RM E51D17

NACA RM E51D17

RESEARCH MEMORANDUM

EFFECT OF SURFACE FINISH ON FATIGUE PROPERTIES AT ELEVATED TEMPERATURES

I - LOW-CARBON N-155 WITH GRAIN SIZE OF A.S.T.M. 1

By Robert R. Ferguson

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

June 26, 1951

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF SURFACE FINISH ON FATIGUE PROPERTIES AT ELEVATED TEMPERATURES

I - LOW-CARBON N-155 WITH GRAIN SIZE OF A.S.T.M. 1

By Robert R. Ferguson

SUMMARY

The effect of three surface finishes of roughnesses 4 to 5, 20 to 25, and 70 to 80 microinches rms on the fatigue properties were determined for low-carbon N-155 alloy of grain size A.S.T.M. 1 at temperatures of 80°, 1000°, 1350°, and 1500° F. The fatigue properties for the various finishes differed appreciably at room temperature; however, after short periods at 1000° F and for all periods investigated at temperatures above 1000° F, specimens having different finishes had the same fatigue strength. It was concluded that the primary cause of the difference in room-temperature strength was due to compressive stresses set up in the surface and that at elevated temperatures these compressive stresses were relieved by annealing. Apparently, roughness alone did not significantly affect the fatigue strength of the material investigated.

INTRODUCTION

The room-temperature fatigue strength of engine components is influenced by the condition of the surface, which is often polished or shot-peened for improvement of fatigue properties. Polishing smoothes and possibly works and stresses the surface, which is reported in reference 1 where abrasive polished specimens are compared with electropolished specimens. Shot-peening cold-works and places compressive stresses in the surface (reference 2). The test results obtained on polished, shot-peened, and other finishes indicate that the smoothness of the surface, state of stress in the surface, and the amount of cold-work in the surface are the primary factors that affect the fatigue life of surfaces at room temperature. This investigation was undertaken to determine the effect of surface condition on the fatigue properties of N-155 at elevated temperatures.

MATERIAL

The material initially studied and reported herein was low-carbon N-155 hot-rolled bar stock supplied by the Haynes Stellite Company. The following information was supplied by the producer:

Chemical composition (percent by weight; all material from same heat). -

C	Si	N_2	P	S	W	Mn
0.15	0.99	0.14	0.025	0.009	2.46	1.42

Cb	Mo	Cr	Co	Ni	Fe
1.12	3.06	20.45	19.16	20.22	balance

Fabrication procedure. - The material was hot-rolled from a 6- by 6- by 40-inch ingot to a $2\frac{3}{4}$-inch square on a 24-inch mill and then to a 13/16-inch-diameter round on a 10-inch mill. The maximum reheat temperature was 2140° F and the minimum rolling temperature was 1800° F. After rolling, the bar stock was given a full anneal for 45 minutes at a temperature between 2100° and 2150° F.

Mechanical properties. - The mechanical properties reported for room temperature on 3/4-inch-diameter bars of low-carbon N-155 are:

Ultimate strength (lb/sq in.)	Yield strength (0.2 percent offset) (lb/sq in.)	Elongation in 1 inch (percent)
124,800	73,100	49.0
126,600	73,600	50.0

APPARATUS AND PROCEDURE

Method of heat treatment. - Bar stock in 5-inch lengths were heat-treated as follows: 1 hour at 2200° F, water-quenched; 16 hours at 1400° F, air cooled. This heat treatment changed the grain size from A.S.T.M. 6 and 7 to A.S.T.M. 1 and the Rockwell B hardness from 95 to 98. The microstructure of the heat-treated bar stock is shown in figure 1.

Method of surface preparation. - The dimensions of all specimens used in this investigation are given in figure 2. The reduced center section of all the specimens was ground in a cylindrical grinder by form grinding with a 60-grit aluminum oxide, vitrified bonded wheel of grade J and density 5. The grinding wheel speed was maintained between 5000 and 7000 surface feet per minute and the specimen speed for the finishing cut was maintained between 200 and 300 surface feet per minute. This treatment caused circumferential finish marks (ground specimen, fig. 3).

The polished finish was prepared by polishing the ground surface on the specimens with successively finer grades of emery cloth and paper, finishing in the longitudinal direction of the specimen with paper grade 20 (polished specimen, fig. 3).

