OPTIMAL DESIGN AND STATIC LOAD TESTING OF TOW-STEERED AIRCRAFT FUSELAGE FRAMES

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Abstract: Static loads testing of the fuselage frames around the emergency escape door of a single-aisle aircraft was performed. Two test articles were designed, one is the conventional design and the other is the optimal design. For the optimum design which was manufactured by Automated Fiber Placement (AFP), fiber orientation optimization and plate thickness distribution optimization were applied. The results of compression tests show that the optimal design frame is stronger than the conventional design frame.

Keywords: Automated Fiber Placement, Static Load Testing

INTRODUCTION

Lightweight is one of the important factors to develop a fuel-efficient airframe. The recent advance of Carbon Fiber Reinforced Plastics (CFRPs) plays an important role to reduce the weight of the structure. Recently, Automated Fiber Placement (AFP) technology is widely used in the aerospace industry to lay tows of CFRPs and capability to place curved fibers, i.e., carbon fiber tow-steering [1,2]. One of the objectives of this research is to establish a design method that can enhance by optimizing fiber orientation and part thickness distribution simultaneously. In addition, it is shown that is possible to reduce the manufacturing cost through the experience of full-scale structure manufacturing for AFP manufacturing, which is expected as a manufacturing method suitable for this design method.

Regarding fiber orientation optimization, tow steering along the load flow using AFP improves strength and makes it possible to reduce weight. Regarding the optimization of sheet thickness distribution, in conventional manual layup, frequent use of part thickness variations leads to an increase in manufacturing costs (fabrication time), but by utilizing AFP, the fabrication time can be shortened and fine variations in part thickness can be provided. This makes it possible to reduce the weight of the structure.

TEST ARTICLE

To demonstrate the effectiveness of our approach, we apply our optimization scheme to the fuselage frames around the emergency escape door of a single-aisle aircraft to enhance the strength of the structure as well as the cost of fabrication. We experimentally and analytically examine the static responses of two different designs, a conventional design and our optimized one, for comparison. The conventional design is fabricated by hand layup, whereas we fabricate the optimized one by using the AFP technique.

Figure 1 shows the test article consists of skin/sill/auxiliary sill/fittings to consider the constraint of the FWD/AFT (actual fuselage) frame. The test articles have been manufactured two types; One is the conventional design frame manufactured by hand layup (Fig. 2). The material was T800S/3900-2B, and the laminate configuration was [45/0/0/-45/90/+45/0/-45/90/45/0/-45]s. The other is the optimal design frame manufactured by AFP (Fig. 3). The material was T800S/3900-2C. These frames have thickness change and tow steering. The ply table and steering ply are shown in Figure 4.

