NATIONAL BUREAU OF STANDARDS REPORT

9971

THE EFFECT OF CHROMIUM PLATING ON THE FATIGUE PROPERTIES OF TRANSFER PLATE SPECIMENS

To

Electrolytic Section
Bureau of Engraving and Printing
Washington, D.C.

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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Reactor Radiation—Linac Radiation—Applied Radiation—Nuclear Radiation.

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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NBS PROJECT 3120641

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THE EFFECT OF CHROMIUM PLATING ON THE FATIGUE PROPERTIES OF TRANSFER PLATE SPECIMENS

By

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The Effect of Chromium Plating on the Fatigue Properties of Transfer Plate Specimens

Tests were conducted on specimens from a stock transfer plate in order to determine the effect of chromium plating and the effect of baking subsequent to plating on the fatigue properties of the material. Tests were conducted in such a manner as to simulate the conditions under which plates have been failing at the Bureau of Engraving and Printing. Specimens in three conditions were tested in reversed bending:

1. Cyanided and hardened
2. Cyanided, hardened, and chromium plated
3. Cyanided, hardened, chromium plated, and baked

Definition of Terms:

S_A	Stress amplitude
S_M	Mean stress
N_F	Cycles to failure
S-N Plot	Semilog plot of stress amplitude of testing vs. cycles to failure.
Ksi	Thousand pounds per square inch.

Specimens and Specimen Preparation: Specimens (Fig. 1) were machined from a stock transfer plate furnished by the Bureau of Engraving and Printing. The thickness of the as-received plate was reduced to 0.180 in. by planing and grinding material from the back. Cuts were made parallel to the long edge of the plate. Specimens were machined from the plate with the long dimension of the specimen parallel to the long dimension of the plate. The width of the minimum section was 0.390 ± .002 in. at this stage of preparation.

Specimens were then sent to the Bureau of Engraving and Printing where they were divided into two groups and treated as follows:

1. Group 1: Cyanided, hardened and tempered.
2. Group 2a: Cyanided, hardened, tempered and chromium plated on the front face (plating approximately 0.00025 to 0.0003 in. thick).

Group 2b: Cyanided, hardened, tempered and chromium plated on the front face and subsequently baked at NBS.

The specimens were then returned to NBS where 0.007 ± .001 in. was removed from each side of the reduced section by grinding with the plane of the grinding wheel parallel to that of the specimen. This was done in order to remove any chromium from the specimen sides that may have been plated there. The final width of the minimum section was then nominally 0.376 in.

It would be expected that a considerable amount of hydrogen would diffuse into the basis material during the plating operation. Hence, approximately one-half of the chromium plated specimens were baked at 400°F for four hours before being tested in fatigue in order to reduce the hydrogen content. It is probable that the baking procedure changed the residual stress pattern, particularly near the chromium-basis material interface.

Fatigue Tests: The specimens were fatigue tested in reversed bending. About half of the specimens in each condition were tested with zero mean stress. The rest were tested with the mean stress tensile in the back (mean stress approximately one-half stress amplitude of testing) since failures start on the back.

Results and Discussion: The results from the fatigue tests are given in tables and are shown on S-N plots. An arrow drawn next to a data point on an S-N plot or next to an N_F value in a table indicates a runout. This means that the specimen yielding this data did not fail at that particular combination of stress amplitude and testing cycles. In order to obtain maximum data from a limited number of specimens, in most cases, a specimen which ran out at a given stress amplitude was tested at a higher stress amplitude.

The fatigue test results for cyanide hardened, but unplated , specimens are given in Table 1 and in Fig. 2. In the finite life portion of the S-N plot, the median fatigue strength of specimens tested at zero mean stress was greater than that for specimens tested at $S_M = S_A/2$ by from about six percent at $N_F = 9 \times 10^4$ cycles to about 21 percent at $N_F = 2 \times 10^4$ cycles. The 50 percent runout fatigue limit was approximately 11 percent greater for tests at $S_M = 0$. All but one of the cyanided specimens failed due to a fatigue crack which originated on the back of the specimen. In the one specimen in which failure started on the front ($S_M = 0$), there was a large surface pit at the crack origin. Specimens tested with mean stress tensile in the back would be expected to fail from the back. Specimens tested with zero mean stress failed from the back because of the poorer surface finish.

