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Report GDCA-DBG-71-003

FLEXURE FATIGUE TESTS OF
Ti-5Al-2.5Sn AT -423°F

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Prepared by

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Convair Aerospace Work Order No. 171-7000-030
Aerojet Nuclear Systems Company, P. O. No. N-900101

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INTRODUCTION

This report covers the testing performed under Purchase Order No. N-900101 for Aerojet Nuclear Systems Company. The testing was conducted at Convair Aerospace's Site B under the direction of Mr. B. Ganue. Dr. N. R. Adsit, of the Materials Research Group, had overall cognizance of the work.

MATERIALS

The material for this program was Titanium-5% Al, 2.5% Sn ELI grade furnished by Aerojet. The specimens were flexure fatigue test specimens, and were machined by the supplier according to Aerojet Drawing No. 1137254.

Specimens were cut from two different forgings and were numbered in the following manner:

	<u>X</u>	<u>Y</u>	<u>Z</u>
	(Wyman Gordon Forming		-
X	(		
	(Carlton Forming		C
	(Radial Direction		R
Y	(		
	(Tangential Direction		T
Z	(Serial number of specimen		1-15

The tests were sequential numbered, and the specimen identification maintained at all times.

TEST APPARATUS AND PROCEDURE

The testing on this program was carried out in a BLH SF1-U fatigue testing machine. The specimen was installed in a special cryostat mounted on the machine, as shown in Figure 1. The cryostat was fitted with a double seal on the bottom, and the space between the seals purged with He gas so that the loading rod would not ice up and cause errors in the load.

The machine was installed in its test position and tuned according to the manufacturer's instructions. No static load was used during testing; only dynamic load. To ascertain that the bending beam formula gave the correct stresses on the test specimens, the first sample was strain gaged. This specimen was calibrated using the bending fixture that was later installed in the LH_2 cryostat. The specimen was then installed in the fatigue machine and loaded statically. This check assured the investigators that the calculated stresses were equal to the actual stresses.

The first specimen tested failed because of fretting damage at the point of contact with the fixture. To prevent this type of failure, two actions were taken. First, the specimen was coated with a thin layer of zinc chromate; second, the fixture itself was coated with a tough layer of Teflon. These actions prevented metal-to-metal contact, and no further fretting damage was observed. Some failures were observed at the bolt holes because of two factors. First, the specimen rocked at the large (fixed end); second, because of the tendency to rock, the Teflon coating was extruded and slightly increased the amount of rocking. Periodically, the Teflon was stripped off and a new flat smooth layer was applied.

The procedure for installing specimens was as follows: the specimen was secured to the fixture, as shown in Figure 2. The load was applied through a rod coming through the bottom of the cryostat. To insure that no static preload was applied, the system had a link which was removable. (This link also served to insure that no lateral motion was transmitted to the rod through the seals.) The bottom bolt in the link was left out, as shown in Figure 3, while the specimen was installed. The loading rod was then positioned so that the bolt slipped into position and did not cause a static load. The bolt had a positive locking mechanism to keep it in place during testing. After the specimen was secured, the top lid was installed, the chamber was purged with helium gas, and was finally filled with liquid hydrogen. A thermocouple was installed on top of the test fixture to measure the temperature (-423°F), and the specimen was submerged in the liquid at all times during test insuring a test temperature of -423°F . The calculated load was set on the dynamic scale and the machine was turned on, brought up to speed, and allowed to run. The test was terminated at failure, or 2,000,000 cycles (with some exceptions noted later), whichever came first. At the request of the contract monitor, one specimen was notched with a fine scribe line across the surface of the specimen. This was accomplished by using a hand-held diamond tool. The specimen was then tested the same as the other specimens in this program.

RESULTS

The results of the tests performed during this program are given in Table I. The data has been tabulated by the material supplier, and stress levels to facilitate reading. Figures 4 and 5 show the broken specimens.

TABLE I
TEST RESULTS

<u>Specimen No.</u>	<u>Max. Stress</u>	<u>Cycles to Failure x 10³ Cycles</u>	<u>Notes</u>
CT-12	90 KSI ↓	210	*
CT-7		164	
CR8		138	
CR11		142	*
T-14		64	
R-11		40	
R-5		37	
R-9		17	
CR-5	80 KSI ↓	137	*
CT-6		78	*
CT-5		162	*
CT-2	72 KSI ↓	327	
CT-3		440	
CR4		1,137	
CT9		449	
CR-1		353	
R4		84	
R3		75	
T11		67	
T-16		81	
R3		61	
R2		61	
CT-10	60 KSI ↓	1,329	
CR10		2,000+	+
CR7		408	
CR6		112	*
CT11		1,232	*
CT14		2,020+	+
CR3		229	
CR9		6,340	*
CR2		319	
T-17		201	
T-13		189	
R-14		128	
R10		95	*
R1		106	

TABLE I (Continued)

<u>Specimen No.</u>	<u>Max. Stress</u>	<u>Cycles to Failure x 10³ Cycles</u>	<u>Notes</u>
R6	40 KSI	390	
R8		635	
R12		302	
T15		1,042	
T9		541	
CR4		2,000+	+
CT8		10,000+	+
T-10	30 KSI	2,000+	+
R-7		2,000+	+
T-12		1,394	
T-7		6,949	