The rough finish was prepared by semipolishing the ground specimens to remove the grinding scratches and then roughening the surface by holding a strip of 46-grit abrasive cloth against a slowly rotating specimen. This treatment also caused circumferential finish marks (rough specimen, fig. 3).

The following table lists the surface roughness and the test temperatures for each finish. Surface roughness measurements were made in the longitudinal direction with a profilometer.

Surface		Test temperature ($^{\circ}F$)
Finish	Roughness (microin. rms)	
Polished	4-5	80, 1000, 1350, 1500
Ground	20-25	80, 1000, 1350, 1500
Rough	70-80	80, 1350

Method of evaluation. - All tests were run in a high-temperature fatigue machine (fig. 4). The specimen is a fixed nonrotating cantilever stressed in completely reversed bending at a frequency of 120 cycles per second. The drive mechanism consists of a cantilever beam mounted on a torque bar, which is caused to vibrate by electromagnets denoted as drive coils in figure 4. The entire vibrating system operates very close to resonance.

The stress in the specimen was calculated from an equation based upon the inertia loading at resonance of the specimen assembly. The equation is believed to be accurate to ±2 percent of the true stress.

The factors entering the stress were measured closely enough for the stress to be within ±500 pounds per square inch of the nominal stress.

The specimens tested at elevated temperatures were heated to temperature in 1/2 to 1 hour and held at temperature from 2 to 4 hours prior to the start of the test. The temperature was controlled to within ±3° F.

RESULTS AND DISCUSSION

The test results on the surface finishes at 80° F are listed in table I(a) and plotted in figure 5(a). The strengths of the finishes for life of 10^8 cycles taken from figure 5(a) are compared in the following table:

Surface finish	Stress for life of 10^8 cycles (lb/sq in.)
Ground	38,000
Polished	46,000
Rough	54,000

Polishing the ground surface of 20 to 25 microinches rms roughness to 4 to 5 microinches rms roughness improved the fatigue life as expected. Roughening of the surface to 70 to 80 microinches rms, however, further increased the fatigue life. The fatigue life was expected to decrease with surface roughness and consequently give the roughened material a shorter life than the ground material. Roughening of the surface probably cold-worked the material and resulted in specimen-surface compressive stresses that were more beneficial than the damage due to increased surface roughness.

The test results on the finishes at 1350° F are listed in table I(b) and plotted in figure 5(b). All the finishes have approximately the same strength at this temperature. The factor or factors causing a difference in room-temperature strength are apparently removed by a temperature of 1350° F. Assuming that the difference in room-temperature strength is mainly due to compressive stresses set up in the outer fibers, it appears that at a temperature of 1350° F these stresses are removed by annealing so early in the tests that they do not affect the fatigue life.

If the material is sensitive to roughness at 1350° F, it would be expected that these data would show, after the surface stresses are removed by annealing, the polished finish to be stronger than the ground, and the ground stronger than the rough. The data do not indicate significant differences so it would seem that the material is insensitive to the differences in roughness of the finishes at 1350° F.

Following the tests at 1350° F, additional tests were run at temperatures of 1000° and 1500° F on specimens with ground and polished surfaces. The test results at a temperature of 1000° F are listed in table I(c) and plotted in figure 5(c). The fatigue strength of the polished surface was appreciably stronger than that of the ground surface for periods up to approximately 5,000,000 cycles of stress (14 hr at temperature, 3-hr soak, 11-hr running). For longer periods, any possible difference between the finishes is within the average scatter of the data, approximately ±2000 pounds per square inch. Better definition of the fatigue strength for longer periods would require considerably more testing, and because of the results anticipated, it is felt that further testing is not warranted. Assuming again that polishing placed compressive stresses in the surface, it would seem that after a short period of time at 1000° F, these compressive stresses would be removed by annealing. In order to place compressive stresses in the surface by polishing, some plastic flow of surface layer resulting in cold-work of the surface layer must take place. If the improvement in room-temperature fatigue strength by polishing was mainly due to cold-work in the surface, the strength of the polished surface would remain higher than that of the ground surface at 1000° F because stress-rupture data on cold-worked N-155 indicate that a temperature of 1000° F does not relieve the effect of the cold-work (reference 3). The improvement in strength by polishing is therefore believed to be due to the compressive stresses in the surface layer and not due to the cold-work in the surface layer.

