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FINAL REPORT

THE FATIGUE PROPERTIES OF FLAME-PLATED HEAT-TREATED SAE 4130 STEEL

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INTRODUCTION

The purpose of this investigation was to determine the effect of Flame-Plating on the fatigue properties of a heat-treated SAE 4130 steel. Replicate rotating-beam fatigue tests were made on Flame-Plated test specimens and the results compared with the results obtained on unplated specimens of the same type of steel.

SUMMARY

Flame-Plating decreases the fatigue life, which is the number of cycles of stress to cause failure at a given stress; and the endurance limit, defined as the maximum stress which will not cause failure in 10^7 cycles of stress.

The decrease in fatigue life of the Flame-Plated steel as compared to the unplated steel varies from 15 percent at the shorter cycles to failure to 25 percent at the lower stress levels.

The apparent decrease in endurance limit is approximately 19 percent of the endurance limit of the unplated steel.

The variance of the results at any given stress level on the plated samples is less than the variance reported for unplated steels.

The standard deviation (2-sigma limits) of the fatigue life of the Flame-Plated specimens has been determined, but the mean and standard deviation of the endurance limit have not been determined.

EXPERIMENTAL PROCEDURE

Test Material

Bars of aircraft-quality 1/2-inch-round SAE 4130 steel, all from the same heat, were used in the experimental work of this investigation. The original stock was cut into 12-inch lengths and heat-treated by quenching from 1550°F into water and then tempering for 1 hour at 800°F. This treatment resulted in a hardness of RC 40-41, a proportional limit of 165,000 psi, an ultimate strength of 185,000 psi, an elongation in 2 inches of 10 percent, and a reduction in area of 60 percent. These results were obtained from two previous heats of this same material which were given this treatment. Each bar in the heat used in this investigation was checked for hardness after heat treatment; the results fell in the same hardness range, and the steel will have, therefore, the same general mechanical properties listed above.

Test-Specimen Preparation

The heat-treated 12-inch lengths of steel were cut into 4-inch lengths prior to machining to the final test-specimen specifications. Figure 1 is a sketch of the test specimen that was used in this work. It

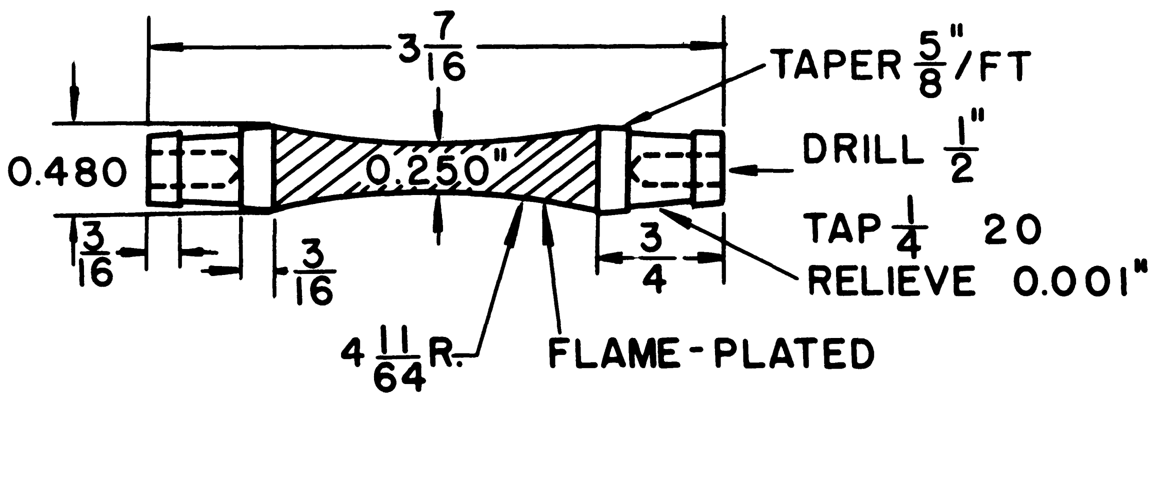

Fig. 1. Fatigue-Test Specimen Specification.

generally follows the suggested standard test specimen to be used in R. R. Moore fatigue testing machines, but the design has been modified slightly to facilitate preparation. Test results obtained with this type of specimen have been shown to be comparable to those obtained with the more usual type.[1]

The fatigue specimens were prepared by the N. A. Woodworth Company of Detroit to the specifications of Fig. 1 and then forwarded to the Linde Air Products Company for Flame-Plating. Prior to Flame-Plating the specimens were grit-blasted with 40 mesh alundum. After Flame-Plating (the area plated is shown in Fig. 1), the specimens were returned to the Woodworth Company for finish grinding and then they were shipped to the University for testing.