* Broke at bolt line

+ No failure

TABLE II

Statistical Data for Ti-5Al-2.5 Sn Tested at -423° F

<u>Forging</u>	<u>Stress Level KSI</u>	<u>No. of Spec.</u>	<u>$\bar{y}$ $\times 10^3$ Cycles</u>	<u>S $\times 10^3$ Cycles</u>	<u>k_{99}</u>	<u>$\bar{y} - k_{99} S$</u>
Carlton	90	4	164	33	2.601	78
	72	5	563	334	2.526	0
	60	7	1424	2,306	2.455	0
Wyman-Gordon	90	4	40	19.3	2.601	0
	72	6	71	10	2.483	46
	60	4	156	45	2.601	39
	40	5	582	288	2.526	0

$\bar{y}$ - Mean

S - Standard deviation

k_{99} - k factor for 99% survival, 50% confidence level

STATISTICAL TREATMENT OF THE DATA

Test schemes for fatigue are presented in ASTM STP 91-A, "A Guide for Fatigue Testing and the Statistical Analysis of Fatigue Data." For reasons of economy and time, a more elaborate test program was not practical for the present study. In fact, fatigue testing at -423°F is quite uncommon, and comparative data is unknown. It has been the experience of General Dynamics, Convair Aerospace, that materials do not behave in textbook manner when immersed in liquid hydrogen. Some of the techniques of STP 91-A were applied to the present program. As in all fatigue testing, a relatively large amount of scatter was observed.

The statistical approaches of STP 91-A were used to try to provide 99% probability curves for the tests performed. The results were not entirely satisfactory. The combination of large scatter and insufficient sampling in most cases invalidated 99% probability limits.

For the Carlton forgings (Figure 4), some estimates of the 99% survival (probability) limits are shown. The line plotted is the normal 50% survival or median curve. At a stress level of 90 KSI, the lower limit 99% survival point is shown. That is, at a confidence level of .5, 99% of all test specimens taken from the population will survive 78,000 cycles. At the other end of the curve, the statistical limits are more difficult to predict. For example, one might say that the 50% survival point at 60 KSI is 1.28 million cycles. By extrapolation, the 50% survival limit at 2 million cycles is 58 KSI.

In order to obtain a lowest ranking point that corresponds to the 99% survival limit, it is necessary to test approximately 32 specimens at a given stress level. The 99% survival limit shown was obtained by determination of the standard deviation of the sample (S). The lower limit is determined by the equation $\bar{y} - k_{99}S^*$, where $\bar{y}$ is the sample mean, and k is the one-sided tolerance factor (a function of confidence level, probability, or survival level, and the number of specimens tested). These values are tabulated in Table II. In the case of the 60 KSI stress level, the standard deviation of the sample is simply too large to obtain the required lower limit. In addition two of the tests were discontinued after 2 million cycles, as originally agreed upon. The 50% survival curve based on the median results in a cyclic life of 1.28 million cycles, while the mean at the same stress level is 1.81 million cycles. Two test results were discarded because of premature equipment failures. Two specimens tested at 40 KSI did not fail in 2 million and 10 million cycles, respectively, which provides reassurance that the fatigue strength at two million cycles falls between 40 and 60 KSI.

An attempt was made to determine 99% survival limits for the Wyman-Gordon forgings also (Figure 5). In like manner, few of the results were meaningful. The best results were obtained at 70 KSI where good grouping was obtained resulting in a small standard deviation. The only other meaningful statistic occurred at 60 KSI, where a smaller sample and larger deviation results in a 99% limit at a lower cyclic life than that of the 70 KSI limit.

Again, the 50% survival curve (median) is plotted. In this case, the fatigue strength at 2 million cycles appears at a higher stress level than two of the tests specimens survived, as well as two other tests which did not fail at 2 million cycles. Had the test that failed at about 6 million cycles been terminated at 2 million, the median curve would have dropped below 20 KSI.

COMPARISON OF RESULTS

If one were to judge the results of this test program by comparing scatter data, the Carlton forging would be suspect, particularly at 60 KSI where enormous scatter was experienced. The 50% survival curves for both forgings are shown in Figure 6. In this context, the Carlton forging shows a marked advantage. A point-by-point examination shows the following

- 1) Despite the scatter at 60 KSI, all test points of the Carlton forgings fall to the right of the Wyman Gordon 50% survival curve. In fact, the lowest point on the Carlton curve is higher than the highest point on the Wyman Gordon curve. Statistically speaking, however, the 99% survival curve of Wyman Gordon at 60 KSI is 3.9×10^4 cycles, which exceeds that of Carlton (zero cycles).
- 2) It is relatively certain that the fatigue strength of the Carlton forging exceeds 40 KSI.

Less certain is the fatigue strength of the Wyman Gordon forging at 2 million cycles of approximately 20 KSI.

Figure 1. Fatigue Test Machine with LH_2 Chamber Installed

(Photo No. 115273B)

Figure 2. Titanium Flexure Fatigue Specimen Installed in LH_2 Cryostat
(Photo No. 115270B)

Figure 3. Test Specimen With Loading Linkage

(Photo No. 115271B)

STRESS, KSI

Figure 4. S-N Curve for the Carlton Forging Ti-5Al-2.5Sn Tested at -423°F

Figure 5. S-N Curve for the Wyman-Gordon Forging Ti-5Al-2.5Sn Tested at -423°F

Figure 6. 50% Survival Curves for 2 Forgings of Ti-6Al-2.5Sn Tested at -423°F