SUBMILLIMETER ARRAY PROJECT
TECHNICAL MEMO 145

TITLE: **TESTING OF NYTEX TUBES FROM ANTENNA 1 AFTER 3 YEARS OF SERVICE AT SIMPSON, GUMPERTZ & HEGER, INC.**

FOREWORD: Joshua B. Kivela (SGH) provided the description on how the tests were conducted and documentation of the results. George Nystrom (SAO) has provided an engineering assessment and recommendations for future testing to ensure BUS safety and performance.

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REPORT ON SMA TESTING, JOSHUA B. KIVELA

SUBJECT: Strength of Carbon Fiber Tube Assemblies

TEST DATE: 20 March 2002

SAMPLES: George Nystrom submitted seventeen carbon fiber tube assemblies on 18 March 2002 for testing. The assemblies were constructed of various length and diameter carbon fiber tubes with stainless steel end fittings inserted and adhered to the tubes.

PROCEDURES

We followed the procedures outlined in “Antenna 1 Crack Tube Test Procedure, number 41700490001 Rev. OB” written by George Nystrom dated 20 January 2002. The following summarizes our procedure:

- We configured our MTS Testing Machine with a 10,000 lbf. Load cell and fixtures (Photo 1).
- We screwed forged steel threaded eyebolts into both stainless steel ends of the carbon fiber tube assembly.
- We mounted both ends of the carbon tube assembly in the fixtures and applied a 20 lbf. seating load (Photos 2-3).
- We aligned the specimens in the fixtures and moved the crosshead up at a rate of 1.5 mm/min.
- We recorded the amount of creep (for both hold load segments, if applicable), and the peak load for each specimen.

- <u>Cracked Tubes</u>: When the “Hold Load 1” in Table 1 was reached we held the load for 5 minutes and recorded the distance the crosshead moved. After we confirmed that the creep rate was less than 5 microns/minute we moved the crosshead up at a rate of 1.5 mm/minute until we reached the “Hold Load 2” value listed in Table 1. We held the load at this value for 5 minutes. After we confirmed that the creep rate was less than 5 microns/minute we moved the crosshead up at a rate of 1.5 mm/minute until the specimen failed.

- <u>Non-Cracked Tubes</u>: When the “Hold Load” listed in Table 2 were reached we held the load for 5 minutes and recorded the distance the crosshead moved (i.e., creep). After we confirmed that the creep rate was less than 5 microns/minute we moved the crosshead up at a rate of 1.5 mm/minute until the specimen failed.

- We pulled the stainless steel end fitting out of the failed end of the carbon fiber tube assembly and inspected the structural bond line on the carbon tube and the end fitting (Photos 4-8).

RESULTS

All of the carbon fiber tube assemblies failed by pullout of the end fittings. There is no apparent difference between the failure modes of the cracked and non-cracked tubes.

The test results for the cracked and non-cracked tubes are presented in Tables 1 and 2, respectively. The following is a summary of the failure modes and observations of the construction of the tubes.

The 19.20 mm and 23.30 mm I.D. carbon fiber tubes appear to have grooves on their inner surfaces. This is noticeable when looking at the stainless steel end fittings and the inside surface of the carbon fiber tubes (Photos 4, 5, 7). Most of the specimens failed adhesively between the epoxy adhesive and the carbon fiber tubes. Carbon fibers are visible on some of the stainless steel end fittings.

The 31.50 mm I.D carbon fiber tubes do not appear to have grooves on their inner surfaces (Photos 6, 8). All of the 31.50-mm I.D specimens failed adhesively at the bond line between the carbon fiber tubes and the adhesive.

Table 1 - Cracked Tube Test Data

Tube Type	Reference Number	Inside Diameter (mm)	Creep				Hold Load (lbf.)		Peak Load (lbf.)
			At Load 1		At Load 2				
			Total (μm)	Rate (μm/min.)	Total (μm)	Rate (μm/min.)	1	2	
1	1	23.30	1	0.2	2.5	0.5	719	1079	2835.0
4	2	23.30	0	0	0.5	0.1	149	258	1915.3
4	3	23.30	2	0.4	1	0.2	149	258	3741.4
5	4	23.30	1	0.2	1	0.2	300	331	1631.4
6	8	19.20	4	0.8	2.5	0.5	340	656	1942.1
7	9	19.20	1	0.2	0.5	0.1	175	238	2720.8
11	10	23.30	1.5	0.3	1	0.2	530	588	4300.0
19	15	31.50	-	-	-	-	653	1384	400.5

