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SGH

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M E M O R A N D U M

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To: George Nystrom, Smithsonian Astrophysical Observatory

From: Joseph Antebi

Comm. 96755 – Carbon Fiber Tube Assemblies for the SMA Antennas

Subject: Short term and cyclic testing of Type -25 tube specimens

These tests are part of a test program to evaluate the adequacy of the bonded joints between the CFRP tubes and their stainless steel end fittings for members to be used in the backstructure of the SMA antennas.

BACKGROUND

In May 1997 we tested 35 specimens of Type -25 tubes assembled NYTEX. The tests included short term pull-to-failure tests for samples under three types of conditions: room temperature and 50% humidity, "hot and humid" (140°F, 100% humidity), and "cold and dry" (0°F and dry). Also included were tests under eccentric loads, and tests of specimens which had been grooved to' eliminate the tension bond at the end of the tube. The results and photographs of the specimens were forwarded to you on 13 June 1997. The results were presented and discussed at a meeting at SAO on 6 June 1997 and the conclusion summarized in the minutes of the meeting were as follows:

> "The test results achieved are not conclusive enough to qualify the present design, its materials and processing for the highly stressed joints of tubes -25 (and perhaps others) for use in the backup structure. The reason for this position is that although the tubes show an adequate mean breaking strength, the standard deviation or variation in strength is excessively large. Also, the sustained load tests were not completed because the deviation in breaking strength encumbered the ability to make a reasonable sustained load test."

Consequently it was decided at that meeting to recycle the CFRP tubes with longer end fittings installed (1.3 in. long instead of 1.0 in.) using the new glue, procedures, and quality controls proposed by NYNEX.

In June 1997 we performed short term pull-to-failure tests under axial load of 14 specimens of type -5. The standard deviation was large, 23 percent of the mean. These specimens differed from earlier -25 specimens in that the cylindrical surface of the stainless steel end fittings had been grooved to improve the bond at the stainless steel surface. In addition to the photographs of these specimens forwarded to you with the results on 19 June 1997, we took photographs of the failure surfaces through a microscope. These photographs are attached for your reference. Note the circumferential breaks in the carbon fibers giving the appearance of steps, and that the spacing of the steps match the spacing of the grooves in the fittings.

TESTS

The plan called for testing 27 specimens as follows:

- Short term axial tests with specimens conditioned and tested as follows:

Laboratory conditions	(70°F 50% humidity) 8 specimens
Hot and humid	(140°F 100% humidity) 4 specimens

  Cyclic loading, 15 specimens.

  The purpose of these cyclic tests is to establish an S-n curve for the bonded joints, that is the relation between load level and number of cycles to failure. The specimens are subjected to cyclic axial tension loads, and for a given load amplitude the number of cycles to failure is counted. SGH will coordinate with SAO on the specification of test parameters to be used and validate whether this method can be used in place of sustained load testing.

Since we received only 23 specimens, we decided, in consultation with SAO, to eliminate the "hot and humid" tests.

The results of the short term axial tests are shown in Table 1. In the specimens with the lowest failure loads the failure was in the adhesion to the metal. The appearance of the failure surfaces are described in the table and shown in the photographs. (In two of the specimens the studs broke, and the load recorded is the stud failure load)

Based on the results of the above 8 tests, the load level of the first cyclic tests were set at 50 kN (11,240 lbs), the highest level at which one would not expect failures at the first cycle. The other two load levels were set at 40 kN (8,992 lb), and 30 kN (6,744 lb). The results of the cyclic tests are shown in Table 2. The tests were delayed by repeated fatigue failure of the high strength studs until the test fixture was modified so that the studs were preloaded so that the stress level in the studs remained near constant.

In view of the scatter in the results at the 50 kN and 40 kN tests, and after the specimens at 30 kN had sustained a large number of cycles without any failures, the cyclic testing was stopped, and the specimens which had survived the cyclic loading were subjected to short term axial tests to determine if the cyclic loading had reduced their strength. The results of those tests are shown in Table 3, and photographs show the failed surfaces.

The S-n plot (load vs cycles) of the cyclic loading results is shown in Figure 1, a semi-log plot. The plot shows the number of cycles each specimen was subjected to, and whether or not it failed.

DISCUSSION

The results in Table 1 show that the standard deviation is 14.5 percent of the mean, a considerable reduction from the 23 percent for the Type -5 specimens referred to above and the prior Type -25 specimens, In all specimens the failure of adhesion in tension failed at the metal surface. For the specimens with the lowest strengths, e.g. 25-l 1 and 25-23, the adhesion in shear failed at the metal surface. In the specimens with higher strengths, e.g. 25-6 and 25-33, in the area in shear the failure was through the CFRP.

Similarly, in the specimens that failed under cyclic testing the failures were in the adhesion to the metal. The results for short term axial tests for the specimens that survived the cyclic loading, Table 3, compared to those for specimens not subjected to cyclic loading, Table 1, show no reduction in strength. The mean is the same and the standard deviation reduced. One, specimen 25-34, failed at a low load, 51.94 kN (11,677 lb) with a split tube. Of the 8 remaining specimens the lowest failure load was 65.79 kN (14,790 lb), and 4 specimens failed by stud break. Thus the cyclic loading eliminated the specimens with weak adhesion, but did not cause a noticeable reduction of the strength of the other specimens. This is similar to cases in which fatigue failure is initiated by crack growth; the crack will grow only if it is larger than some initial size.