Profilometer measurements made on several fractured specimens showed that the average surface finish was of the order of 8 microinches. The readings on the group tested ranged from a high of 11 to a low of 6.

Metallographic measurements showed the finished, ground Flame-Plate to be quite uniform in thickness and of the order of 0.0025 inch.

In all phases of specimen preparation, care was taken to insure identical treatment in order to minimize any variations that might be introduced in the machining, Flame-Plating, or finish grinding.

Fatigue Testing

Standard R. R. Moore rotating-beam fatigue machines were used to obtain data on the fatigue properties. The speed of testing was maintained at 1800 rpm during all testing and two identical testing machines were used in obtaining the data. Replicate tests were made on both machines, and the results showed that there was no significant difference in performance between the two units. The maximum probable error in stress on any given specimen was of the order of ± 200 psi. The load to be applied was calculated by the usual formula, using the O. D. of the finished Flame-Plated specimen.

The usual operating procedure, of selecting successively lower values of stress and determining the number of cycles of stress to failure until a stress level is reached at which the specimen does not fracture in 10^7 cycles of stress, was followed. Because of the known statistical nature of any fatigue failure, replicate tests were made at each of eight stress levels in order to determine the mean value and the standard deviation.

If a material shows a fatigue limit, i.e. some stress which can be applied for an infinite period with no failure, the above-described procedure will pick up such a limit, and by successive raising and lowering

TABLE I

Fatigue Test Data on Flame-Plated
Heat-Treated SAE 4130 Steel

Stress, psi	1000 Cycles to Failure	Mean, Cycles to Failure	1-Sigma Limits
100,000	52		
	28		
	24		
	24		
	29		39,400
	28	29,600	22,300
90,000	45		
	79		
	43		
	52		
	41		62,600
	42	48,900	38,100
80,000	92		
	61		
	62		
	78		
	51		94,100
	102	72,100	55,000
75,000	119		
	167		
	188		
	83		
	168		179,000
	101	132,000	96,800
72,500	138		
	90		
	109		
	66		
	145		145,000
	10,264*	105,000	76,500
70,000	86		
	208		
	137		
	102		
	10,161*		184,000
	10,484*	125,000	85,500
65,000	2,376		
	254		
60,000	10,093*		
	10,000*		

*Did not fail.

of the stress about this limit it can be determined with reasonable accuracy. In the present investigation there were insufficient specimens available to follow this technique; as a consequence, the fatigue limit has not been too accurately defined.

Table I lists the experimental data, the mean values, and the standard deviations for the Flame-Plated specimens. Table II shows the data for the unplated specimens. The log-stress versus log-cycles-to-failure

TABLE II

Fatigue-Test Data on Heat-
Treated SAE 4130 Steel

Heat A		Heat B	
Stress, psi	1000 Cycles to Failure	Stress, psi	1000 Cycles to Failure
119,000	20	134,000	22
108,200	32	131,000	37
95,000	174	108,000	56
90,000	222	95,000	131
86,200	402	89,800	272
84,400	1216	88,500	184
84,200	2733	87,200	132
83,200	10126*	84,600	569
82,700	10311*	82,000	1672
80,400	10178	80,050	12706*
		79,400	12500*
		77,450	10500*
		74,200	11450*

*Did not fail.

graph of these data, the S-N plot, is given in Fig. 2. Also shown on this figure are the fatigue data taken on this same type of steel given the same treatment but not Flame-Plated. These data are taken from previous work of the author and were not part of the program being reported. The data on the unplated samples were not taken in such a manner that the means and deviations could be determined. As a consequence the lines drawn through these date are merely estimates of the mean values in order to draw comparisons between these samples and the Flame-Plated samples.