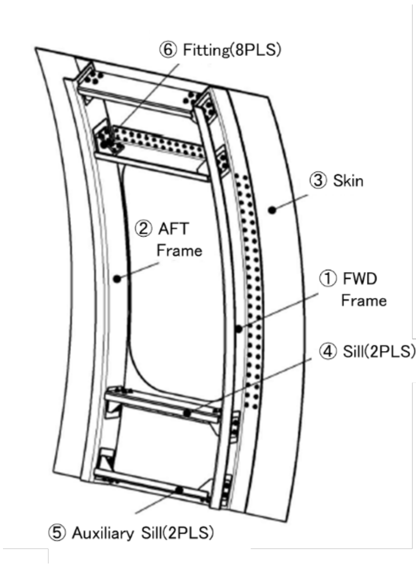

Figure 1: Test article

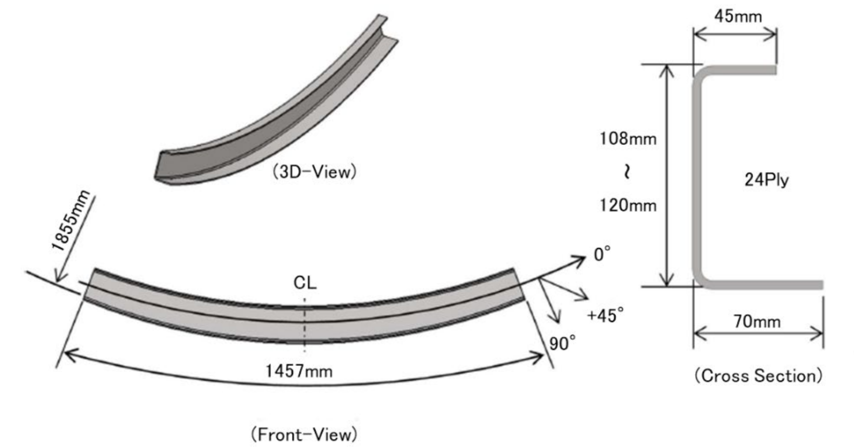

Figure 2: Conventional design frame

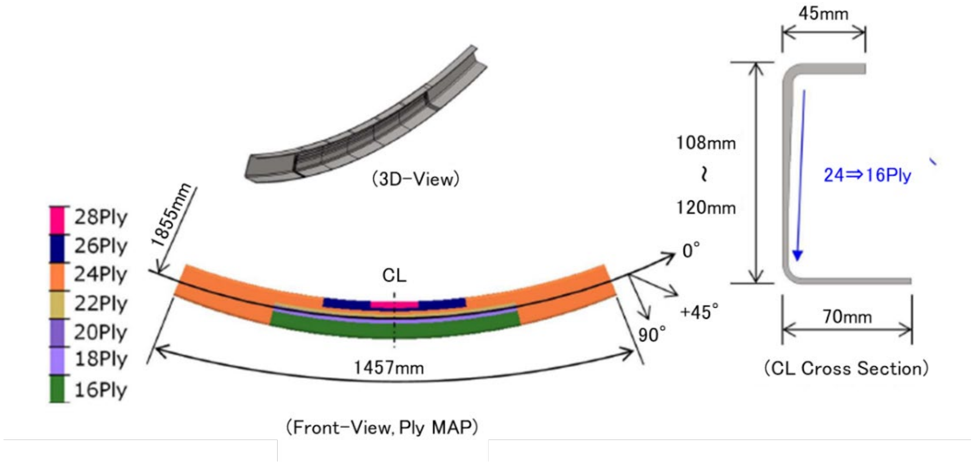

Figure 3: Optimal design frame

PLY No.	PLY 16	18	20	22	24	26	28
P1	+45	+45	+45	+45	+45	+45	+45
P2	0	0	0	0	0	0	0
P3	0	0	0	0	0	0	0
P4	-45	-45	-45	-45	-45	-45	-45
P5	90	90	90	90	90	90	90
P6	+S	+S	+S	+S	+S	+S	+S
P7	0	0	0	0	0	0	0
P8	-S	-S	-S	-S	-S	-S	-S
P9	(90)	90	90	90	90	90	90
P10			+S	+S	+S	+S	+S
P11				0	0	0	0
P12					-S	-S	-S
P13						90	90
P14							+S
P15							+S
P16						90	90
P17					-S	-S	-S
P18				0	0	0	0
P19			+S	+S	+S	+S	+S
P20	(90)	90	90	90	90	90	90
P21	-S	-S	-S	-S	-S	-S	-S
P22	0	0	0	0	0	0	0
P23	+S	+S	+S	+S	+S	+S	+S
P24	90	90	90	90	90	90	90
P25	-45	-45	-45	-45	-45	-45	-45
P26	0	0	0	0	0	0	0
P27	0	0	0	0	0	0	0
P28	+45	+45	+45	+45	+45	+45	+45