The studs used to apply tension to the specimens are cut from high strength bolts of the size corresponding to the tapped hole in the end fittings. For the Type -25 specimens that is an Ml 0x1.5 bolt, and high strength bolts of this size have a minimum ultimate strength of 70 kN. Since drilling larger holes and retapping the end fittings might have damaged the adhesive bond, it was not practical to use larger bolts. Thus, when specimens failed by stud break above 70 kN the load was recorded as the failure load, it being a lower bound of the strength of the specimen.

Examination of the failure surfaces in the 17 failed specimens shows that the adhesion in tension failed in nearly all cases in adhesion to the metal. Of the area in shear, the specimens fall into two categories, 8 in Category A, and 15 in Category B. Category A those which fail by failure of adhesion at the metal surface and Category B those which do not fail by adhesion to the metal. In all cases the lower strength specimens are in Category A, the ones with failure of adhesion to the metal. Typically in bonded joints such differences are due to, deviations in following surface preparation and bonding procedures.

Since none of the 5 specimens tested at the cyclic load of 30 kN failed by adhesion to metal in the subsequent short term test, there is no data as to the number of cycles a specimen of Category A would sustain at the 30 kN level.

CONCLUSION ,

The strength of bonded joints with good adhesion to the metal, such as Category B specimens, is consistently in the 70 kN (15,700 lb) range for short duration loads, and does not degrade due to cyclic loads at lower levels.

There were no reported differences in the preparation by NYTEX of the joints that failed in adhesion to the metal at lower loads. Based on experience, the differences were probably due to deviations in surface preparation. The manufacturing procedures and quality controls must address the issue of very strict adherence to the specified procedures.

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Table 1 Results of short term axial load tests

Specimen	Load kN	lbs	Failure mode Adhesive in Shear	Failure mode Adhesive in Tension
25-27	75.98	17,080	Stud Break	
25-33	72.45	16,287	100% in CFRP	25% CFRP;75% adh to metal
25-7	66.25	14,893	75% CFRP; 25% adh to metal	adhesion to metal
25-13	77.36	17,391	100% CFRP	adhesion to metal
25-8	81.36	18,290	Stud Break	
25-23	60.93	13,697	5% CFRP; 95% adh to metal	adhesion to metal
25-6	75.83	17,047	100% CFRP;	25% CFRP;75% adh to metal
25-11	50.79	11,418	100% adhesion to metal	adhesion to metal
Mean	70.12	15,763		
Min	50.79	11,418		
Max	81.36	18,290		
n	8	8		
Std Dev.	10.17	2,287		

Table 2 **Results** of cyclic load tests

Cyclic loading in tension from 4kN to 50kN (899 to 11,240 lbs) - cycle time 25 seconds

Specimen	Cycles	Comment	Failure mode Adhesive in Shear	Failure mode Adhesive in Tension
25-2	108		15% CFRP;85% adh	adhesion to metal
25-l 9	760		adhesion to CFRP	adhesion to metal
25-l 0	174		adhesion to metal	adhesion to metal
25-30	2725	stud broke at 964 cycles, test retsarted stud broke again **after** 1761 more cycles		
25-3	3372	stud broke at 2619 cycles, test retsarted stud broke again after 753 more cycles		

Cyclic loading 4kN to 40kN (899 to 8,992 lbs) - cycle time 5 seconds

Specimen	Cycles	Comment	Failure mode Adhesive in Shear	Failure mode Adhesive in Tension
25-9	17,777	Failed	75% adhesion to metal	adhesion to metal
25-25	107,372	Failed	75%adhesion to metal	adhesion to metal
25-26	107,200	Not failed		
25-28	9,498	Failed	100% adhesion to metal	adhesion to metal
25-29	103,730	Not failed		

Cyclic loading 4kN to 30kN (899 to 6,744 lbs)

Specimen	Cycles	Comment	
25-4	4,000,000	Not failed	Cycled at 1 Hz for 1 st 600,000 cycles then at 5Hz
25-18	4,000,000	Not failed	Cycled at 1 Hz for 1st 600,000 cycles then at 5Hz
25-24	600,000	Not failed	Cycled at 1 Hz
25-31	600,000	Not failed	Cycled at 1 Hz
25-34	600,000	Not failed	Cycled at 1 Hz

Table 3 Short term test to failure of samples that had survived cyclic testing

Specimen	Load kN	lbs	Failure mode Adhesive in Shear	Failure mode Adhesive in Tension
25-24	69.22	15,561	100% CFRP	adhesion to metal
25-31	65.79	14,790	100% CFRP	adhesion to metal
25-34	51.94	11,676	100% CFRP, tube split	adhesion to metal
25-4	70.70	15,893	Stud break	
25-l 8	70.25	15,792	Stud break	
25-26	72.86	16,379	Stud break	
25-29	69.94	15,723	100% CFRP	25% CFRP;75% adh to metal
25-3	72.29	16,251	75% adh. to CFRP25 % to metal	98% adh to metal 2 % to CFRP
25-30	, 74.5	16,748	Stud break	
Mean	68.61	15,424		
Min	51.94	11,676		
Max	74.50	16,748		
n	9	9		
Std Dev	6.72	1,511		

Figure 1. S-n plot