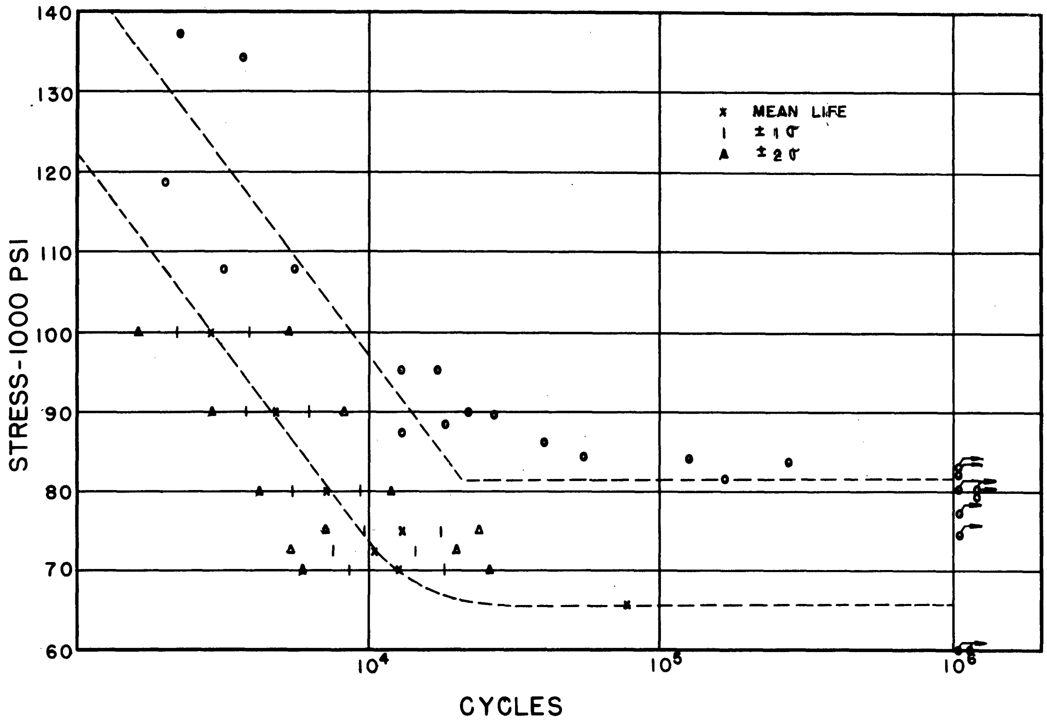

Fig. 2. S-N Plots of Unplated and Flame-Plated Test Results. Lower Curve is Flame-Plated Results. Limits Shown are 1-Sigma.

In none of the failures was spalling of the Flame-Plating evident prior to failure and only slight evidence of spalling occurred on actual failure.

Table III is a comparison of the fatigue life of the Flame-Plated and unplated specimens based on the data of Fig. 2.

TABLE III

Estimated Fatigue Life of
Flame-Plated and Unplated SAE 4130 Steel

Cycles to Failure	Stress, psi Flame-Plated	Stress, psi Unplated
10,000	123,000	145,000
30,000	98,000	123,000
100,000	73,500	97,000
200,000	67,000	83,000
10^6	65,500	81,500
10^7	65,500	81,500

DISCUSSION

The statistical treatment of fatigue data is a relatively new development and is not too well-known except to those following the work in this field closely. In order to assist in a more complete understanding of the results of the present investigation, the use of statistical methods in fatigue investigations will be described briefly, although there are more comprehensive treatments to be found in recent literature.[2,3,4]

In any type of measurement there is some variance or scatter that occurs in making the measurement. In fatigue testing a scatter can be expected in the cycles-to-failure data when testing at a fixed stress level, or there can be a scatter in the stress required for fracture in a fixed number of cycles of stress. The only way to obtain a measure of the scatter is by making replicate tests. From such data a mean value can be obtained and the scatter described by determining the standard deviation. A more common term used to describe the standard deviation of a series of measurements is the term "sigma limits". The 1-sigma limits define, on the basis of the variance of the data, a range such that approximately 67 out of every 100 test points will fall within this range. The 2-sigma limits are such that 95 out of every 100 test points will fall within these limits. The greater the number of tests the more reliable is the mean and deviation. This means then that in place of the usual S-N plot of fatigue data an S-N-P plot should be constructed, where P is the probability of failure and can vary from 0 to 1, the mean value being P = 0.5. In order to estimate the mean value with reasonable accuracy, at least 6 and preferably 8 or 10 specimens should be tested at any given stress level. If an estimate requiring a P of 0.01 is required, the number of test specimens should be increased to 20.[2]

In the work being reported, some 6 specimens were tested at 6 stress levels and the mean values and standard deviations computed. As the fatigue or endurance limit, in this work 10^7 cycles of stress, is approached, some of the test specimens in a given group fracture, while others run out. There is no satisfactory method of treating statistically such a mixture of data other than to reject the run out data and base the mean and deviation on the specimens that failed. This results in a mean value which is lower than the true value and is probably as conservative a method as can be used to treat the data.

