

Application of CFRP Stator to HF120 Turbofan Engine

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ABSTRACT

Materials such as aluminum alloys (A7075) are often mentioned as candidates for use in the manufacture of Fan Outlet Guide Vane components. As a part of weight-saving of the HF120 turbofan engine, an Fan Outlet Guide Vane made from CFRP was developed.

Sheet Molding Compound containing approximately 60% carbon fiber was used for the Fan Outlet Guide Vane. In order to apply the Sheet Molding Compound to the Outlet Guide Vane, material certification from the United States Federal Aviation Administration was acquired.

To utilize the light-weight characteristics of CFRP, the shroud and vane were integrally molded. The introduction of Sheet Molding Compound permitted the number of prepreg laminations reducing to six, even on the thick vane section, as well as achieving near-net-shape press molding within 20 minutes. As a result, weight was reduced by 40% in comparison with A7075, and press molding process time was reduced by 90% in comparison with the continuous fiber Carbon-Fiber-Reinforced Thermo-Plastic's molding process.

Outlet Guide Vane components underwent assessments such as impact and fatigue testing to ensure the successful completion of engine certification testing. Subsequently with the completion of certification testing, the application of CFRP Outlet Guide Vane in the HF120 has been achieved.

1. Introduction

The Fan Outlet Guide Vane (OGV), one of the stator vanes that constitutes the HF120 turbofan engine (HF120), is located behind the fan rotor in a relatively low-temperature environment. The OGV is generally larger and heavier than other stator vanes, and therefore provides a significant opportunity for a weight savings. Given this, research was pursued on the application of Carbon Fiber Reinforced Plastic (CFRP), one of light-weight materials, to the OGV. In the HF120's development, one of the established goals was integrally molding the vane and shroud to take an advantage of the light-weight characteristics of CFRP.

2. Part Configuration

The location of the OGV in the HF120 is shown in Fig. 1.

The OGV is a stationary part behind the fan rotor, and plays a role in the removal of residual swirl contained in the airflow from the fan rotor to increase static pressure. The air outflowed from the OGV is divided into the core side of the engine and the bypass duct.

To help utilize a design potentially using CFRP, the OGV was designed as an integral vane with shroud. The

OGV is 125 mm high, 85 mm wide and 50 mm in length. The stainless-steel Leading Edge Protector (LEP) was bonded on the leading edge of the vane. This LEP protects a part of the leading edge of the CFRP from abrasion by the sand, and other contaminants that may be ingested by the engine inlet.

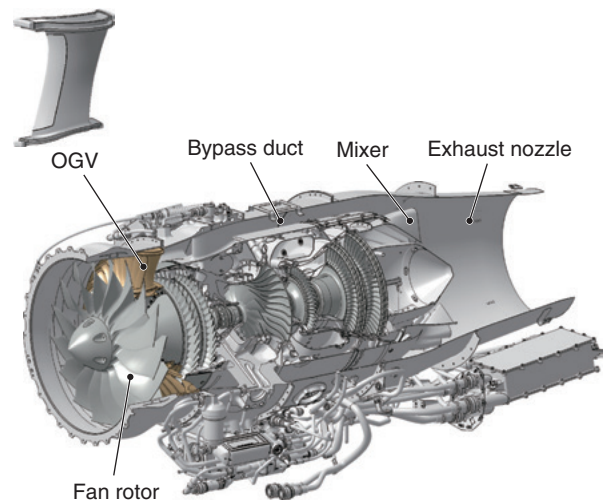


Fig. 1 HF120 OGV location

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The OGV assembly is configured by combining 42 separate OGVs, 42 sets of rubber boots made of silicone rubber and an inner ring made from aluminum alloy. Each OGV is joined to the adjacent OGV at the shroud by rubber boots, forming a circular ring, and this ring form is fixed by inner ring. The diameter of the OGV assembly is approximately 480 mm. Diagrams of the OGV assembly and the OGV are shown in Fig. 2.

