Low Cost Composite Wing Structure Manufacturing Technology Development Program in JAXA

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Abstract

This program is aiming at development of the low cost manufacturing technology for composite material structure. Since autoclave is unnecessary when manufacturing by VaRTM, it is known that it is very effective for the reduction in cost. However, the improvement of quality is needed in order to use for airplane structure manufacturing. Moreover, there is also no example of application to the airplane major structure by a VaRTM manufacturing process. Therefore, it has also been the big purpose of this research to clarify the subject of type certification acquisition of the airplane manufacturing by this process. In this research, taking advantage of the feature of VaRTM, integral molding is used extensively, and weight reduction is also made into the target. This paper reports the manufacturing subjects and countermeasure which occurred during development.

1. Introduction

This research is aiming at the development of the composite material structure manufacturing technology by low cost applicable to the prime structure of a small passenger aircraft. Although aiming at weight reduction of aircraft structure by adopting composite materials already being performed, there is still no example put in practical use widely applied to the main-wing structure for a larger passenger transport. One of the factors which have not been able to apply composite materials widely to the passenger aircraft is that cost becomes higher when compared with an aluminum structure. Although prepreg is used as the conventional composite material, it is one of the causes by which the cost of materials becomes higher. Then, in order to reduce the cost of processing or an assembly, integral structure has been adopted extensively. However, since a product becomes a complicated shape, inspection becomes difficult, and there is a case where it is not necessarily effective in cost reduction. On the other hand, it becomes possible to reduce the cost of materials by using the method of RTM (Resin Transfer Molding) which carries out impregnation of the resin after laminating only fibers, compared with the case where prepreg is used. Since the resin impregnation is performed by VaRTM (Vacuum assisted RTM) at low temperature, an autoclave which applies high temperature and high pressure for molding the products made by prepreg becomes unnecessary. Moreover, it is known that it is very effective for the cost saving. The 20m class vane of windmill shown in Fig.1 and the structure of

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Fig.1 The 30m length blade and appearance of a windmill

the small ships has been already manufactured by VaRTM. There are many track records in manufacture of industrial products, for example, cowling of the motor-cycle is manufactured by VaRTM using carbon fiber. However, since top priority is given to cost reduction in such industrial use, this material is inapplicable to airplane structure as it is. It is necessary to decrease the void and the shortage of resin impregnation for the purpose. Moreover, it is necessary to improve the quality of fiber content (Vf) and to stabilize quality.

On the other hand, there is no example of application to the aircraft prime structure by a VaRTM process. Therefore, it is another big objective of this research to clarify the subject of TC procurement of the aircraft manufactured by this process. In this research, a wing box for a mid-sized passenger aircraft is manufactured by VaRTM. An integral molding is applied extensively. The 20% reduction of weight is aimed at as compared with the airplane structure which uses an aluminum alloy. Moreover, it aims at 20% of cost reduction compared with the cost of production of the composite structure which is manufactured with the conventional prepreg. This research is a plan for 4.5 years since the second half of 2003 to the end of the 2007 fiscal year.

2. Key task of program

In this research, the followings are set as the specific target.

- Setup of the high quality and the stabilization process for VaRTM
- Molding of the wing box structure by integral molding extensively
- The trial proof of a VaRTM structure (apply to TC procurement)

The building block method shown in MIL-17 as the development technique of the composite material structure for airplanes is the most common. It is planning that this research also develops according to it. The image of test pieces and the outline of step-up are shown in Fig.2. The outline of a technique is as follows although the details of this method can be understood by referring to MIL-17. That is, thousands of or more test pieces are required of approval of a material level. Then, it is the technique of performing a check and actual proof of safety gradually by each examination of a structural element, sub-size structure, and actual sized large structure. By this technique, the number of test piece decreases gradually. This has sufficient reliability for the data in each stage, and stands on the premise that the characteristic is guaranteed, at the following step. If the mechanical properties of a material level are checked when the conventional prepreg is used, it is recognized that the mechanical properties of a structural level are also equivalent. Therefore, it is satisfactory by this technique in case of adopting prepreg for the material of structure.

