Standardization of Tests for Advanced Composites

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1. Introduction
Advanced composites are essentially the only feasible materials for the construction of newly developed aerospace vehicle\(^1\). However, the path to be followed for the validation, evaluation and certification of composite aircraft structures is quite different from that of traditional metallic aircraft structures, and the importance of a composites database is now well recognized\(^2\). A key issue in constructing a fully descriptive composites database is to establish standard composite test methods, so the standardization of tests for composites has become a very important issue, and the object of much study in aerospace composites research.

2. Background
The established composite handbook is US MIL-HDBK-17\(^3\), which specifies many test methods for the characterization of composites. Naturally, these are American-based standards, like those of the ASTM (Test Methods by American Society for Testing of Materials) and SACMA (Supplier of Advanced Composite Materials Association). Although a great many tests have been conducted based on these methods, and they are already regarded as “de facto” standard methods at least in the USA and Japan, some of the methods include awkward requirements, such as unreasonable specimen sizes or inappropriate loading fixtures. In particular, unnecessarily large specimen sizes add greatly to costs, especially because of the large number of data points required for database generation. In some situations, new test methods may be required due to new and improved properties of the composites. To meet these needs, NAL/ACE TeC is promoting new test method definitions and modifications of test methods for some Japanese standards. Two examples of such activities will be explained here.

3. Definition of Interlaminar Shear Strength Test by the Double Notch Compression Method
An example of improved materials making the tests obsolete is the case of very tough composites such as reinforced thermoplastic resin, or composites with translaminar reinforcements, 3-D textiles or stitching. The typical traditional method to determine interlaminar shear strength (ILSS), the short beam shear (SBS) test, does not work well for those new types of composites. In fact in the extreme case, shear failure never happens. An alternative to a wide spread SBS is a shear-strength test that uses a double notched specimen. Although tension or compression may work equally well if the fixture design is appropriate, compression is considered to be easier and to require a smaller size specimen. Thus an NAL-driven committee was formed to define the details of this method in the fall of 2000. The essence of the activities was as follows: Several types of specimens were fabricated for testing with the final candidate (shown in Fig. 1) and distributed to nine organizations (industry, university and government institutes) for round-robin tests (RRT). All data were collated and the method definition was discussed. The baseline case with a 6.4 mm notch distance and 1.0 mm notch pit width is referred to as MA\(^1\), and other notch distances, 3.2 and 9.6 mm, are indicated with the prefixes S and L. The suffix B denotes a 1.5 mm notch pit width. For case MA\(^1\), some specimens were intentionally machined over-depth by -0.0 to 0.4 mm, where the normal depth tolerance is -0.0 to 0.2 mm. This type is denoted MA\(^1\). In order to check the torque effects of fitting screws, double the normal torque (0.113 Nm) was employed (MA\(^2\)). Thus several cases were explored: SA, MA, LA, SB, MB, LB, MA\(^1\) and MA\(^2\).

Pictures of typical failure modes are shown in Fig. 2, where the longer notch distance specimen (LA) does not fail in the pure shear mode and the over-depth specimen (MA\(^1\)) exhibits mixed mode failure. These are not appropriate as stan-
standard specimens. The results of tests conducted by NAL\(^4\) are shown in Fig. 3. A shorter notch distance leads to lower strengths if the notch pit width is large (1.5 mm), and may not be compatible with the pitch of translaminar reinforcements. Thus the middle distance of 6.4 mm at both notch pit widths was selected as the candidate for the JIS test method standard, as shown in Fig.1. Additional data shown in Fig.3 indicate the insensitivity of DNS strengths to screw torque at levels up to double the normal.

The present RRTs were almost sufficient for a preliminary draft for a JIS standard DNC shear test. Broadly, the decision is this: The specimen geometry shown in Fig. 1 and the supporting fixtures shown in Fig.4 (Left) will be adopted, as well as the L-shaped holding fixture for faster and easier alignment of the specimen. Clamping torque range and crosshead speed will be defined as 0.1 - 0.15 Nm and 1.0 - 2.0 mm/min, respectively.