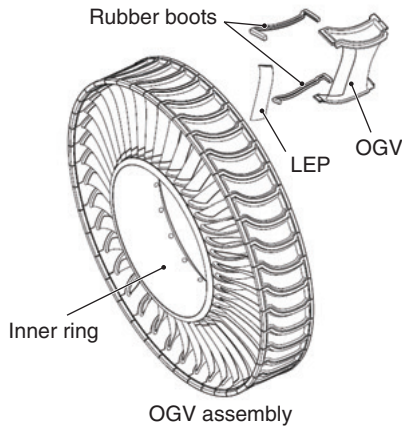


Fig. 2 Configuration of OGV and OGV assembly

3. Materials

3.1. Configuration of Materials

The main structural material for the OGV is an Sheet Molding Compound (SMC) composite material. Its matrix resin is epoxy and is reinforced by carbon fibers. A plain fabric material was applied to the airflow surface since the surface has an effect on aerodynamic character.

This SMC is a prepreg sheet approximately 2 mm in thickness, and is formed by randomly oriented and laminated carbon fiber bundles that were chopped off from unidirectional prepreg to be 50 mm in fiber direction and 8 mm in width. Photographs of the SMC are shown in Fig. 3. The volume fraction of carbon fiber after molding SMC is approximately 60%.

3.2. Mechanical and Light-weight Characteristics of Materials

The static specific tensile strengths of SMC and A7075 as a comparative material are shown in Fig. 4. The vertical scale indicates the rate of specific strength relative to the SMC specific strength at room temperature (R.T.) as 100%.

Judging from the finding that SMC specific tensile strength is higher than that of A7075, SMC was judged to be more suitable for weight saving than A7075. Utilizing the light-weight character of SMC and applying it to the OGV reduced the weight by 40%, as compared to A7075 applied to OGV.

The anisotropy of strength and stiffness per one ply of SMC is not more noticeable than unidirectional CFRP, because SMC form has randomly oriented carbon bundles. Also, the maximum tensile strength of SMC is lower than that of unidirectional CFRP. However, with respect to interlaminar fracture toughness which is typically believed to be the greatest weakness of CFRP, the toughness of SMC tends to be higher than that of unidirectional CFRP with a tough epoxy matrix. Since SMC's fiber bundles are mixed and laminated in the lamination direction by the effect of random orientation, when comparing Mode II interlaminar fracture toughness between SMC and unidirectional CFRP, the toughness of SMC is approximately twice as high as that of unidirectional CFRP. The comparison chart of unidirectional CFRP and SMC is shown in Fig. 5.

3.3. New Material Certification of SMC

As this SMC is a new material for aircraft engines, it is required to be certified by the Federal Aviation Administration (FAA) as a new material for application to aircraft engine parts.

Four years were required to complete the material certification process, starting from the selection of materials, followed by the material tests to investigate typical

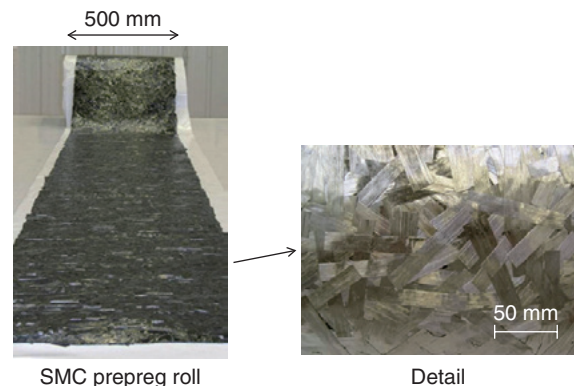


Fig. 3 Carbon-fiber-reinforced SMC

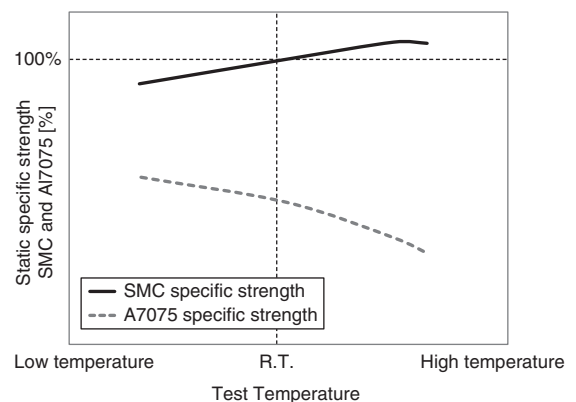


Fig. 4 Comparison of specific tensile strength

mechanical properties, examination of evaluation items, and finally the material certification test.