The fatigue test results for cyanided specimens plated on the front face with chromium, but not baked after plating, are given in Table 2 and in Fig. 3. In the finite life portion of the S-N curves, there is essentially no difference between results from tests at $S_M = 0$ and tests at $S_M = S_A/2$. The 50 percent runout fatigue limit results, however, exhibit about a 28 percent improvement for tests at $S_M = S_A/2$ when compared to tests at $S_M = 0$. As in the case of the unplated material, all specimens but one failed due to a fatigue crack originating at the back. It is surprising that tests at $S_M = S_A/2$ yielded the higher fatigue limit.

The fatigue limits for plated, but not baked, specimens are considerably lower than those for unplated specimens which would indicate that the plating operation has had a deleterious effect on the basis material, apparently in the form of hydrogen embrittlement. The average fatigue limit for both stress conditions is approximately 30 percent higher for unplated specimens than for plated specimens.

The fatigue test results for specimens which were cyanided, chromium plated on the front, and baked for four hours at 400°F are given in Table 3 and in Fig. 4. As with the unbaked specimens, there is little difference between results from tests at $S_M = 0$ and $S_M = S_A/2$ in the finite life region of the S-N plot. The 50 percent runout fatigue limit for tests conducted at $S_M = S_A/2$ is about 6 percent higher than that for tests at $S_M = 0$.

The baking procedure appears to have been very helpful in eliminating the effects of hydrogen embrittlement. The average fatigue limit for the two stressing conditions for baked specimens is approximately 29 percent higher than the average for unbaked, plated specimens, and only 9 percent lower than that for unplated specimens. The fatigue limit for baked specimens tested at $S_M = S_A/2$ is essentially the same as that for unplated specimens tested at $S_M = S_A/2$. Since all specimens tested at $S_M = S_A/2$ from both of these groups failed from the back, the basis material appears to have lost all evidence of hydrogen embrittlement during baking.

All baked specimens tested at $S_M = 0$ failed due to fatigue cracks originating in the plated front surface indicating that the plated surface is now more subject to fatigue failure than the back. This may be due in part, at least, to an unfavorable stress pattern induced in the material during plating and only partially relieved during baking.

<u>Conclusion</u>: The fatigue strength of this transfer plate was severely impaired during the chromium plating process by hydrogen embrittlement. Baking of the plated specimens at 400°F for four hours appears to have completely eliminated the effects of hydrogen embrittlement, at least in the back of the specimen, as is shown by the fatigue test results at $S_M = S_A/2$. Even after baking, the fatigue strength of the plated surface was poorer than that of the unplated surface. This may be due in part to an unfavorable stress pattern induced in the material during the plating process and incompletely relieved during baking.

Table 1 Fatigue Test Results for Cyanided, but Unplated Specimens

$S_M = 0$

S_A, Ksi	N_F, Cycles
100	20×10^3
90	136×10^3
	49×10^3
	34×10^3
	19×10^3
87.5	56×10^3
85	$1830 \times 10^3 \rightarrow$
	169×10^3
	68×10^3
	24×10^3
	19×10^3
80	$7405 \times 10^3 \rightarrow$
	$5757 \times 10^3 \rightarrow$
	$1262 \times 10^3 \rightarrow$
	70×10^3
	51×10^3

$S_M = S_A/2$

S_A, Ksi	N_F, Cycles
90	4×10^3
85	493×10^3
	21×10^3
	8×10^3
80	$7709 \times 10^3 \rightarrow$
	$2980 \times 10^3 \rightarrow$
	10×10^3
	8×10^3
	8×10^3

Table 1 Fatigue Test Results for Cyanided, but Unplated Specimens (Con't)

$$S_M = S_A/2$$

S_A, Ksi	N_F, Cycles
75	$7428 \times 10^3 \longrightarrow$
	$4402 \times 10^3 \longrightarrow$
	330×10^3
	135×10^3
	22×10^3
	11×10^3
70	$3106 \times 10^3 \longrightarrow$
	$3012 \times 10^3 \longrightarrow$
	$2607 \times 10^3 \longrightarrow$
65	$7869 \times 10^3 \longrightarrow$
60	$3358 \times 10^3 \longrightarrow$
	58×10^3
55	$4074 \times 10^3 \longrightarrow$
50	$3203 \times 10^3 \longrightarrow$

