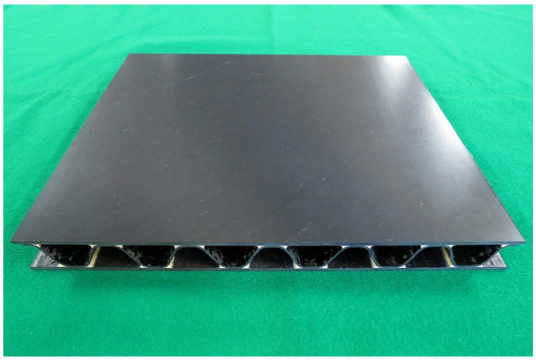
Development of CFRP (Carbon Fiber Reinforced Plastic) Monolithic Sandwich Construction



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To realize a light-weight, low-cost airframe for future aircraft, fewer components and boltless assembly through the large-scale one-shot construction using carbon fiber-reinforced plastic (CFRP) are key technologies. For parts for large-scale one-shot construction, the application of a sandwich structure where high rigidity can be easily obtained is effective. This paper discusses the CFRP monolithic sandwich structure, which is lighter and less corrosive than a traditional honeycomb structure. In particular, the corner fillets (placed around the corners) in this structure were focused on, and an adhesion peel strength improvement effect was identified through numerical analysis. A prototype was manufactured in accordance with the one-shot curing process and its favorable quality was verified.

1. Introduction

An airframe uses numerous parts and, for its assembly, a huge number of fasteners (tens of thousands to hundreds of thousands per plane), so fewer components and boltless assembly (assembly without fasteners) are key technologies to the realization of lighter weight and lower costs.

To achieve lighter weight and lower costs, parts integration, particularly the integration of large primary structural member parts, is effective. This paper discusses a high-rigidity panel structure with high-efficiency transverse shear stiffness, which is important for the further integration of parts.

2. Motivation toward CFRP monolithic sandwich structure

In recent years, CFRP application to airframes has been spreading rapidly for reasons such as its high specific strength, but the CFRP structures actually applied are mostly co-bonded or bolted joints of a so-called skin-stringer panel construction, adopting a structural type similar to that selected when metal material is used.

In future airframes, it seems promising to apply the sandwich structure as an alternative to the conventional structural type. Since a sandwich structure can take in-plane/out-of-plane shear loading, out-of-plane compressive load and axial tension by itself and is further characterized by its high transverse stiffness (buckling strength), its frames/stringers can advantageously be spaced wide. Specifically, fewer frames, stringers and other load-sharing members may possibly result in a lighter weight and lower parts assembly costs.

Among sandwich structures, the honeycomb structure is generally well known and such cores are made mainly of aramid fibers (Nomex®) or aluminum. Both materials, however, have problems including corrosion due to moisture absorption by the core and/or water retention into the core as a result of environmental exposure during long-term operation. Since corrosion and moisture absorption deteriorate core strength, continual operation requires periodical repairs, and results in an increase in their life cycle cost.

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In contrast, the application of a CFRP monolithic core to a sandwich structure is quite advantageous in terms of life cycle cost since it ultimately eliminates corrosion risk.

For the specific strength of CFRP monolithic cores, **Figure 1** compares weights of Nomex® core, aluminum honeycomb core, CFRP laminated plate and CFRP corrugated sheet (monolithic). Each weight is given in the value calculated, assuming that the out-of-plane shearing load will act as a typical wing load.

As seen from Fig. 1, when compared with the same strength, CFRP corrugated sheets are lighter in weight than typical honeycomb cores and CFRP laminated plates. Namely, they were found capable of sharing the out-of-plane shear loading most efficiently.

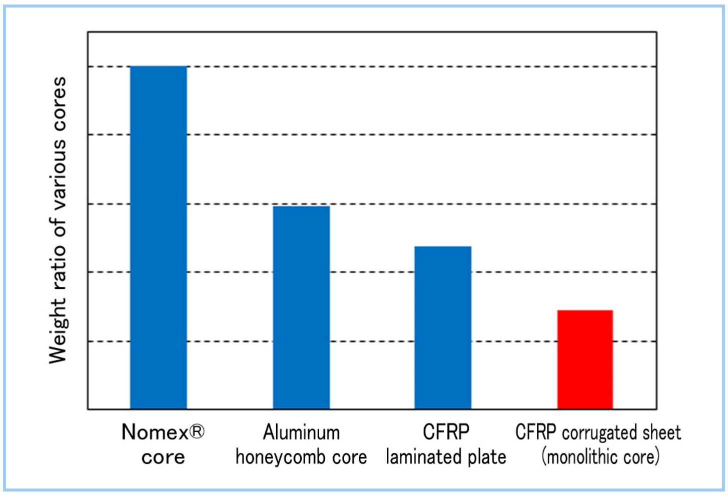

Figure 1 Weight comparison of various structural types under working out-of-plane shearing loads