4. Modification of the Open Hole Compression (OHC) Test from the SACMA Method

This procedure deals with the requirement for excessively large samples mentioned above. The open hole compression (OHC) test provides one of the most critical measures of strength among all coupon level tests. In some respects this test is considered a measure of the damage tolerance of a composite, which is determined by the matrix, and the cost of which is much less than the compression after impact (CAI) test. So the demand for this test is rising rapidly, and any reduction in its cost results in sizeable savings in evaluation costs. The current “de facto” standard of SACMA SRM 3R-94\(^5\) is defined in MIL-HDBK-17 and used widely in the USA and Japan. However, this method requires an unnecessarily long specimen measuring 304 mm by 38.1 mm, probably due to peculiarities of testing practices in the USA. This large size quite significantly increases the cost of testing.

Based on this finding, the NAL has developed a new testing method using a shorter specimen and a supporting fixture similar to ASTM D695 with rectangular window. This method is referred to as NAL-III and its window size is the same as in the SACMA 3R-94 fixture. The purpose of the window is to permit out-of-plane deformation to occur around the hole before failure. Comparisons in specimen size and fixture configuration are shown in Figs.5 and 6, respectively.

As shown in these figures, the NAL-III method has the advantages of using a shorter specimen and also a simpler and lighter fixture that improves ease of handling. Clamping devices are installed at the top and bottom of a NAL-III specimen in order to prevent blooming failure at the ends. Once the size and fixture definitions are completed, the next issue is the comparison of test results. Again, RRT by 7 organizations is underway for SACMA 3R-94 and NAL-III. Figure 7 shows the results of a preliminary part of the RRT for OHC\(^6\) conducted at NAL, where four
types of carbon/epoxy composites were tested and compared. If we consider that each data point represents an average of 6 specimens, it can be concluded that SACMA and NAL-III provide almost identical OHC strength data. If this is confirmed by the final data unification of the RRT, the committee will propose NAL-III as an alternative OHC test to replace SACMA. The draft will be written in the near future.

From an engineering standpoint it is simple to see why both methods lead to similar results. Figure 8 shows the trace of damage propagation by ultrasonic C-scan and x-ray radiography during OHC tests of the IM600/QC101 CFRP system. It is very clear that the final failure propagates transversely to the load and that no propagation at all was seen in the longitudinal direction. This finding is quite compatible with the absence of any effect of the upper and lower tongue portions of the specimens upon OHC strengths.

5. Proposal for Compression after Impact (CAI) Test to ISO TC61/SC13

The compression after impact (CAI) test is another very important determinant of allowable design strain levels in aircraft composite components. CAI tests usually provide the critical limits for design stress or strain in the primary...
composite structure. For this method, the current "de facto" standard is generally considered to be SACMA SRM 2R-947). However, JIS CAI methods established following SACMA 2R-94 in 1996, and an outline of those CAI test methods, will be summarized in this article. The first key test is impact. The clamping device, a rubber bushing, may be a point of future discussion. After impact, SACMA and JIS require non-destructive inspection of impact damage by ultrasonic C-scan. In the European de facto standard, the measurement of the impact dent is compulsory, rather than an ultrasonic C-scan. This kind of discrepancy will be a discussion point in the ISO proposal. If NDI or dent depth measurement is completed, the impacted specimen will be subjected to an in-plane compressive load by the supporting fixture. Boundary conditions shall require that the specimen be clamped at loading and supporting edges and simply supported at side edges. Concepts of support and compression are quite similar in current US/Japanese and European standards. Due to the efforts of Japan’s delegate, the new work item of CAI test standardization has just been approved by the ISO TC61/SC13 committee, and these issues will be explored in depth for several years. Hopefully, these ideas to improve important tests of composites for structural applications will be incorporated in the fundamental framework of future ISO standards.

6. Concluding Remarks

In order to establish comprehensive and reasonable test methods, a deep understanding of the mechanics underlying the behavior observed during testing is required. Furthermore, in addition to this understanding of mechanics, establishing widely accepted test methods also requires recognizing the unavoidable engineering compromises between precision and optimal cost. We have presented here some typical examples of standardization initiatives undertaken in Japan that will be important to the wide use of advanced composites in aerospace fields.

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