Table 2 Fatigue Test Results for Cyanided and Chromium Plated, but Unbaked Specimens

$S_M = 0$

S_A, Ksi	N_F, Cycles
80	52×10^3
	50×10^3
75	92×10^3
70	139×10^3
60	247×10^3
50	303×10^3
45	$2001 \times 10^3 \longrightarrow$

$S_M = S_A/2$

S_A, Ksi	N_F, Cycles
70	157×10^3
	31×10^3
65	$2017 \times 10^3 \longrightarrow$
60	$2000 \times 10^3 \longrightarrow$
	507×10^3
55	$2540 \times 10^3 \longrightarrow$
	80×10^3
50	$7016 \times 10^3 \longrightarrow$
	$2510 \times 10^3 \longrightarrow$

Table 3 Fatigue Test Results for Cyanided, Chromium Plated, and Baked Specimens

$S_M = 0$

S_A, Ksi	N_F, Cycles
80	119×10^3
75	$2576 \times 10^3 \longrightarrow$
	230×10^3
70	$2446 \times 10^3 \longrightarrow$
	$2241 \times 10^3 \longrightarrow$
	87×10^3
65	176×10^3
	166×10^3
60	$2700 \times 10^3 \longrightarrow$
55	$7239 \times 10^3 \longrightarrow$
	$2214 \times 10^3 \longrightarrow$

$S_M = S_A/2$

S_A, Ksi	N_F, Cycles
80	121×10^3
75	$2568 \times 10^3 \longrightarrow$
	46×10^3
	16×10^3
70	$2592 \times 10^3 \longrightarrow$
	94×10^3
65	$10074 \times 10^3 \longrightarrow$
	$2174 \times 10^3 \longrightarrow$

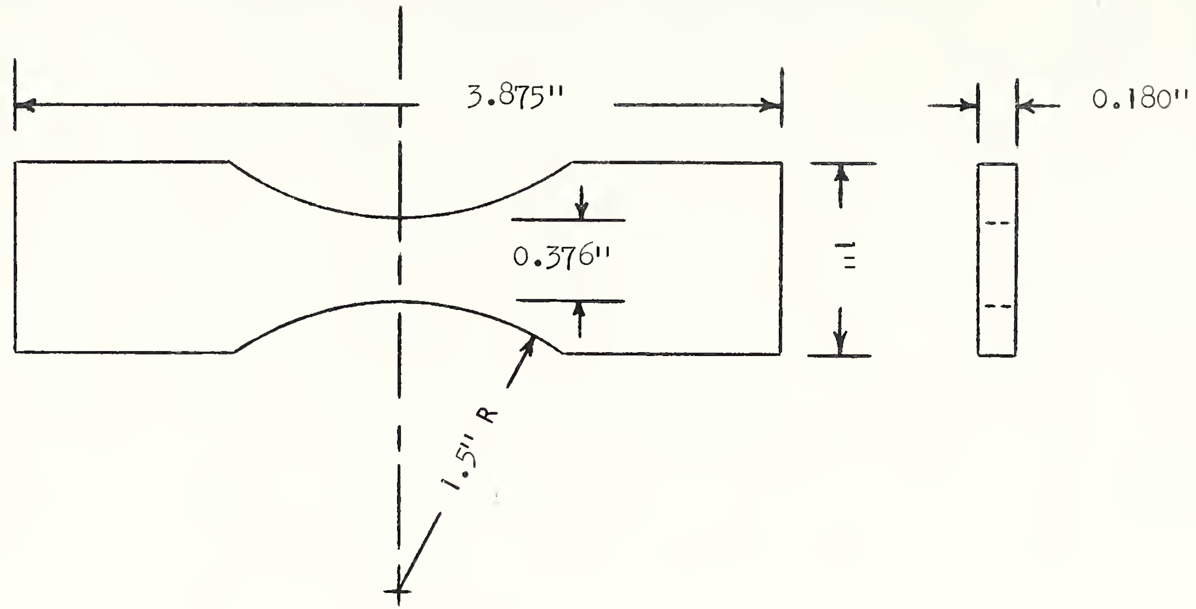

Fig. 1. Transfer plate fatigue specimen.

