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**TORQUE LIMIT FOR BOLTED JOINT FOR COMPOSITES
PART A
TTTC PROPERTIES OF LAMINATED COMPOSITES**

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Introduction

The existing design code for torque limit of bolted joints for composites at Marshall Space Flight Center is MSFC-STD-486B, which was originally developed in 1960s for metallic materials. The theoretical basis for this code was a simplified mechanics analysis, which takes into account only the bolt, nut and washers, but not the structural members to be connected. The assumption was that metallic materials would not fail due to the bearing stress at the contact area between washer and the mechanical member. This is true for metallic materials; but for composite materials the results could be completely different. Unlike most metallic materials, laminated composite materials have superior mechanical properties (such as modulus and strength) in the in-plane direction, but not in the out-of-plane, or through-the-thickness (TTT) direction. During the torquing, TTT properties (particularly compressive modulus and compressive strength) play a dominant role in composite failure. Because of this concern, structural design engineers at Marshall are currently using a compromised empirical approach: using 50% of the torque value for composite members. Companies like Boeing is using a similar approach.

An initial study was conducted last summer on this topic to develop theoretical model(s) that takes into consideration of composite members. Two simplified models were developed based on stress failure criterion and strain failure criterion, respective. However, these models could not be used to predict the torque limit because of the unavailability of material data, specifically, through-the-thickness compression (TTTC) modulus and strength. Therefore, the task for this summer is to experimentally determine the TTTC properties. Due to the time limitation, only one material has been tested: IM7/8552 with $[0^\circ, \pm 45^\circ, 90^\circ]$ configuration. This report focuses the test results and their significance, while the experimentation will be described in a separate report by Mr. Kris Kostreva.

Through-the-Thickness Compressive (TTTC) Properties

Two types of joining methods are widely used in aerospace/aircraft structures: adhesive bonding and bolting. Almost all of the primary joints (joints to carry major loads) are bolted joints. But how to determine the torque limit of bolt joint for composites is a big challenge for structural engineers at MSFC and other aerospace/aircraft industry since there is no design standard and/or code for composites. The compromise is to use reduced torque value. This is apparently an empirical approach, and it is material type oriented.

It can be found that all of the composite materials data books contain only in-plane material properties, but not through-the-thickness properties. There could be many reasons behind this fact, but the technical challenge in determining TTT properties experimentally is no doubt one of the major reason. Since the thickness of a composite laminate is fairly small, say 1/8", it is difficult to either mount a strain gage or other measuring tools. Almost all of the analyses of composite structures are based on laminate theory. According to this theory, TTT properties are assumed to be the same as in-plane 90° tension (ASTM D3039) or compression (ASTM D3410) properties regardless of fiber configuration of the laminates, provided fiber fraction remains the same.

The failure due to bearing stress at the washer area is dominated by material's behavior in the thickness direction, particularly TTTC modulus and TTTC strength. Therefore, design a feasible test fixture and using this fixture to obtain TTTC properties become one of the major parts of this torque limit project. After several trials, an innovative test fixture has been designed that uses linear displacement sensors (LDS). Because of the extremely small displacement in the TTTC tests, a highly accurate measuring device has to be employed. LDS becomes an ideal choice to serve our purpose due to its high accuracy. Table 1 shows the comparison among three measurement tools.

Table 1. Comparison of Various Measuring Tools

Measuring Tools	Features
LDS	$\leq 0.1\%$ full scale error No external conditioners 3.5 mV/V output Medium cost
LVDT	0.25% full scale error External conditioners required 4 mV/V output Low cost + conditioners
Extensometer	0.1-0.5% full scale error No external conditioners 3.5 mV/V output High cost

Test Fixture and Specimens

A detailed description of TTTC test fixture can be found in Part B of this report (by Kris Kostreva). The TTTC tests were conducted on an MTS universal testing machine with 220 kips capacity. In order to see the effect of fiber configuration on TTTC properties, coupons with four different fiber configurations were tested:

- Unidirectional [0°]
- Cross ply [0°, 90°]
- Quasi-isotropic [0°, ±45°, 90°]
- Quasi-isotropic [0°, ±30°, ±60°, 90°]

Three different thicknesses were used for IM7/8552 to investigate the thickness effect: 0.132", 0.176" and 0.220".