Results from specimens with polished and ground surfaces tested at 1500° F are listed in table I(d) and plotted in figure 5(d). No significant difference exists between the fatigue strength of polished and ground surfaces. The surface stresses are quickly removed by annealing and the difference in roughness between ground and polished surfaces does not appear to affect the fatigue life. The effect of the stress concentrations caused by surface roughness may have a greater effect on fatigue of materials that are more notch sensitive than the N-155 used in this investigation.

From data presented in figure 5, polished and rough finishes were considered better than the ground finish at room temperature because of the compressive stresses in the surface of these finishes; at elevated temperatures, these compressive stresses were removed by annealing.

In order to check this conclusion, room-temperature fatigue tests were made on rough, polished, and ground specimens that were stress-relieved at 1400° F for 4 hours subsequent to surface finishing. Assuming that this heat treatment does not significantly alter the structure and that the effects of corrosion are negligible, then the fatigue strengths of polished and rough specimens should be reduced due to the elimination of surface stresses. The results presented in table II and figure 6 indicate that at a stress level of approximately 53,000 pounds per square inch the fatigue life of all surface finishes after this heat treatment is approximately equal to the original ground specimens. In addition, specimens repolished after heating had fatigue properties of the original polished material indicating that the significant effects were confined to the surface. In order to determine whether corrosion influenced the results, one polished specimen was stress-relieved in argon and one in a vacuum. These specimens exhibited very little oxidation and had essentially the same properties as those stress-relieved in air.

SUMMARY OF RESULTS

Results of tests on three mechanically prepared surface finishes of low-carbon N-155 alloy of grain size A.S.T.M. 1 indicated that each specimen finish had appreciably different fatigue strengths at room temperature but had the same fatigue strength at elevated temperatures.

At room temperature, the rough finish was superior in strength to the polished, and the polished was superior in strength to the ground. The probable cause of this variation at room temperature in strength is a difference in the degree of surface stresses present in the finishes. The ground surface appeared to be relatively stress free, whereas the polished and rough surfaces appeared to contain compressive stresses.

At 1000° F, specimens with a polished finish were stronger than those with a ground finish for periods up to 5,000,000 cycles of stress (approximately 14 hr at temperature). For longer tests, the difference between the strength of the polished and ground specimens was not appreciable.

At 1350° F, no significant difference in strength was found between specimens with polished, rough, and ground finishes. At 1500° F, the ground and polished specimens had the same strength. It is believed that the beneficial compressive stresses present in the polished and rough specimens were relieved by annealing at those test periods and test temperatures at which the strengths of the various specimen finishes were the same.

When the surface stresses were relieved, roughness changes from 5 to 80 microinches rms did not appear to have an appreciable effect on the room-temperature or elevated-temperature fatigue strength of the material.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Russell, H. W., Gillett, H. W., Jackson, L. R., and Foley, G. M.: The Effect of Surface Finish on the Fatigue Performance of Certain Propeller Materials. NACA TN 917, 1943.

2. Moore, H. F.: Shot Peening and the Fatigue of Metals. Am. Foundry Equipment Co. (Mishawaka, Ind.), 1944.

3. Freeman, J. W., Reynolds, E. E., Frey, D. N., and White, A. E.: A Study of the Effects of Heat Treatment and Hot-Cold-Work on Properties of Low-Carbon N-155 Alloy. NACA TN 1867, 1949.

TABLE I - RESULTS OF FATIGUE TESTS ON SPECIMENS OF LOW-CARBON N-155

(a) Temperature, 80° F.

Specimen	Stress (lb/sq in.)	Cycles to failure
Ground finish		
A8	59,900	389,000
A1	59,400	518,000
B15	54,000	691,000
B1	50,500	1,685,000
A15	45,500	1,900,000
E11	41,800	4,150,000
G19	38,600	20,700,000
G18	37,400	5,150,000
G12	36,300	101,000,000[a]
Polished finish		
A5	60,700	735,000
A3	60,500	778,000
E2	52,700	5,100,000
G5	50,800	5,659,000
G13	48,300	6,270,000
F17	47,600	30,300,000[a]
G2	47,000	8,294,000
G7	45,400	66,800,000
Rough finish		
A7	59,900	1,166,000
A4	59,400	1,382,000
E12	54,100	21,260,000
F19	52,600	39,200,000[a]
G8	52,600	99,200,000[a]

(b) Temperature, 1350° F.