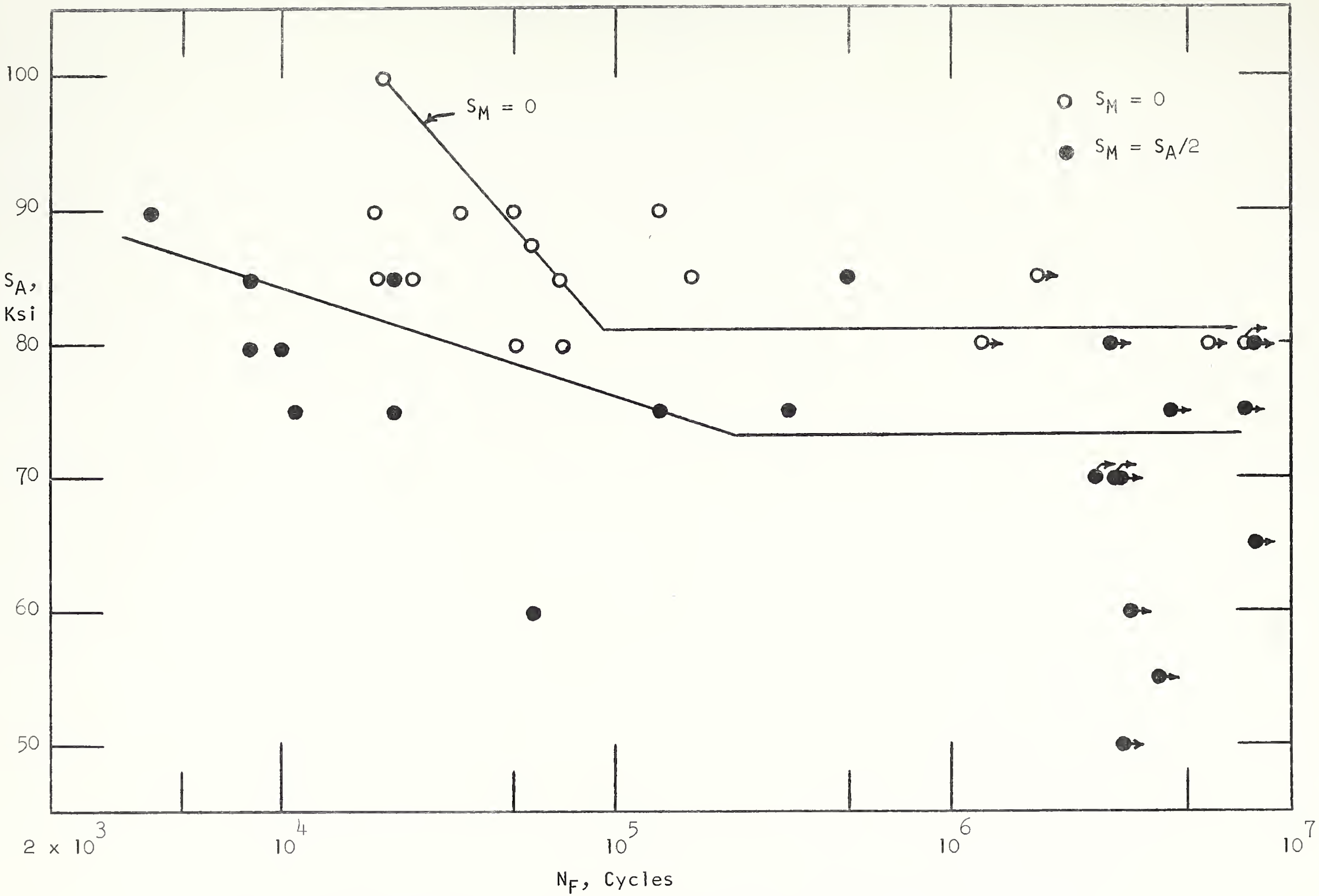

Fig. 2. Fatigue test results from cyanided, but unplated, transfer plate specimens.