Test Results

The test results of TTTC modulus and TTTC strength are shown in Fig. 1 and Fig. 2, respectively. Here the relative modulus and relative strength are the test values relative to those from 90° in-plane compressive modulus and strength. These 90° in-plane compressive modulus and strength tests were also conducted by the investigators using the ASTM D3410 fixture, as shown in Fig. 3, following the test procedure specified by the standard.

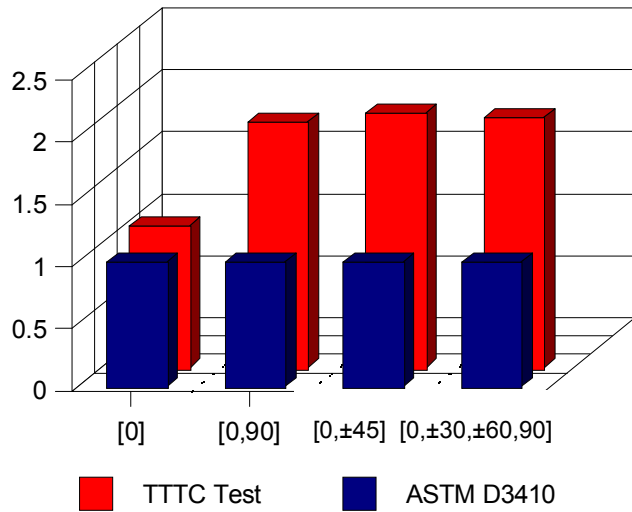


Fig. 1 Comparison of Relative Modulus

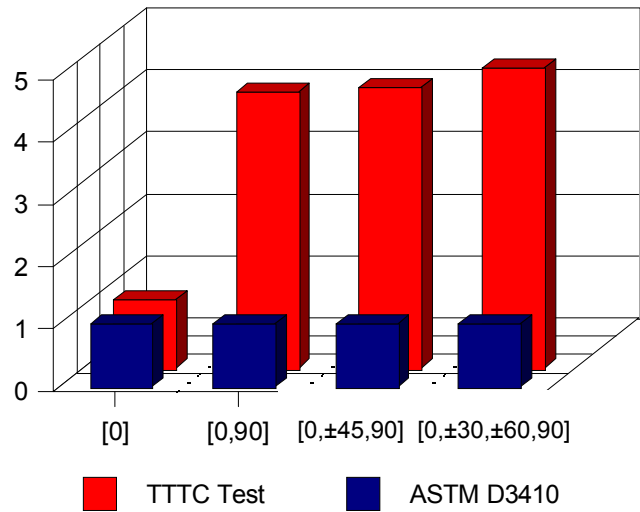


Fig. 2 Comparison of Relative Strength

The results from the TTTC tests are significant, not only to the design and stress analysis engineers in aerospace/aircraft industry, but also to the composites research community. Up to this point, the analysis of composite structures are mainly based on laminate theory. According to this theory, the TTTC modulus obeys the “Rule of Mixture” that applies to modulus in any other direction. This theory also suggests that both TTTC modulus and strength could be approximated by those obtained from 90° tension or compression tests. But the results from this study show that the “Rule of Mixture” is not applicable for TTTC modulus. The four fiber configurations we used in tests have the exact same fiber volume fraction, but have significant different values for TTTC modulus: except for [0°] coupon that is about the same as that from 90° compression test, all three other fiber configurations have a modulus that is at least twice the value as that from 90° compression test. The differences in strength are more notable: the data for three fiber configurations (except for [0°] coupon) are at least four times greater than the strength obtained from 90° compression test.



Fig.3 ASTM D3410 Test Fixture and 90° Specimen

Preliminary Conclusions

While it is premature to conclude that existing theories/methods in determining the TTTC properties for laminated composites are incorrect, this study clearly shows that there is a possibility that TTTC properties have to be determined in a different way other than the existing theories/standards suggest. The preliminary conclusion from this experimental study is summarized in the following:

- For the material tested (IM7/8552), TTTC modulus does not obey “Rule of Mixture.”
- For the material tested (IM7/8552), both TTTC modulus and strength vary with fiber configuration.
- For unidirectional laminate, TTTC modulus is about the same as in-plane 90° compression modulus; while the TTTC strength is about 3% higher than in-plane 90° compression strength.
- For cross ply and two other quasi-isotropic materials, the TTTC moduli are at least four times greater than that of in-plane 90° compression strength.

Since there is only material (IM7/8552) tested, it is necessary to test some different fiber/resin composite materials in order to reach some ultimate conclusions.

Acknowledgment

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