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**TORQUE LIMIT FOR BOLTED JOINT FOR COMPOSITES  
PART B  
EXPERIMENTATION**

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## **Introduction**

Today, aerospace quality composite parts are generally made from either a unidirectional tape or a fabric prepreg form depending on the application. The matrix material, typically epoxy because of its dimensional stability, is preimpregnated onto the fibers to ensure uniform distribution. Both of these composite forms are finding themselves used in applications where a joint is required. Two widely used joint methods are the classic mechanically fastened joint, and the contemporary bonded joint; however, the mechanically fastened joint is most commonly used by design engineers.

A major portion of the research up-to-date about bolted composite joints has dealt with the in-plane static load capacity [2]. This work has helped to spawn standards dealing with filled-hole static joint strength. Other research [3,6] has clearly shown that the clamp-up load in the mechanical fastener significantly affects the joint strength in a beneficial manner by reducing the bearing strength dependence of the composite laminate. One author reported a maximum increase in joint strength of 28% [3]. This finding has helped to improve the reliability and efficiency of the joint in a composite structure.

Hence, the question that many design engineers ask is how much clamp-up load, applied via fastener torque, to specify in this joint. The current practice at MSFC is based on neither analytical techniques nor experimental results for composites. Instead, designers utilize conservative adjustments from the standard MSFC-STD-486B [7]. They use half of the experimentally determined torque value for any given bolt size when designing a composite joint [8]. This practice does not account for possible failure of the joint because of fastener preload.

Speaking with regards to material properties, composites are known to be notoriously poor performers in a state of pure compression. Lack of a fundamental knowledge base concerning the mechanical behavior of fiber-reinforced composites under through-the-thickness compression (TTTC) is responsible. After an extensive literature survey, it has been concluded that very little research has been done up-to-date regarding through-the-thickness (TTT) composite properties and nothing was found regarding TTTC; therefore, an experimental approach was needed to investigate the behavior of a composite single-lap joint.

This work involved development of a recommendation to determine the torque limit in a composite single-lap joint using the guidelines outlined by NASA/MSFC 486B. The graphite/epoxy laminates were configured according to MIL-HDBK-17B [5] and three different through-hole diameters were examined. Acoustic emission (AE) nondestructive testing was employed to supplement the data from the standard 486B test.

## **Acoustic Emission**

The textbook definition of acoustic emission is a transient elastic wave generated by the rapid release of energy from a localized source within a material. AE is a passive, nondestructive technique requiring the structure or specimen to be under load in order to generate the failure mechanisms that produce the elastic waves. Piezoelectric sensors attached to the surface detect the stress waves that propagate throughout the material and output a voltage signal. A

preamplifier is used to boost the voltage signal to a usable level, and a band-pass filter is used to remove unwanted noise. The voltage signal is then fed to a data acquisition system that extracts information about the signal and generates AE quantification parameters.

When stressed, the graphite/epoxy composite material emits acoustic emission from the various failure mechanisms occurring within the material. As noted by Awerbuch, the complexity of failure in composite materials is due to the multiplicity of possible modes of failure. In this project, it is not the intent to be able to discern the different composite failure mechanisms by the measured AE parameters [4], but to clearly detect joint failure and relate that to either the composite or the mechanical fastener. By superimposing the standard torque-tension data with the AE data, a clear picture to the failure mechanism(s) in the simulated joint should emerge.

### **Experimentation**

A single-lap joint made from IM7/8552 prepreg material was chosen for testing. The fiber configuration of the plates was  $(n(0, \pm 45, 90))_s$ , where  $n = 3, 4, 5$ . Nominal cure thickness for each of these laminates was 0.132, 0.176, 0.220, respectively, and surface finish was smooth on both sides. A diamond tipped drill was used to drill the through holes in the coupons. Three different bolt sizes for each plate thickness were intended for investigation: 0.125", 0.250", and 0.500"; however, after initial testing it was determined to use only the largest two bolts. The designations of the bolts were NAS1958C-32 (0.5") and NAS1954C-32 (0.25") with corresponding self-locking threaded nuts. The washers used were NAS1587-8 and NAS1587-4, respectively. There were only two joint configurations tested in the four tests performed due to time constraints, both bolt sizes on the  $(3(0, \pm 45, 90))_s$  laminates. Seen in Figure 1 and 2 is the test fixture according to the standard 486B.

The AE system used was comprised of a R15 transducer (seen in Figures 1 and 2 coupled to the composite with hot glue) whose signal was amplified with a PAC 2/4/6 preamplifier set to 40dB of gain. The test data presented herein were gathered with the PAC DSP-32 and MISTRAS software with all measurable time-domain parameters recorded. AE system settings included: preamp gain, 40 dB; system gain, 20 dB; threshold, 50 dB; peak definition time, 50  $\mu$ s; hit definition time, 100  $\mu$ s; and hit lockout time, 300  $\mu$ s. An attenuation check with a mechanical pencil on the composite laminate showed no significant loss of signal.