Specimen	Stress (lb/sq in.)	Cycles to failure
Ground finish		
B10	39,800	216,000
B4	35,000	1,252,000
B12	34,900	1,123,000
B13	32,500	17,380,000
E6	28,900	59,800,000
Polished finish		
A12	43,400	108,000
F7	38,900	172,000
B9	38,600	432,000
B6	37,400	345,000
B11	36,400	388,000
B8	32,100	4,970,000
E3	30,000	79,700,000[a]
Rough finish		
B3	35,200	302,000
B7	31,700	12,660,000
B14	29,600	34,240,000

(c) Temperature, 1000° F.

Specimen	Stress (lb/sq in.)	Cycles to failure
Ground finish		
F8	46,500	302,000
F9	43,900	259,000
F2	42,000	65,300,000[a]
F20	41,300	39,312,000[a]
Polished finish		
F16	52,700	172,000
F21	49,600	994,000
F14	46,800	1,684,800
F3	46,400	1,598,000
E5	45,200	27,200,000

(d) Temperature, 1500° F.

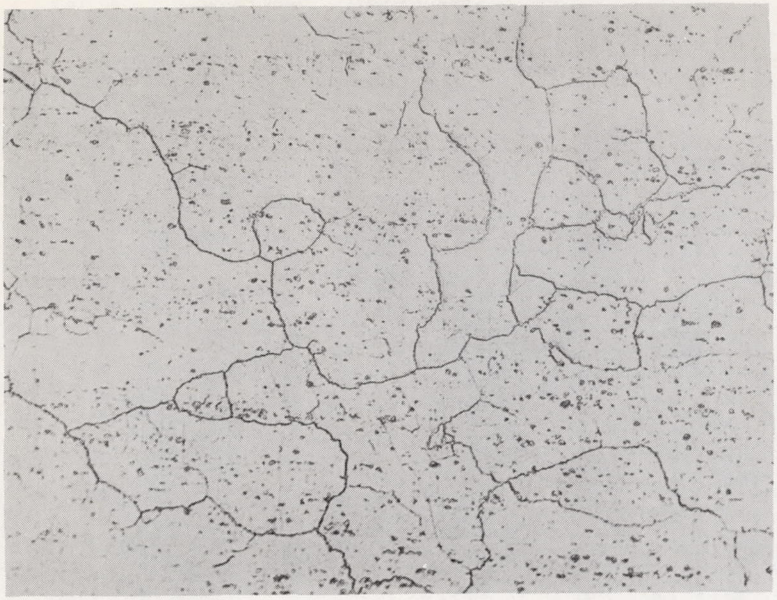
Specimen	Stress (lb/sq in.)	Cycles to failure
Ground finish		
E10	33,800	172,000
E20	30,000	1,598,000
E4	26,150	5,486,000
F12	23,000	64,200,000
Polished finish		
E14	29,100	691,000
E13	25,000	10,950,000

[a]Unbroken.