When data of this type are encountered, the use of a technique known as "staircase" testing is indicated. This involves varying the stress in the vicinity of the fatigue or endurance limit in order to determine the mean and standard deviation on the stress for a given number of cycles of stress, usually 10^7. A complete fatigue curve obtained by utilizing this technique is shown in Fig. 3. Unfortunately, because these statistical studies

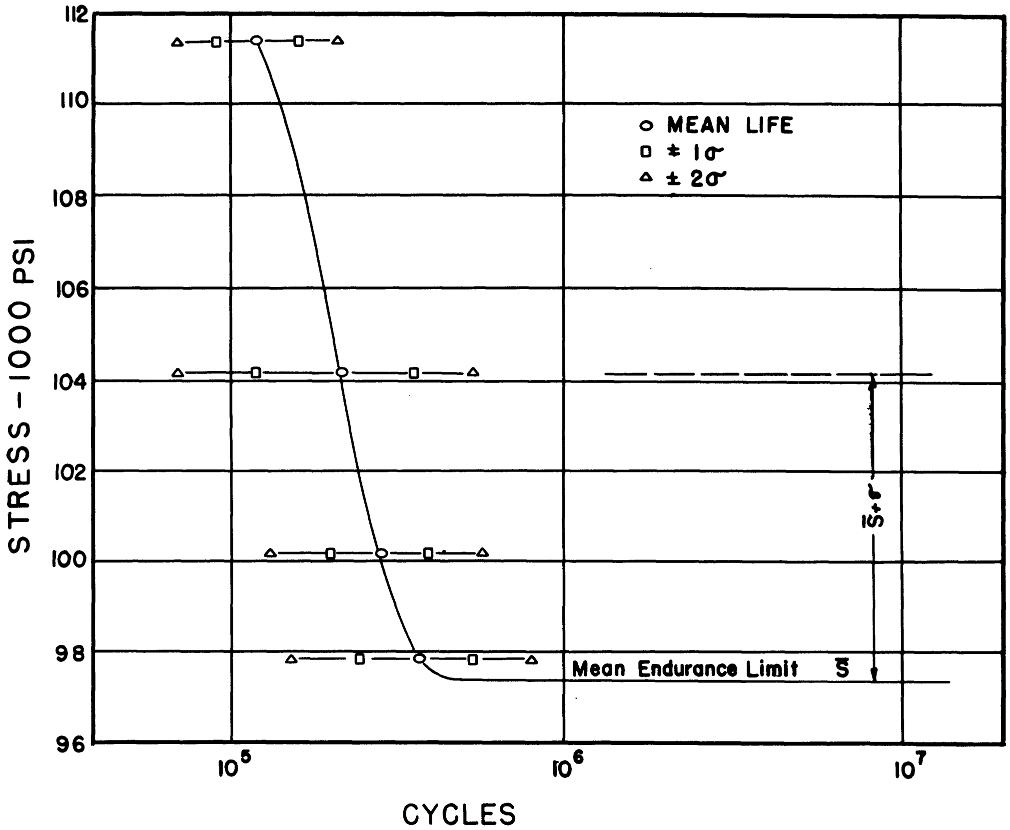

Fig. 3. S-N Plot, Statistically Determined, of SAE 4340 Steel, Quenched and Tempered (taken from ref. 3).

are relatively new, specific information on SAE 4130 steel treated as in this investigation is not available. Figure 3, however, is such a study on a quenched and tempered SAE 4340 steel and shows quite graphically the large deviations that do exist.

The present investigation has determined the fatigue life of the Flame-Plated steel with reasonable accuracy, but the endurance limit is not too well defined. The curve given for the unplated steel in Fig. 2 is at best a median value, since no statistical evaluation has been made. It can be seen, however, that if 2-sigma limits are placed on this median they would overlap the 2-sigma limits of the Flame-Plated steel, but it is also evident that a significant difference does exist between the means of the two groups.

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