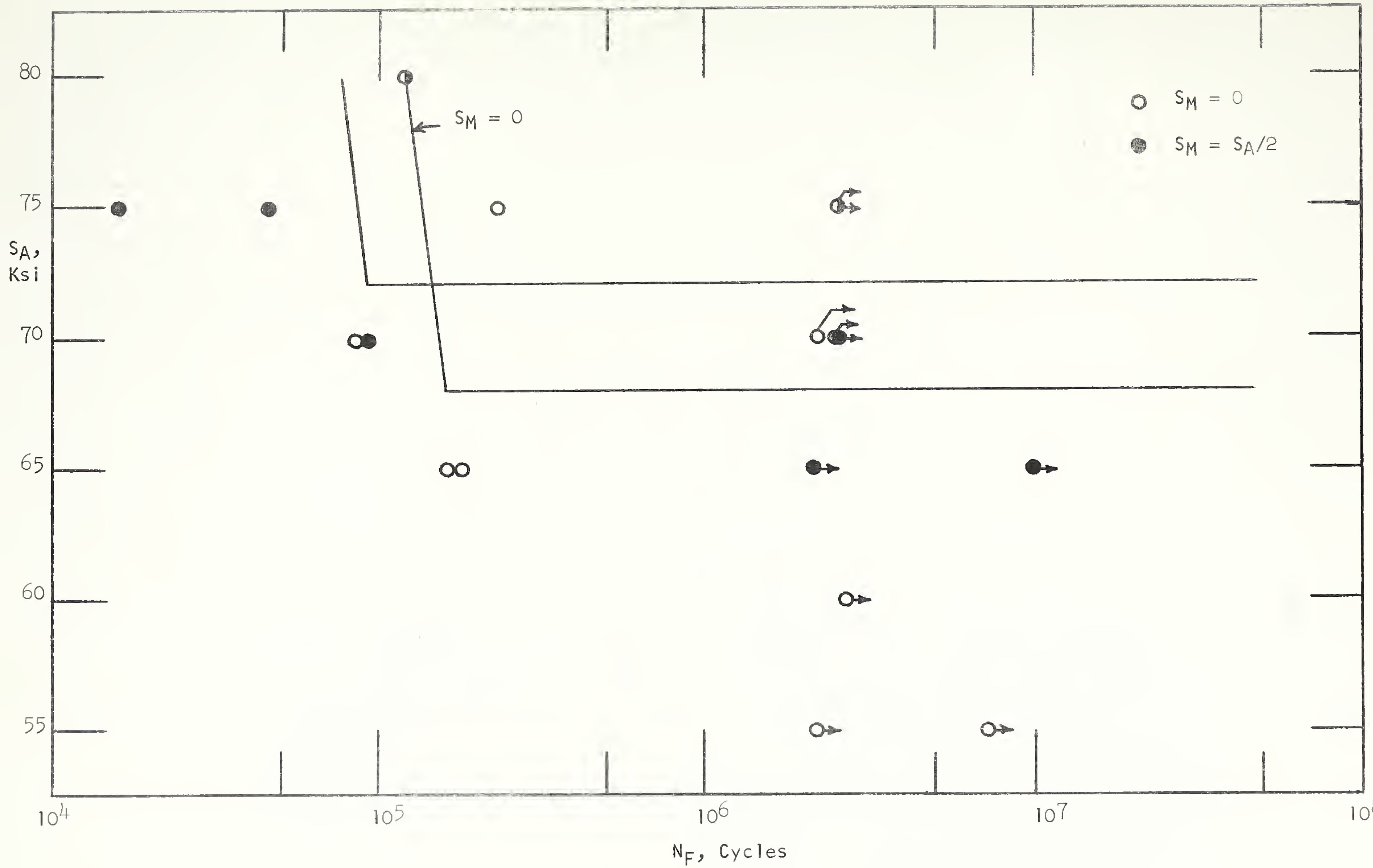

Fig. 3. Fatigue test results from cyanided and chromium plated, but not baked, transfer plate specimens.