The evaluation tests were performed in the material certification test program regarding various items including mechanical properties, physical properties, and fatigue characteristics that were needed for OGV evaluation.

In the case of the composite material, even if test specimens are fabricated from the same prepreg, molding method and material anisotropy etc. has an effect on some test results. Thus, the material specification defines the methods for CFRP plate fabrication, cutting test specimen, and material tests. The specimens were manufactured and material tests were carried out based on the specifications. To calculate allowable design limits of aircraft engine parts from the test results, statistical processing was required based on military standards and other methods⁽¹⁾.

After completing above processes, a material specification was finalized reflecting the material test results of the SMC. Based on the material specification, the material certification report in compliance with the requirements of Federal Aviation Regulations (FAR)⁽²⁾ was drawn up with General Electric Company (GE), Honda's joint venture partner on the HF120's development. The report was submitted to FAA and the SMC was certified.

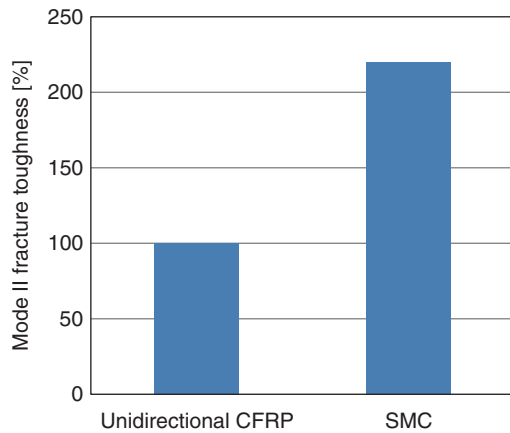


Fig. 5 Comparison of mode II fracture toughness

4. Manufacturing Process

4.1. Press Molding CFRP Vane

Aircraft engine parts are sometimes produced in small lots and demand high precision. In addition, a high degree of freedom for molding is required, because an OGV is formed by varied thicknesses. As previously mentioned, high flexibility against complex shape forming was one of the reasons for selecting SMC for OGV.

The CFRP portion of the OGV was molded by an SMC method.

In the selected SMC method, a charge-pattern is cut to form as prescribed from SMC roll, multiple of those patterns are laminated in accordance with part thickness and weight, then hot pressed by mold die⁽³⁾.

In past research, hot-press molding of continuous fiber Carbon Fiber Reinforced Thermo-Plastic (CFRTP) was carried out over 180 minutes, and the number of charge-patterns at a vane was 17. Use of SMC made it possible to reduce the charge-patterns to six sheets, and press time was reduced to 20 minutes, which is 90% shorter than that of the continuous fiber CFRTP. In addition, the cutout layout of the charge-patterns on the SMC roll became easier because it is no longer necessary to pay attention to precise details of fiber orientation angle. Shown below is the SMC method procedure applied to CFRP vane molding. Field pictures showing a part of the procedure are shown in Fig. 6.