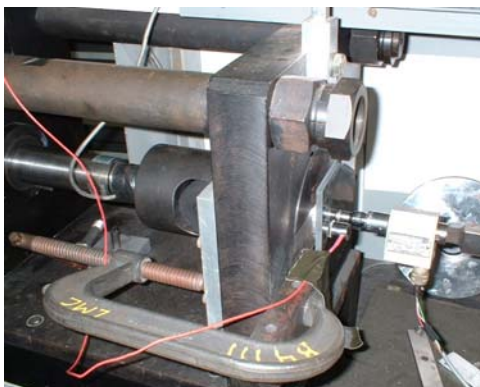


Figure 1: Test Fixture



Figure 2: Close-up of Coupon

## Discussion of Results

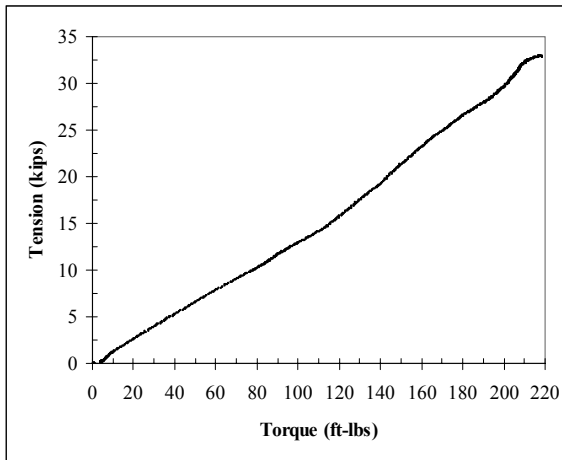


Figure 3: 0.5 inch Bolt T-T Data

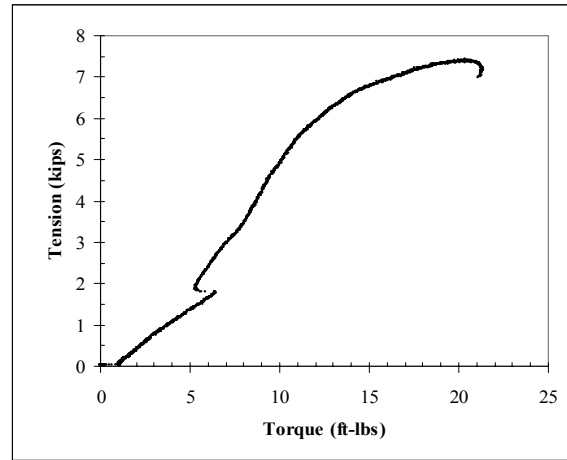


Figure 4: 0.25 inch Bolt T-T Data

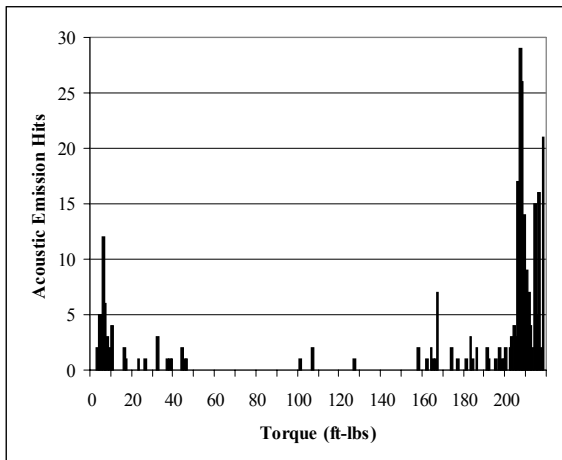


Figure 5: 0.5 inch Bolt AE Data

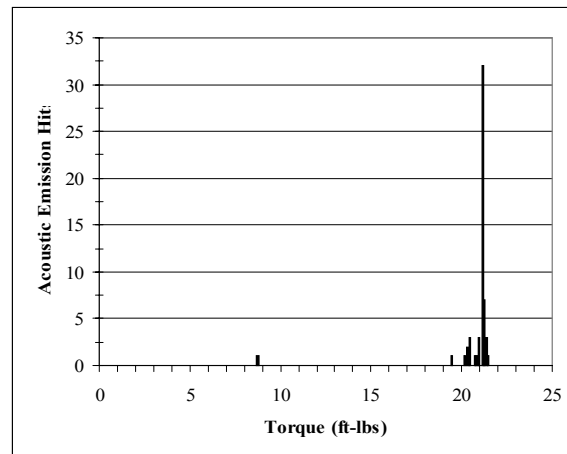


Figure 6: 0.25 inch Bolt AE Data

The torque-tension data produced from the tests (Figures 3 and 4) were typical of those seen in a 486B test. The anomaly at 6.5 ft-lbs in Figure 4 is attributed to slack in the test fixture during loading. In all the tests performed, the threads of the bolt failure first, which the AE data confirmed. This can be seen by comparing the AE activity level at a given torque load to the torque tension curve. Figure 5 shows some ambiguous signals at the beginning of the test. The recorded signals did not originate from a source dislocation, rather these signal were generated from unwanted friction as the washer spun against the composite plate during torque-up. Using calcium grease in the washer/composite, the washer/nut and the nut-thread/bolt-thread interfaces solved this problem. Figure 6 shows the AE data taken from the 0.25 inch bolt test with the calcium grease. Compared to Figure 4, it is clear that the failure of the bolt was identified by the exponentially increasing AE activity as the torque-tension curve kneeled over (the same can be said about Figure 3 and 5). Inspection of the composite plates at the test showed no obvious signs of failure or damage while the bolt threads were completely stripped.

## **Conclusions and Recommendations**

The results of the tests showed that the composite plates under investigation did not fail before the bolt; hence, the current practice of reducing the fastener preload specified by 486B is a very conservative approach when using IM7/8552 in a single-lap joint. Weight savings in a composite joint using any of the bolts tested and the tested fiber configuration might be achieved by increasing the torque load to 486B standards. This will result in a joint with fewer fasteners will maintaining the same joint strength. Also, once it was shown that the 0.5 inch bolt could not fail the plates it was assumed that the 0.125 inch bolts would not generate a large enough tensile load to cause failure either and consequentially these test were not performed. However, it is important to remember that composites come in many different configurations and this means experimenting with different materials and fastener types, such as the countersunk fasteners used on the graphite/epoxy shuttle nose cone.

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