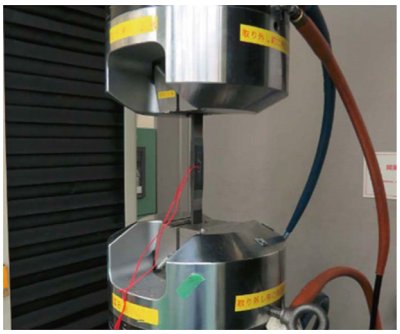

Figure 10 Setup of tensile strength test

5.3 Test results

Table 2 shows the test results. **Figure 11** shows a photograph of the test piece after destruction. The failure mode was interlayer shearing of the repair patch or the repaired material along the bonding area between the repaired structure and the repair patches, and no interface destruction occurred. Therefore it was confirmed that the bonding area generated by this repair process has sufficient bonding strength.

Table 2 Tensile strength test results

No.	Repair patch stress at Failure (MPa)
1	455
2	478
3	458
Average	464

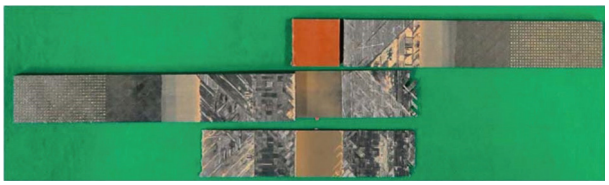

Figure 11 Tensile strength test specimens after failure

6. Conclusion

This paper presented the development of a new repair method that uses pre-cured thin repair patches, as well as confirmation of the feasibility of the developed method through a quality confirmation test, an inspectability confirmation test and a strength test. In the future, we will implement checks of the effects from environmental conditions such as temperature and humidity and the damage tolerance. These checks are necessary for application to aircraft structures. Practical application of this method realizes the quick repair of damage to an aircraft, and therefore allows the aircraft to return to operation earlier than before.

References

1. Y. Yoshida. 2016. “CFRP Repair after 787 Delivery,” presented at the 7th JCCM, March 16-17.