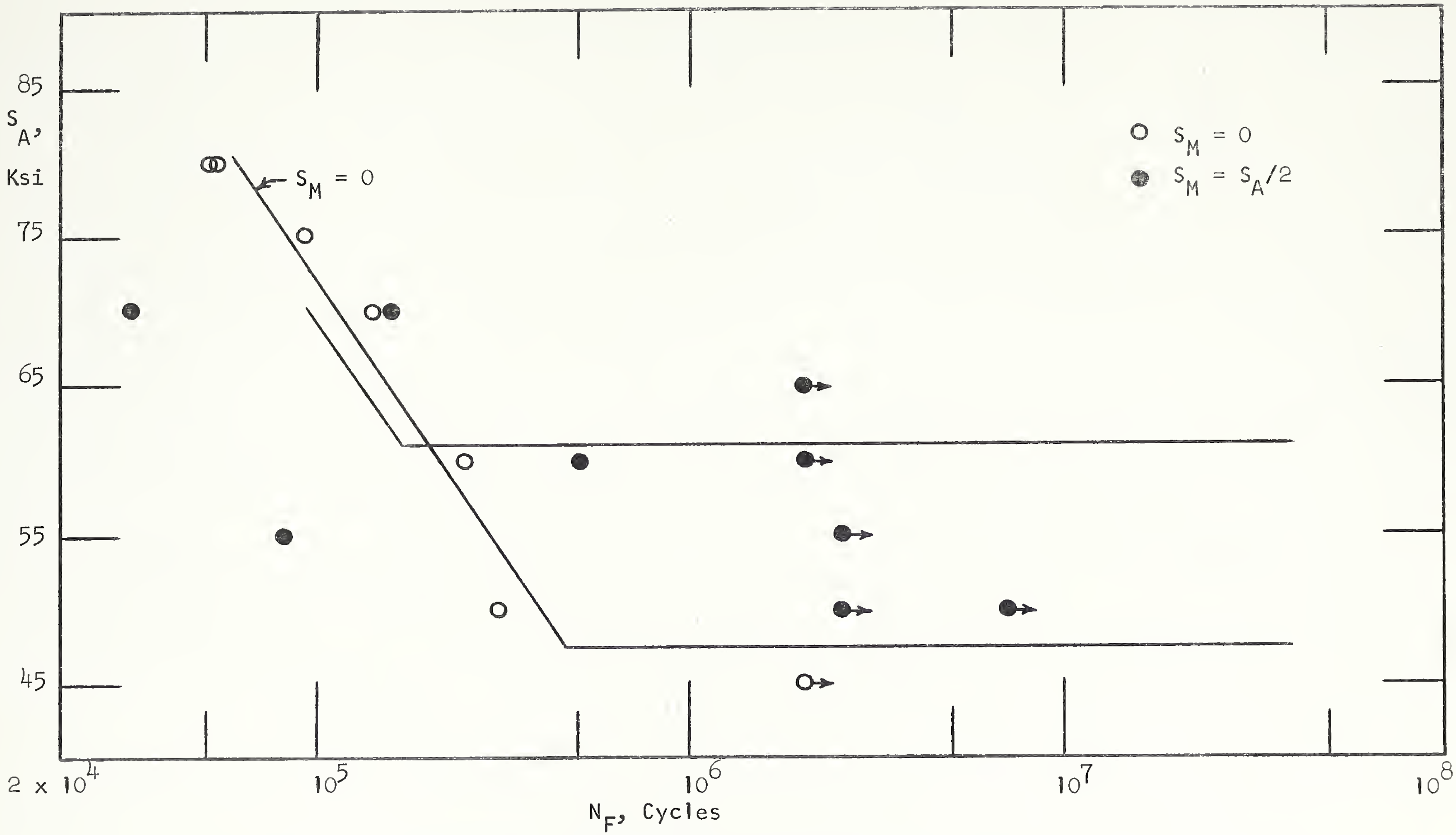

Fig. 4. Fatigue test results from cyanided, chromium plated, and baked transfer plate specimens.

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