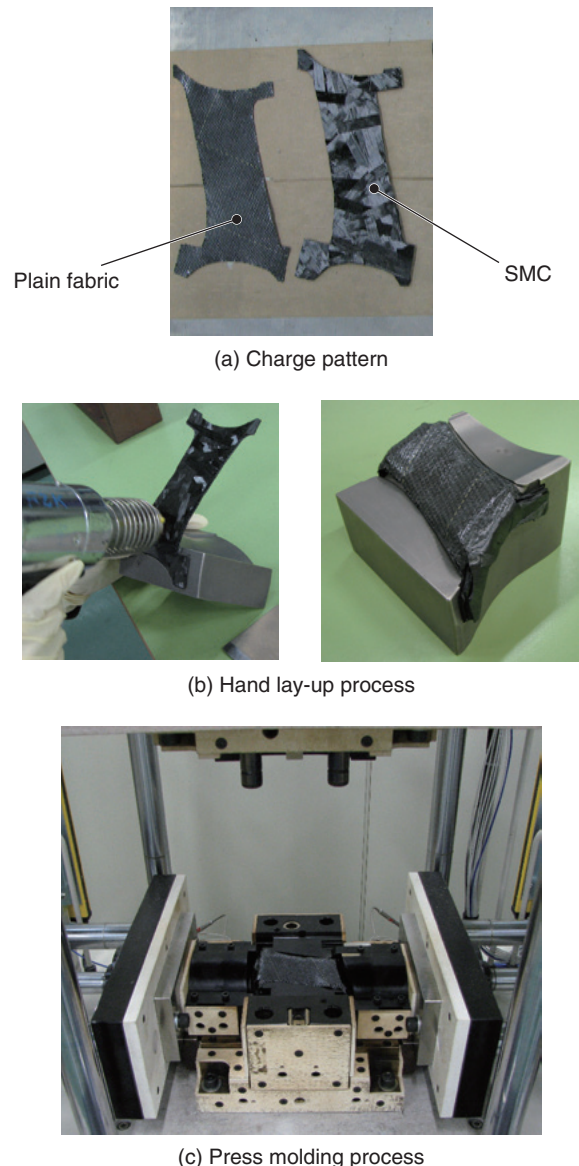


Fig. 6 SMC molding process of CFRP vane

- (1) Material cutting [Fig. 6(a)]: cutting out charge-patterns from SMC and plain fabric material roll.
- (2) Weight measurement and combination of charge-patterns: SMC charge-patterns have weight variation, therefore weight adjustment is performed in the combinations of SMC charge-patterns.
- (3) Staging: the volatile components contained in resin are evaporated. In order to reduce excessive resin spill in the press molding process, curing of resin was started in advance.
- (4) Lay-up [Fig. 6(b)]: lay-up charge-pattern of SMC and plain fabric material to the lay-up fixture.
- (5) Press molding [Fig. 6(c)]: OGV is molded by a 2-axis press molding machine.
- (6) Post-cure: in order to carry out complete curing of the epoxy resin, the molded part is held for a predetermined period at a constant temperature using a heating furnace.
- (7) Trimming: trim resin burrs from molded CFRP vane.

4.2. Cold Press-Forming of LEP

LEP is formed by cold press using stainless steel sheet of 0.1 mm thickness. By rationalizing the press forming process condition of the thin sheet, the forming succeeded in cold press-forming of LEP, which has a complex shape and deep draw. After press forming, trimming is performed to attain the final shape. The image of LEP after press forming is shown in Fig. 7.

4.3. Bonding of LEP

The LEP is adhered to the CFRP vane of the OGV after post-curing. As pre-bonding surface treatment, surface roughening is applied to the LEP adhesion part of the CFRP vane with sandpaper, and LEP is etched. After pre-bonding treatment, an LEP and a CFRP vane are bonded by epoxy film adhesive, using an autoclave after bagging the parts under vacuum. After bonding, adhesive resin flash is trimmed as the finishing processing. The OGV after LEP bonding is shown in Fig. 8.



Fig. 7 LEP

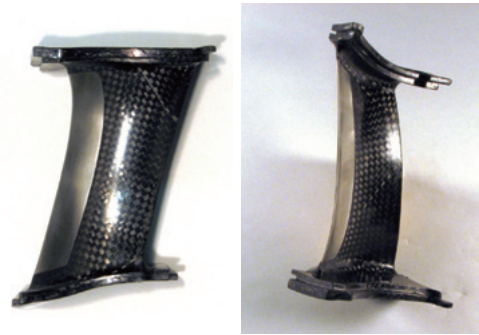


Fig. 8 OGV

5. Component Test

Prior to engine certification testing, component evaluation of the OGV was performed to ensure satisfactory completion of the engine certification test.

5.1. Evaluation Items

For application of the SMC material to an aircraft engine, evaluation of various items including environmental durability, impact resistance and fatigue properties is required. Impact resistance and high-cycle fatigue properties stand out among characteristic evaluation items. The former refers to the evaluation of impact load that can be caused by foreign objects ingested from the engine inlet, while the latter refers to the evaluation of high-cycle fatigue that can be caused by vibration excited from rotational parts.