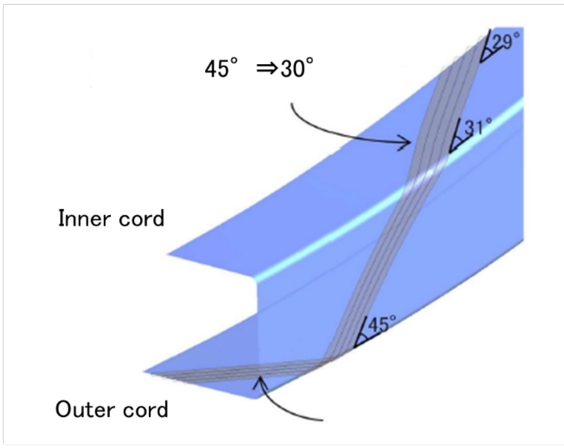

Figure 4: Ply table and steering ply of optimal design frame

TEST SETUP

A universal testing machine (Shimazu, UH-2000kNIR) was used for the compression testing of each test article. Figure 5 shows the overview of test setup. The conventional strain gages and fiber optic strain sensor were installed on the test articles to measure strains. For the fiber optic strain sensor, we used our in-house optical monitoring system, optical frequency domain reflectometry (OFDR) based on long-length fiber Bragg gratings (FBGs) [3-5]. This technique enables to obtains strain and/or temperature data not as a point data from an FBG but as a distributed profile within the FBG. The length of on long-length FBG can reach up to several meters. This system can measure the strain distribution profile with an adjustable high spatial resolution of the mm or sub-mm order in real-time [6,7].

Table1: Instrumentation

Name	*Parts No.*	*Quantity*
Uniaxial strain gage	KFGS-5-120-C1-11 L5M3R	150
Triaxial strain gage	KFG-5-120-D17-11 L5M3S	40
Displacement transducer	DTK-A-30	15
OFDR-FBG sensor	-	10

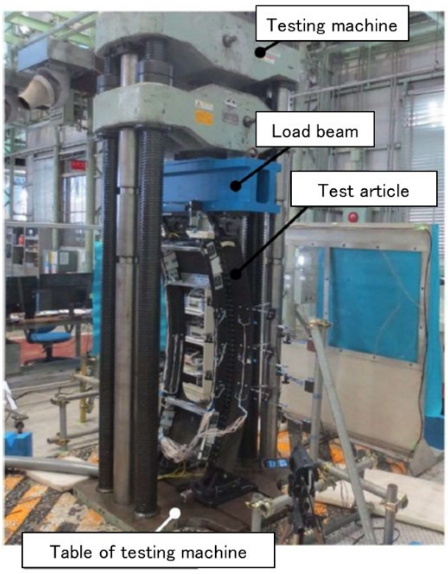

Figure 5: Test setup

RESULTS

Figures 6 and 7 show the load-strain behaviour of around failure point of each test article until the design load (138 kN). Both cases show a good agreement between the experimental results and the analytical results. The strain level of the optimal design frame on failure point is lower than that of the conventional design frame, which illustrates the effectiveness of our approach to enhance the strength.

Figure 8 shows the strain distribution on corner of inner cord. The OFDR-FBG results of strain distribution is good agreement with the analytical results.