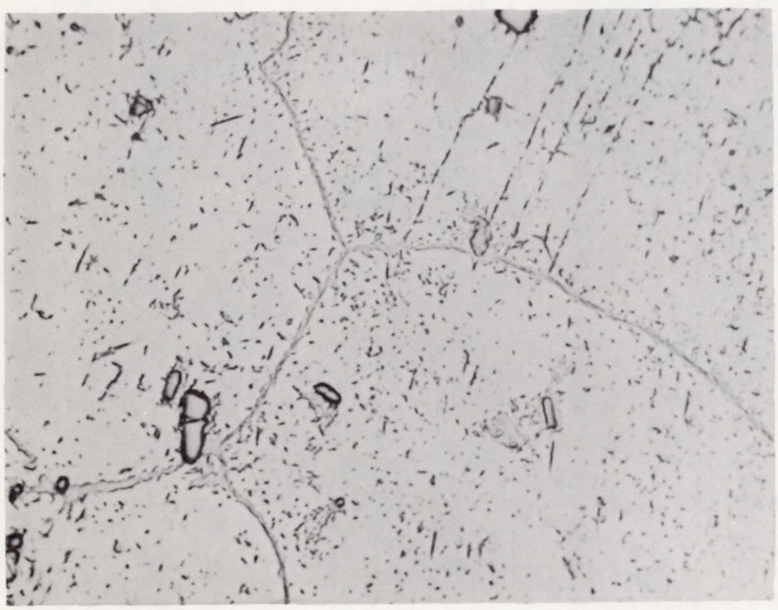
NACA

TABLE II - RESULTS OF FATIGUE TESTS ON SPECIMENS OF N-155 HELD FOR 4 HOURS AT 1400° F PRIOR TO TESTING AT 80° F

Specimen	Stress (lb/sq in.)	Cycles to failure	Remarks
Ground finish			
L9	53,300	1,120,000	
F5	50,100	820,000	
Polished finish			
E17	50,800	1,209,000	
L3	55,100	1,600,000	Repolished after heating
L28	52,400	4,575,000	Repolished after heating
L4	52,600	1,037,000	Heated in a vacuum
E9	52,200	1,166,000	Heated in argon atmosphere
Rough finish			
L12	52,400	994,000	
G11	49,500	1,728,000	



(a) X100.



NACA
C-27561

(b) X1000.

Figure 1. - Microstructure of low-carbon N-155 bar stock. Heat-treated: 1 hour at 2200° F; water-quenched; 16 hours at 1400° F; air cooled. Etched with 10-percent electrolytic chromic acid.

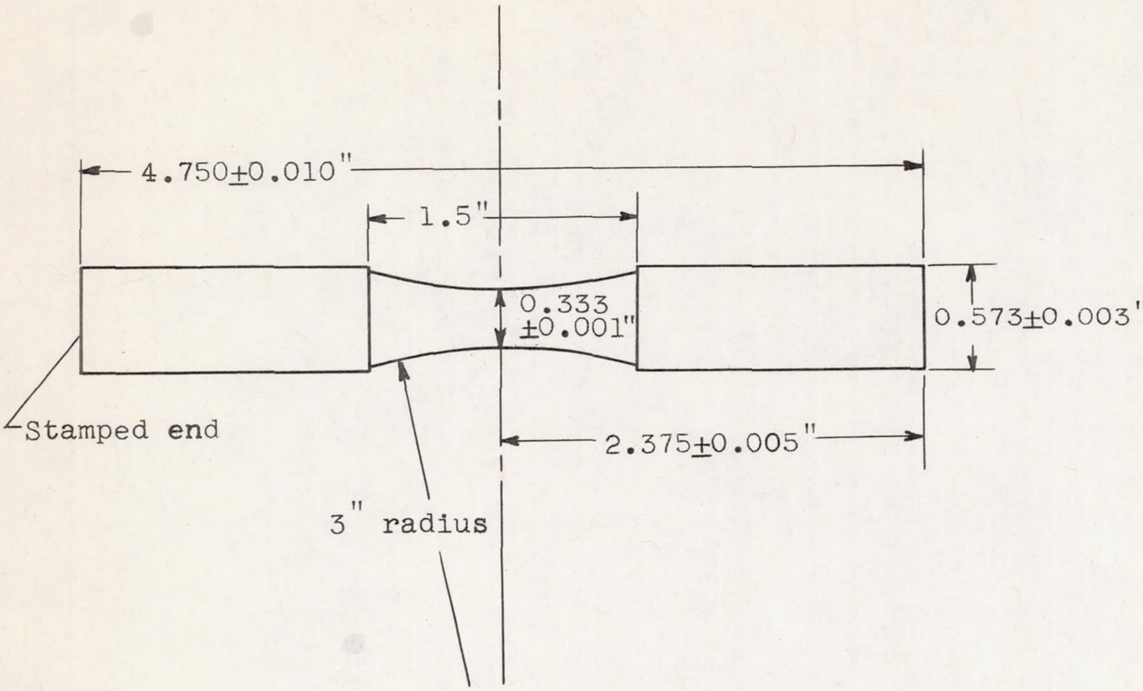
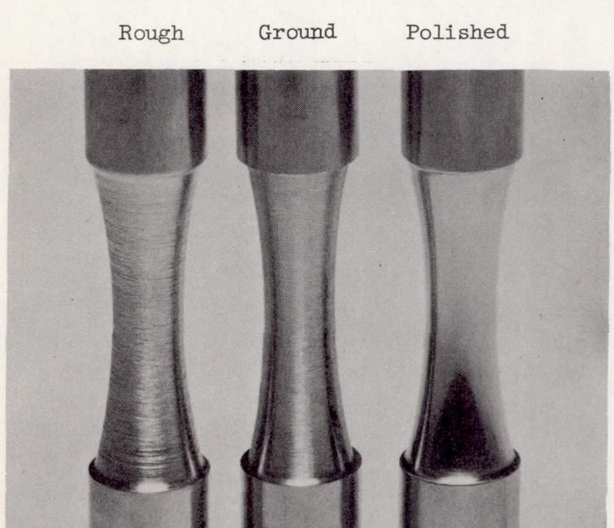


Figure 2. - Fatigue specimen.