Notes:

1. Tube 11 (Ref. # 10) failed at approximately 4300 lbf. We monitored the load meter visually but didn't record the load at failure electronically.
2. Tube 19 (Ref. # 15) failed before the first hold load was reached.
3. Creep is the total crosshead displacement during the hold load period. Creep rate is the total crosshead displacement during the hold load period divided by the hold time (5 minutes).
4. Load 1 is the expected load at 30-MPH wind speed and includes thermal, assembly and gravity loads.
5. Load 2 is the worst-case tube load resulting from a 130 MPH wind speed with the antenna in "zenith" position and thermal, assembly and gravity loads included.
6. Tube ref. Number 1 was tested to its worst-case load and proof test load in error.

Table 2 - Non-Cracked Tube Test Data

Tube Type	Reference Number	Inside Diameter (mm)	Creep Total (㎜)	Creep Rate (㎜/min.)	Hold Load (lbf.)	Peak Load (lbf.)
5	5	23.30	1.0	0.2	497	1135.5
5	6	23.30	0.5	0.1	497	1759.8
5	7	23.30	2.5	0.5	497	3930.0
11	11	23.30	1.5	0.3	882	4578.2
11	12	23.30	1.0	0.2	882	4612.2
11	13	23.30	5.0	1.0	882	3300.6
19	14	31.50	7.0	1.4	2076	2763.8
19	16	31.50	11.0	2.2	2076	4047.9
19	-	31.50	-	-	-	-

Notes:

1. We didn't test tube 19 (no Ref. #) because it only had one end fitting.
2. Creep is the total crosshead displacement during the hold load period. Creep rate is the total crosshead displacement during the hold load period divided by the hold time (5 minutes).
3. The Hold Load is the proof test load that the tubes where tested to at NYTEX. It is 1.5 times the worst-case expected load for the tube.

ENGINEERING COMMENTS, GEORGE NYSTROM

Tube History:

Antenna 1's Backup structure (BUS) was originally assembled using carbon fiber tube assemblies provided by Thermoplastic Pultrusions, Inc. of Bartlesville, OK. These tube assemblies were deemed unacceptable. NYTEX, a Taiwan firm, was then contracted to make wound CRFP tube assemblies. Prior to beginning manufacturing NYTEX visited SAO to outline their capabilities and the plans for Production, Quality Control, Assembly and Testing of the tube assemblies. At this meeting SAO recommended a few changes in the manufacturing process along with technical recommendations to improve strength of the bonded joint. To confirm the bonded joints' strength, NYTEX provided a set of test samples. The results of these tests are reported in Technical Memo 120. These tests showed that the NYTEX bonded joints provided adequate strength and manufacturing was allowed to begin. Technical Memo 119, Titled: SMA Backup Structure Tube Loads was used to define the test loads that NYTEX would use for acceptance testing and also formed the loads to be used in this testing.

Upon receipt of the first set of NYTEX tubes, Antenna 1's BUS was broken down and re-assembled. It was assembled in mid 1999 and was deployed to a pad late that summer. Therefore the tubes tested here have been exposed to the Haystack outside environment for approximately 3 years. Cracked tubes were detected after a year of service, therefore have approximately 2 years of environmental exposure. The BUS was then disassembled. After disassembly, all tubes required that their end fitting's mounting hole be tapped to remove the epoxy remnants used in securing its mounting screws. This operation places small stresses into the joint but well below the testing loads. However, one –19 tube failed during this process.

Results:

All tubes tested show no apparent strength degradation due to the longitudinal crack. This had been predicted by engineering providing that the crack does not propagate across the tube/end fitting bonding area. All cracks in the tested tubes did stop well short of the bond area. Although after testing the cracks extend the tubes' full length. It is engineering's opinion that the bond provides the required hoop strength that the tube is missing due to its lay-up configuration.

All tube types, except –19, have a large factor of safety over their worst case expected load and none failed within their proof test load. Tables 1 and 2 contain the test data and support this point. It is therefore concluded that all these tubes have acceptable performance. The only point to mention is the large factor of safety variance between similar tube types. One would expect the variance to be around 10%. I can't offer any insight to pin point a cause. It may be related to the manufacturing process.

The –19 tubes are a real concern. We had a 50 % failure rate with them. The three tested articles and one that failed when tapping, show different processing of the bond line. The tube ends have not been grooved or even roughened. This was one of the design recommendations mentioned earlier. It is apparent in the small tubes tested that it did significantly increase the bond strength and should be employed throughout the tube family. It is not clear if these –19 tubes where processed before the design changes were implemented. This needs to be investigated.