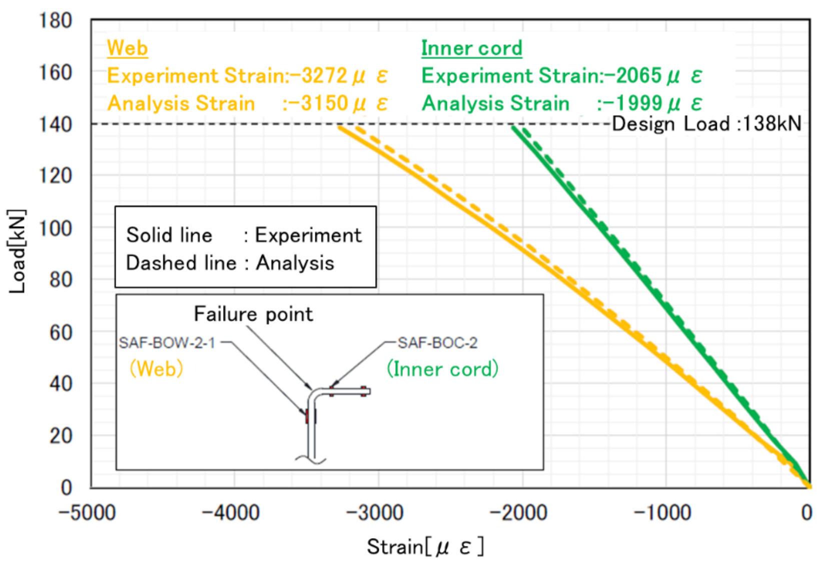

Figure 6: Load-Strain behaviour of conventional design frame

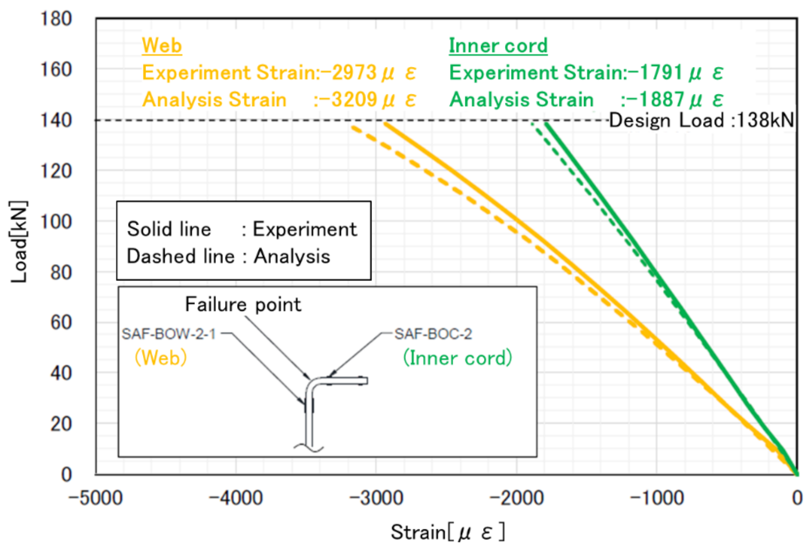

Figure 7: Load-Strain behaviour of optimal design frame

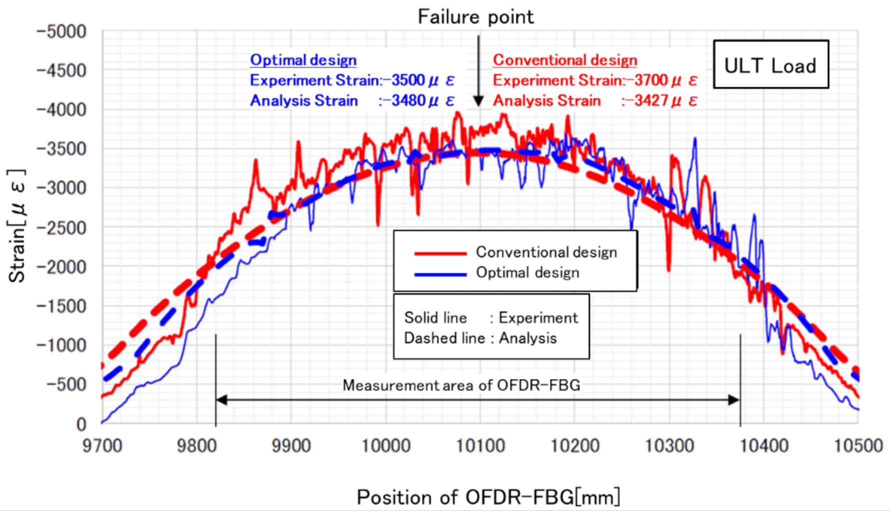

Figure 8: Strain distribution of corner of inner cord

CONCLUSIONS

The static load tests of fuselage frames were performed successfully. Two test articles were designed, one is the conventional design and the other is the optimal design. For the optimum design which was manufactured by Automated Fiber Placement (AFP), fiber orientation optimization and plate thickness distribution optimization were applied. The results of compression tests show that the optimal design frame is stronger than the conventional design frame.

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