3. Design of CFRP monolithic sandwich structure

In this paper, a sandwich structure with a CFRP monolithic core of a corrugated shape, similar to that widely used in cardboard boxes, as shown in **Figure 2** is described for high-rigidity panels.

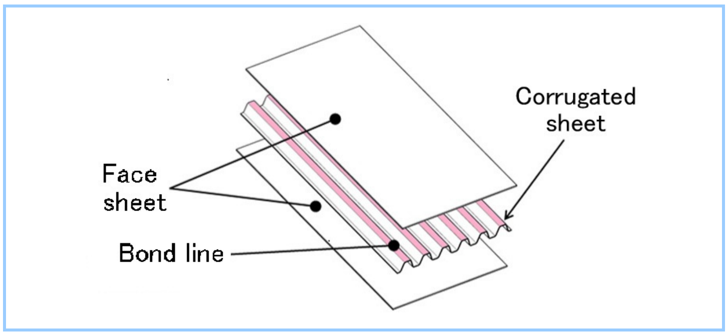

Figure 2 CFRP monolithic sandwich structure
An outline of a monolithic sandwich structure comprised of face plates and corrugated sheets made of CFRP.

Unlike honeycomb cores, corrugated sheets possess strong in-plane anisotropy. This feature can allow them to take axial tension in the direction of their high rigidity as a function of the stringers and, moreover, the face plate-core bonding surface important in transmitting out-of-plane shearing loads can also advantageously be made spacious enough.

As is generally known, the bond line peel strength is critical for this type of structure and the mitigation of stress concentration on the bond line is an important factor to improve peel strength.

Since it is considered an effective method of mitigating stress concentration on the bond line to apply a corner fillet to the terminal end of a bond line, the effect of such corner fillets on the CFRP monolithic sandwich structure was examined in this paper through numerical analysis.

Figure 3 shows two finite element analytical models. One is a model with corner fillets and the other, a model without corner fillets.

Analytical models were made through modeling mainly with hexahedron solid elements, while the face plates and corrugated sheets were CFRP quasi-isotropic laminates. The corner fillets had material properties equivalent to those of the adhesives. The solver used was a linear analysis function of MSC Nastran.

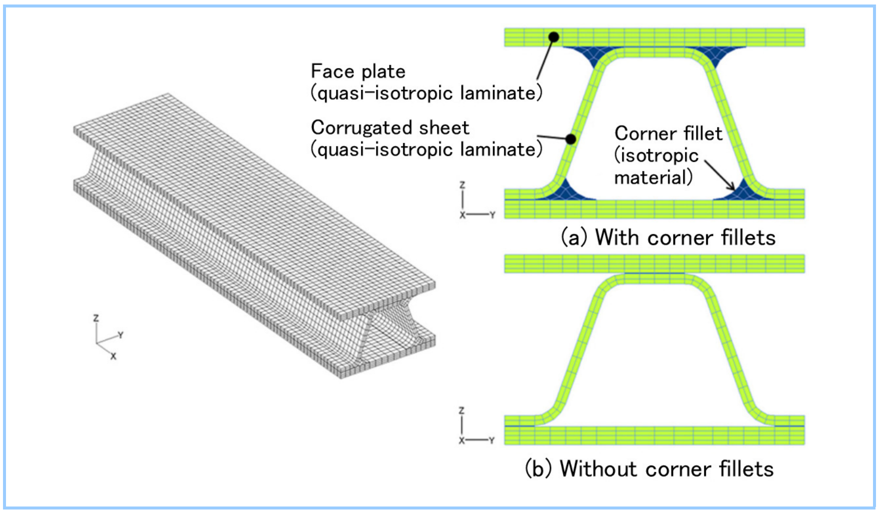

Figure 3　Outline of finite element analytical model

As part of the analytical results, **Table 1** gives a comparison between a bond line with corner fillets and another without such fillets for out-of-plane peeling stress (peak value) under several loading conditions as shown in **Figure 4**. The values given in Table 1 were nondimensionalized, taking the value of stress for the bond line without corner fillets as 1.00.