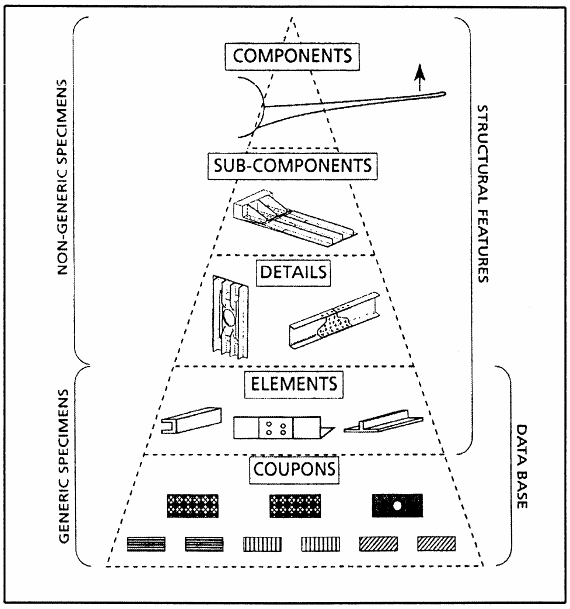


Fig.2 Building Block Approach by MIL-17

On the other hand, by VaRTM, in order to make resin impregnation between laminated fibers, a possibility that the mechanical properties will be influenced by shape and plate thickness of structure should be considered. Since the mechanical properties may depend on the shape in the case of a metal casting, the specimens are cut from an actual structure and the properties are checked by this specimen. It is the same idea as this casting metal. Therefore, the technique of examining by stepping up from flat small specimen to actual size structure was not adopted for our research. Instead of this original building block method, the manufacturing process is checked by making a small size structure, and the actual size structure is manufactured after that. Then, the test pieces cut out from this structure would be evaluated about the mechanical properties. This development step we considered is shown in Fig.3. Singularity of VaRTM structure will be clarified more with this technique, and it has tried to set up the aircraft type certification (for abbreviation to TC acquisition span) acquisition technique which is one of the major themes of this research.

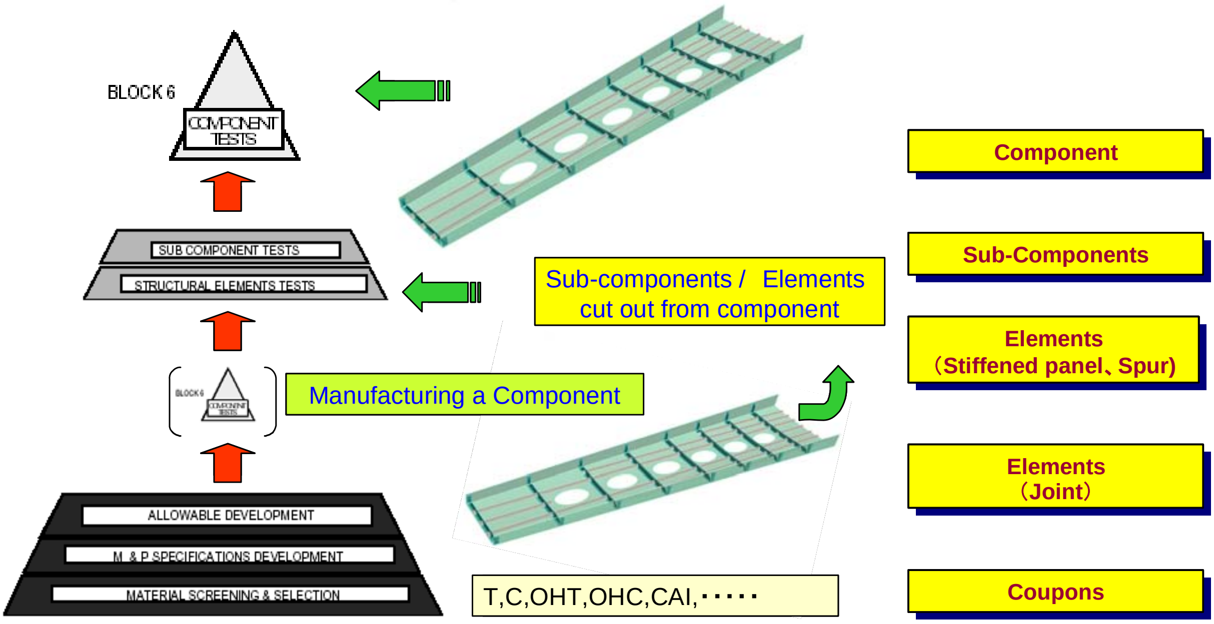
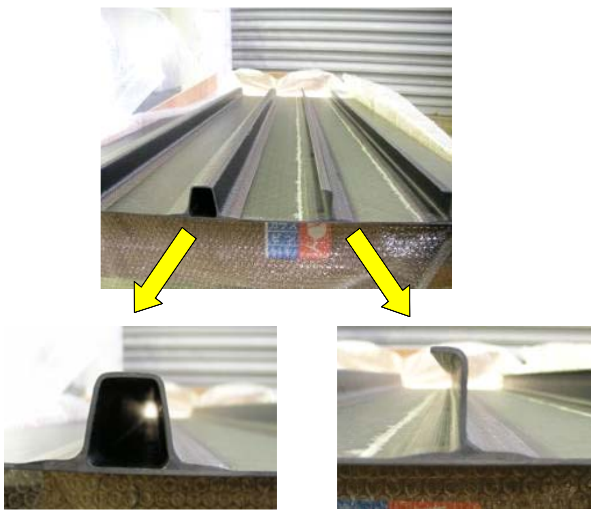