5.2. Impact Resistance

It is possible that a foreign object such as bird or hail could strike the OGVs. One of the goals established was to preclude the separation of the part when it is struck by these foreign objects. This section describes the test result of OGV's resistance to impact by hailstorm. The pictures for the test are shown in Fig. 9.

After continuously impacting hail against the OGV at specified velocity and duration, the test results showed no cracking of the CFRP and no peeling of the LEP, thereby confirming OGV is resistant to impact caused by the assumed hail strikes in the test protocol.

5.3. High-Cycle Fatigue Property

Vibration modes found in parts during engine operation include bending modes and torsion modes. Fatigue test were performed for both vibration modes.

In order to make the impact of part fixation method on vibratory mode smaller, cantilever fixation holding the portion of shroud by resin was applied for part fixation method as shown in Fig. 10.

The natural frequencies of the parts in each vibration mode were checked by the holography. The photographs

of vibration mode form, which were obtained by the holography, are shown in Fig. 11. The striped pattern on the vane which can be found in Fig. 11 appears when the part is deformed by characteristic vibration. The deformation gradient of part is in a direction perpendicular to the stripe. From Fig. 11(a), vane is bending toward span (longitudinal), therefore, this is bending mode. Shown in Fig. 11(b) is torsion mode where vane is twisted.

Figure 12 shows fatigue test condition. Here the part was vibrated to the direction of arrow by adding natural frequency of each mode.

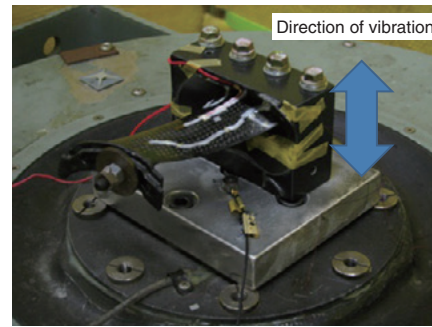


Fig. 12 Fatigue test



Fig. 9 Impact resistance test

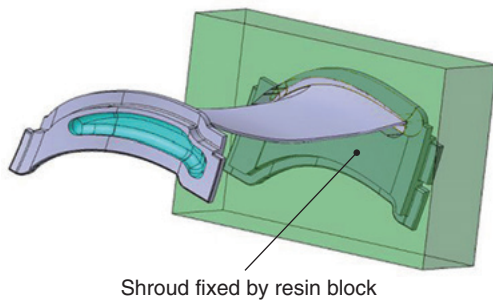
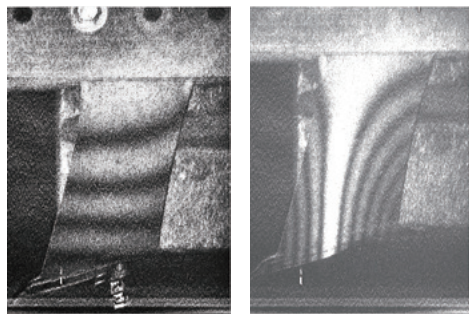


Fig. 10 Cantilever OGV for fatigue test



(a) Bend mode shape (b) Torsion mode shape

Fig. 11 Mode shape

From the test result, it was confirmed that the OGV has enough fatigue property in bending mode and torsion mode for compliance with the engine certification test requirements.

6. Conclusion

Introduction of CFRP, which has both strong and light-weight characteristics, into the OGV design resulted in successful weight reduction and performance compared to A7075. Press molding process time was also reduced in comparison to that of continuous fiber CFRTP.

As a result of the component testing, it was confirmed that the OGV has sufficient impact resistance and fatigue properties for engine certification test requirements.

Reference

- (1) Department of Defense: MIL-HDBK-17
- (2) Federal Aviation Administration: Federal Aviation Regulations
- (3) Hirano, Y.: Fukugo Zairyo Katsuyo Jiten, Vol.3, Chapter 2, Industrial Research Center of Japan, p. 497-501 (2001) (in Japanese)

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