Table 3, lists the post-test inspections of both the tube ends and end-fittings and the factor of safety for each tube tested.

Table 3 – Test Specimen Comments						
Tube Type	Reference Number	Observations		Factor of Safety	Worst Case Load (lbf.)	Photo Refer-ence
		End fitting	Tube end			
1	1	S,R	D + G	3.9	719	4
4	2	S,A,R	D + G	7.4	258	4-5
4	3	S,R	D + G	14.5	258	5
5	4	S,R	D + G	4.9	331	5
5	5	S,R	D + G	3.4	331	5
5	6	S,A,R	D + G	5.3	331	5
5	7	S,R	D + G	11.9	331	5
6	8	S,A	D + G	2.9	656	4
7	9	S,R	D + G	11.4	238	5
11	10	S,R	D + G	7.3	588	5
11	11	S,A,R	D + G	7.8	588	4
11	12	S,R	D + G	7.8	588	5
11	13	S,R	D + G	5.6	588	5
19	14	S,V,G	S	2.0	1384	6
19	15	S,V,G	S	failed	1384	6
19	16	S,V,G	S	2.3	1384	6

Notes:

1. The factor of safety is determined by dividing the failure load by the worst-case expected load.
2. Photo reference is a referral to the photo that is most representative of the end fitting.
3. All failures occurred at the bond line between the tube inside diameter and the adhesive.
4. End fitting symbols: S = an apparent shattering of the adhesive
   A = evidence of tube fibers in the axial direction
   R = evidence of tube fibers in the radial direction
   V = evidence of voids in the adhesive
   G = smooth or glossy appearance
5. Tube end symbols: S = a smooth or glossy appearance
   D = dull or somewhat roughen appearance
   G = the tube has radial grooves over the bond surface.

Conclusions:

These tests showed good performance for properly processed tubes. This is the first test to provide information on the effects of weathering, aging and stressing due to assembly. Also, the testing indicates that a possible problem might exist for the –19 tubes or any other tube that might have been processed in a similar manner.

These tests also indicate that as long as an observed crack doesn't propagate across the bond area, then strength is unaffected.

Recommendations:

1. A continuing test program for crack tubes should be instituted. This will provide additional tube strength/environmental exposure statistics while monitoring tube assemblies from various manufacturing lots.

2. We must develop a method of sealing the tube cracks to prevent possible water/ice cycles, which could further damage the tubes thereby altering their strength.

3. We must investigate which tubes were processed without the tube ends being grooved or roughened.

4. More –19 tubes and other tubes of large inside diameters should be tested. This will provide additional data to explore possible strength issues.

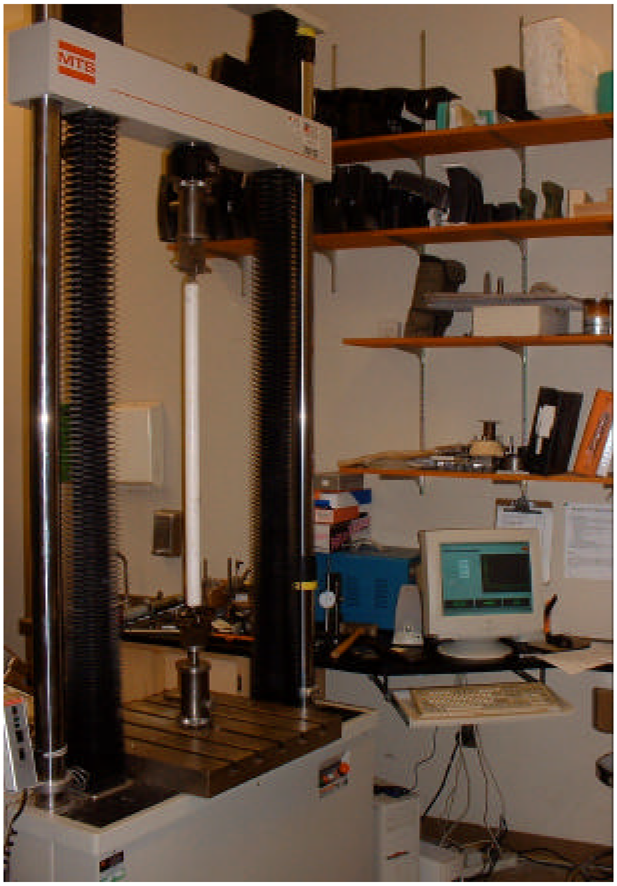

Photo 1

MTS 30/G Testing machine with data acquisition system.