Fig.3 Modified Building Block Approach for VaRTM proposed by JAXA

2.1 The trial molding of a stiffened flat panel

In VaRTM, since it pressurizes only by a vacuum, there are voids and non-impregnation area to increase as compared with the high pressurized method of curing by an autoclave and so on. Or since there are too many amounts of resin impregnation, a volume fraction of fiber (Vf) becomes low in some cases. Therefore, it becomes the subject of investigation to establish the molding approach for such deficiencies not existing and realizing stable high quality. As first step, Z type and the Hat type stringer which are the components of wing structure are molded. This aims at the setup of the mandrel form for fabrication, and the setup of a forming molding process. Since curing temperature is comparatively low, material of the mandrel was made by silicone rubber. The hat type stringer swelled in the shape of a drum by thermal expansion, and the crack broke out on the internal tangent side to a skin. In order to ease this heat modification, we decided to make a hole in a mandrel. According to the heat stress analysis result of a laminate sheet and a mandrel, the position and size of the hole which opens in a mandrel were decided. A result is good and deficiency has not appeared after that.

Then, according to the temporally established molding process, Z type stringer and the hat type stringer were simultaneously fabricated on the flat plate (2m x 1m), and fabrication success-ability was checked. After molding and trimming this stiffened panel is shown in Fig.4. Any stringer has been fabricated well. Moreover, the mechanical properties were acquired with flat plate made by simultaneous process. In VaRTM, since the pressurization to a laminate sheet is below air pressure, the smoothness of the molded plate facing to tool side could be maintained, but the bag side became quite coarse compared with the case of prepreg. Therefore, there was a tendency for compressive strength to become lower than prepreg. It has recognized the smoothness being recovered by placing a punched



Hat type stringer　　Z type Stringer

Fig. 4 Integral molding with different type stringer
(2m length by 1m width stiffened panel)

metal plate (cowl plate) onto a bag side and molding as a countermeasure. Furthermore, it was examined how many compressive strength were recovered. The other mechanical properties have discovered the performance almost equivalent to prepreg using the same fiber. The carbon fiber used for manufacturing this test article is high strength type T800SC, and resin system is epoxy for RTM with a temperature at 40 degrees C for pouring, 60-80 degrees C for hardening, and 120 degrees C for post-curing. The effect on the mechanical properties by application of this punched metal plate is shown in a Fig.5.