In the case with corner fillets, the value stood at 0.65 or less, and in particular, achieved a 0.16 against internal pressure and 0.24 against lateral out-of-plane shearing load to indicate that corner fillets are quite effective to mitigate out-of-plane peel stress.

Table 1　Comparison of out-of-plane peel stress on the bond Line

Loading condition	Out-of-plane peel stress on the adhesion layer (peak value)		Rate of peak value decrease
	With corner fillets	Without corner fillets	
(1) Internal pressure	0.16	1.00	84%
(2) In-plane tension	0.65	1.00	35%
(3) Out-of-plane shear (axial direction)	0.60	1.00	40%
(4) Out-of-plane shear (cross direction)	0.24	1.00	76%

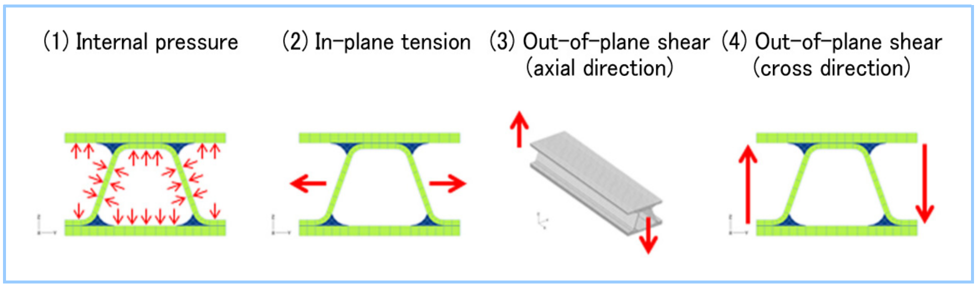

Figure 4　Loading Condition under Which Finite Element Analysis Was Made

4. Prototyping of CFRP Monolithic Sandwich Structure

In the preceding section, it was made clear that corner fillets are effective to improve the adhesion peel strength of a CFRP monolithic sandwich structure.

Following this, a CFRP monolithic sandwich structure with corner fillets was prototyped. **Figure 5** shows a prototype CFRP monolithic sandwich structure. Unidirectional prepregs are used as the face sheet, woven prepregs are used for the corrugated sheet, and adhesive was used as the corner fillet, with an one-shot curing process using an autoclave.

Visual inspection of the prototype found both the base material (face sheet, corrugated sheet) and bond lines favorable in quality. This prototype assured prospects for the potential application of a CFRP monolithic sandwich structure to airframes.

Henceforth, it is necessary to establish a more consistency and improve productivity for future application to airframes.

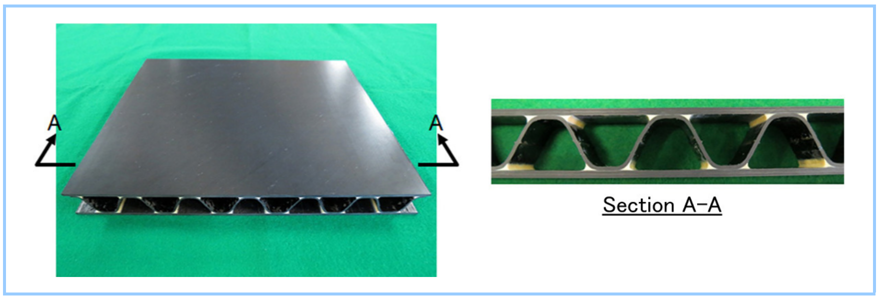

Figure 5 Prototyped CFRP Monolithic Sandwich Structure

5. Conclusion

MHI has proposed the CFRP monolithic sandwich structure as a light-weight/high-strength type of airframe.

Further regarding such a structure, the adhesion peel strength improvement effect of corner fillets was identified through numerical analyses. In addition, a CFRP monolithic sandwich structure with corner fillets was prototyped, using the one-shot curing process, and prospects for potential application to airframes were assured.

Reference

1. Takayuki, K. et al., Efficient CFRP Monolithic Sandwich Construction, SAMPE EUROPE 35th International Conference and Forum, (2014) p.25-30