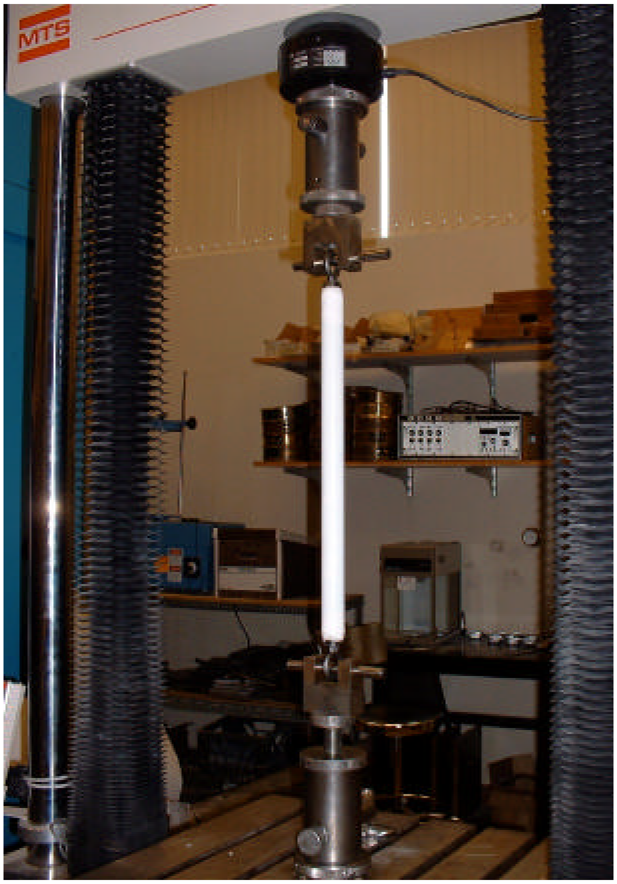

Photo 2

Carbon fiber tube assembly mounted in testing machine.

Photo 3

End of carbon fiber tube assembly mounted in fixture.

Photo 4

Stainless steel end fitting (19.20 mm OD.) with carbon rings and fibers.

Photo 5

Stainless steel end fitting (23.30 mm O.D.) with carbon rings.

Photo 6

Stainless steel end fitting (31.5 mm O.D.) with no carbon rings.

Photo 7

Carbon fiber tube (23.3 mm I.D.) with grooved rings.

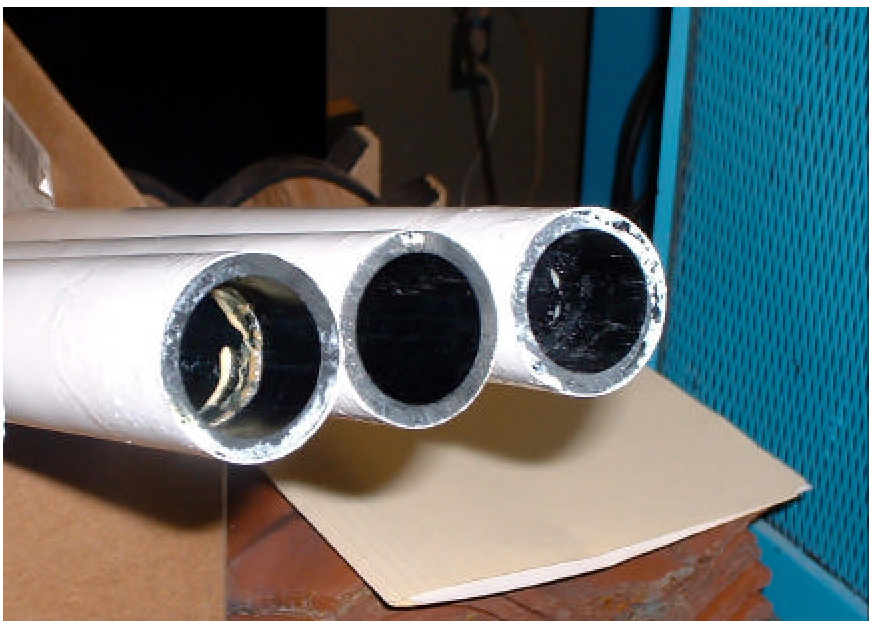

Photo 8

Carbon fiber tube (31.5 mm I.D.) with no grooves.