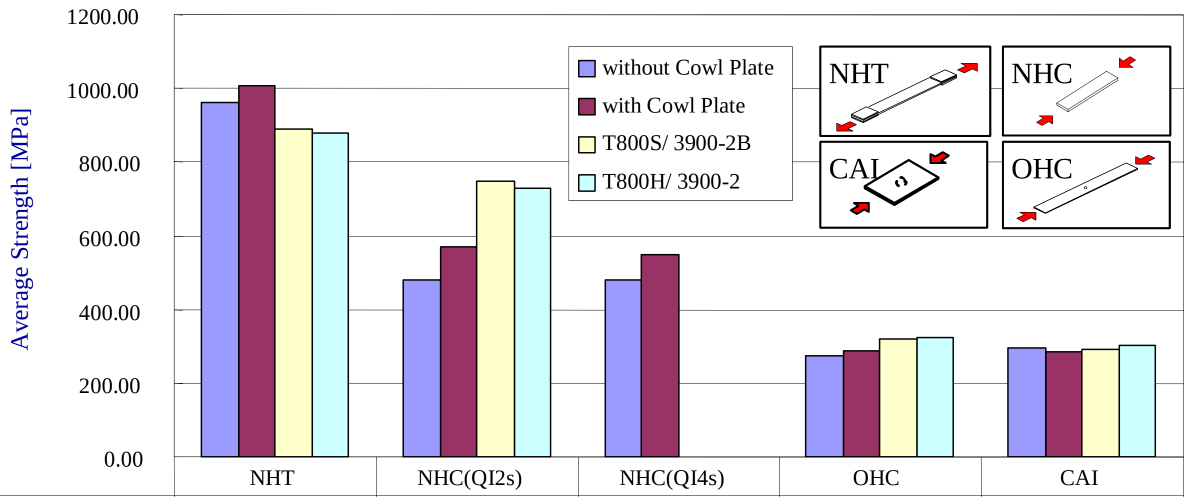
2.2 The trial molding of 2m stiffened wing panel

The trial molding of the stiffened wing panel which was integrated with spar, imitating the outer wing part of the 30- passengers transport plane, was performed following the trial production of a stiffened flat plate. JAXA performed the optimum design to a major load and determined each part size of the main wing. The form of the stringer was adopted as the braid type in consideration of the inspection ability in actual structure. Moreover, since it was positioning of the 6m wing manufacturing capability check, most of structural elements were incorporated in 2m wing, such as a pry-drop for a skin, the doublers formation of reinforcement around the access hole, and a pry-drop for spur web.

A skin was lamination of a unidirectional fiber and the stringer used textiles. The unidirectional fiber uses the non crimp material of SAERTEX^{R}. This material was making polyamide adhere to the mesh pattern of the arbitrary networks on the surface of a layer. Therefore, when laminating, it can fix by heating with a hot iron. The manufacture process of a 2m stiffened wing panel integrated with spar is shown in Fig.6. A general view after completing the manufacture is shown in Fig.7. Moreover, this project has aimed at cost saving for production equipment. Since it is low-temperature impregnation resin, a forming jig does not have the necessity for an existing heat-resistant metal material. Then, the supporting structure of a jig was made with plywood, and only the forming surface was manufactured by GFRP. Moreover, since cure temperature was also low, the hut covered by the heat insulation panel which served as the function of a lamination room and a clean room was made. It was a system which blows warm air from the side part of a hut when curing. In order to equalize an indoor temperature, the electric fan was attached to the upper part of this hut, and indoor air was agitated. An almost uniform temperature was able to be maintained by this system. Wooden form tool and the appearance of lamination/curing room are shown in Fig.8 and Fig.9, respectively.

2.3 The trial molding of 6m stiffened wing panel

As a manufacture result of a 2m wing, the location where impregnation has become insufficient at the joining section of a skin and a spar was



	NHT	NHC(QI2s)	NHC(QI4s)	OHC	CAI
without Cowl Plate	959.70	479.22	481.01	272.71	294.90
with Cowl Plate	1007.90	570.93	547.55	289.91	283.19
T800S/ 3900-2B	889.29	747.86	0.00	319.29	292.50
T800H/ 3900-2	879.64	730.71	0.00	323.57	304.29

Fig.5 The effect on the mechanical properties by application of this punch (Caul plate) plate

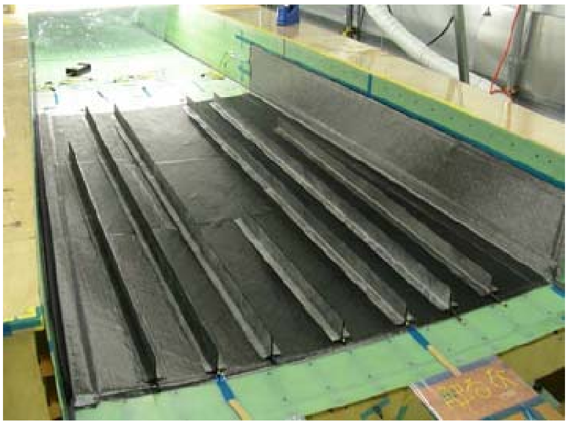


Fig.6 The manufacturing process of a 2m stiffened Wing panel integrated with spar web

Fig.7 The general view after completing the manufacture of 2m stiffened panel

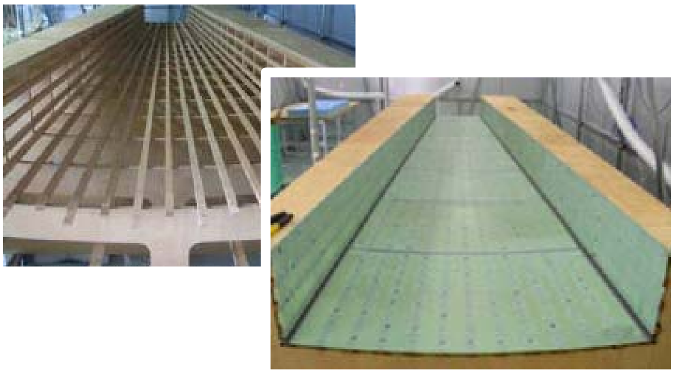


Fig.8 Wooden forming tool (lamination and curing)

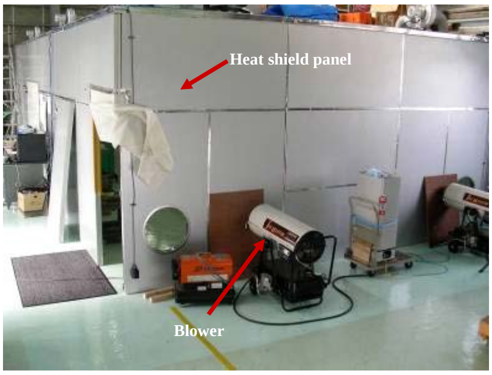


Fig.9 The lamination/curing room

observed. That place was the thickest position of wing box. By the reason of this result, the countermeasure to non-impregnation was worked on in advance of manufacture for the 6m wing. The 2m-length by 1m wide thick skin was manufactured, and the effectiveness of this countermeasure was checked. Six test plates were manufactured with the total and the most effective countermeasure against non-impregnation was set up. The characteristic of resin flow depends on the thickness of plate. Moreover, before the impregnation of resin finished thoroughly, gelatinization started. Moreover, it caused non-impregnation. Then, cooperation of a resin maker had been obtained and the resin flow improvement was accomplished in the range which does not change the mechanical properties of resin. Furthermore, the temperature near the minimum value of a resin maker recommendation was adopted as impregnation temperature. In addition, in order to perform a good molding, it turned out that the location of a resin flow inlet port and the turn of impregnation are important parameters. In order to mold a skin, spur webs and stringers as one piece, the consideration to the stacking sequence of lamination was needed in a design side. The laminated constitution and plate thickness of a skin and a web differed from each other, respectively. Spur flange parts became thick because of reinforcement. Furthermore, the reinforcement layer of the flange was put mutually.

At this time, in order to raise impregnation performance, applying NFC (non crimp fabric) to a flange was taken into consideration. However, that the effect on mechanical properties were unknown, and since resin may have become rich, application was shelved. A molded skin structure is shown in Fig.10. The result of the non-destructive test after molding was good, and neither non-impregnation of resin nor void was seen. Inspection of the cutting plane of a 6m skin structure and the mechanical properties of the structural element were acquired. Inspection for the cutting plane of a 6m skin structure was performed and the mechanical properties of the structural elements which were cut out from this 6m skin were acquired. These results are shown in a Fig.11. The strength test of this wing box structure is scheduled to be conducted this fiscal year.

3. Conclusion

About the low cost manufacture technology of composite material structure, the result obtained by our research outline and the present was shown. Although we succeeded in molding of a high quality thick plate by this test specimen, about molding of the thick plate which is the biggest subject of a VaRTM process, a new idea still needs the further device and research. Moreover, research concerning acquisition of not only low cost manufacturing technology but Type Certification about the "low cost manufacturing technology for composite material structure" for airplanes is another big theme. I want to clarify the test item which should be included in an actual proof plan of TC acquisition for the structure made by VaRTM, obtaining instruction and cooperation of the Civil Aviation Bureau about these. Those research findings were already reported as sponsored research from CAB of the fiscal year in 2005. I would like to advance this investigation, also referring to the investigation trend in the world from now on.

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Fig. 10 Skin-Stringer integral molded 6m wing lower panel

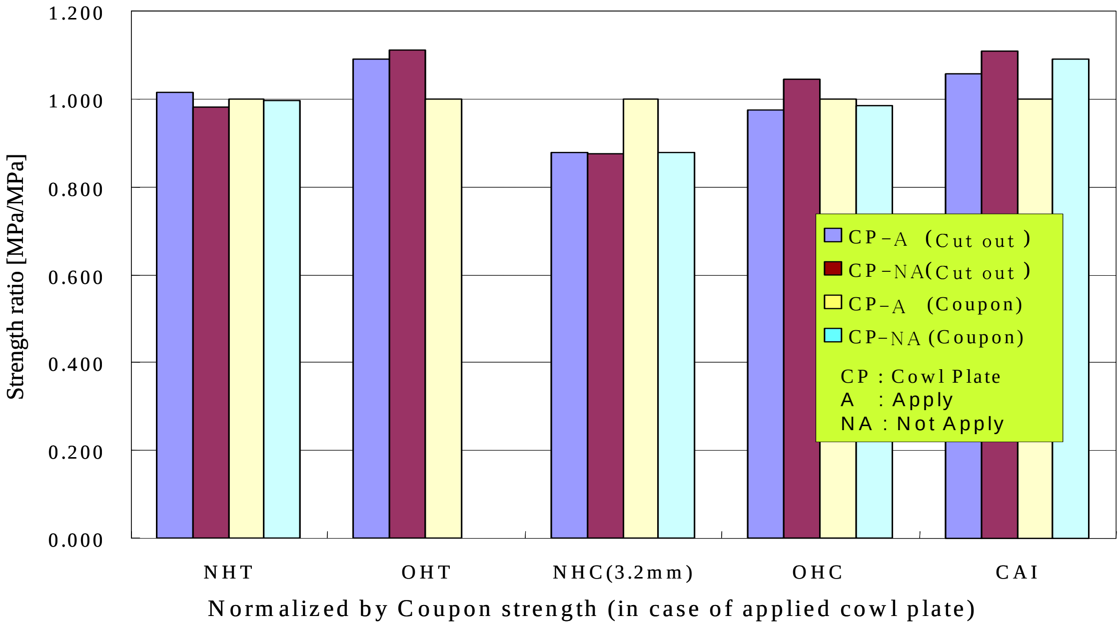

Fig.11 Comparison of strength between Coupon and Test Piece cut out from 6m wing