C-26751

Figure 3. - Fatigue specimens with surfaces prepared for evaluation.

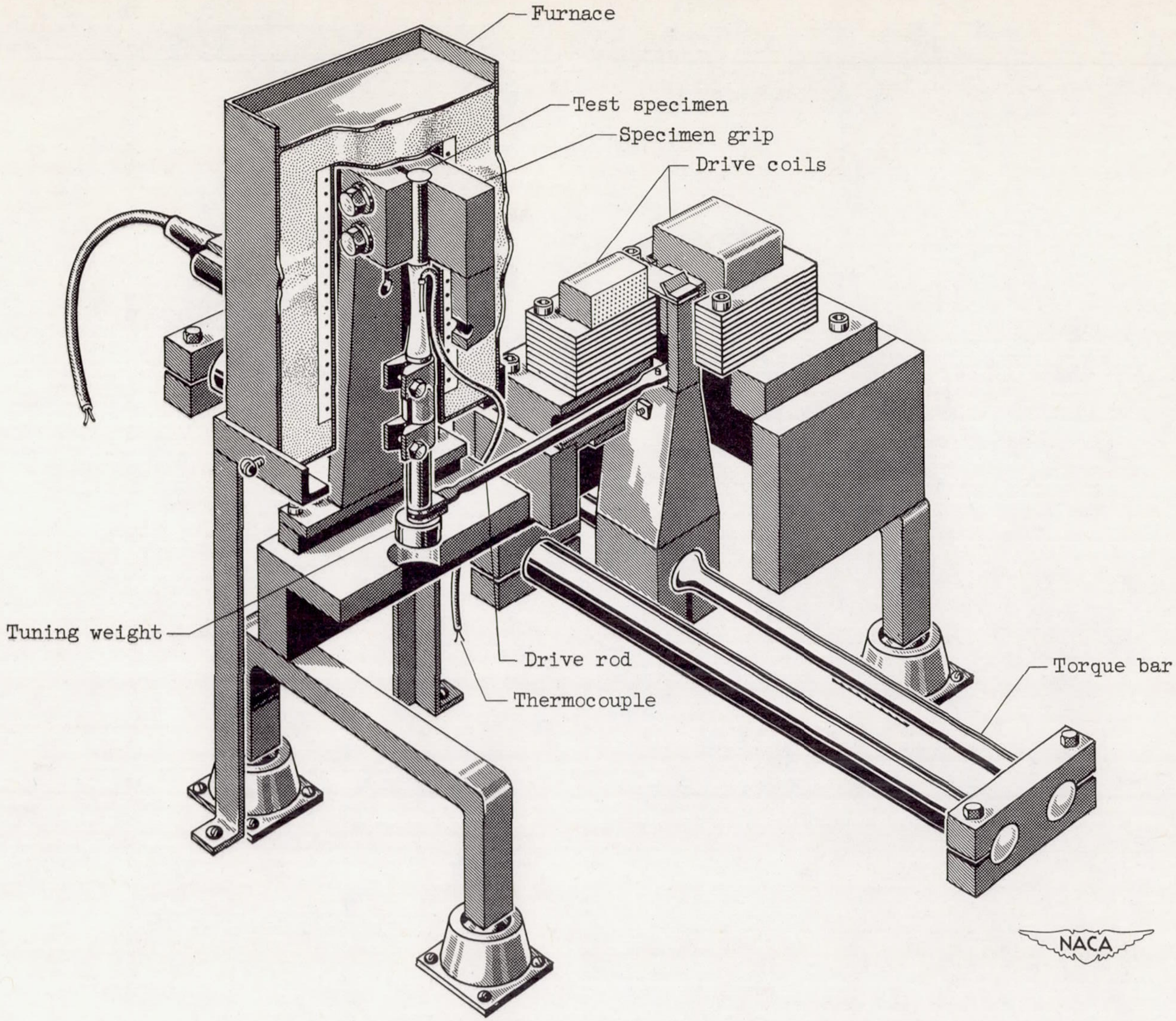


Figure 4. - High-temperature fatigue machine.

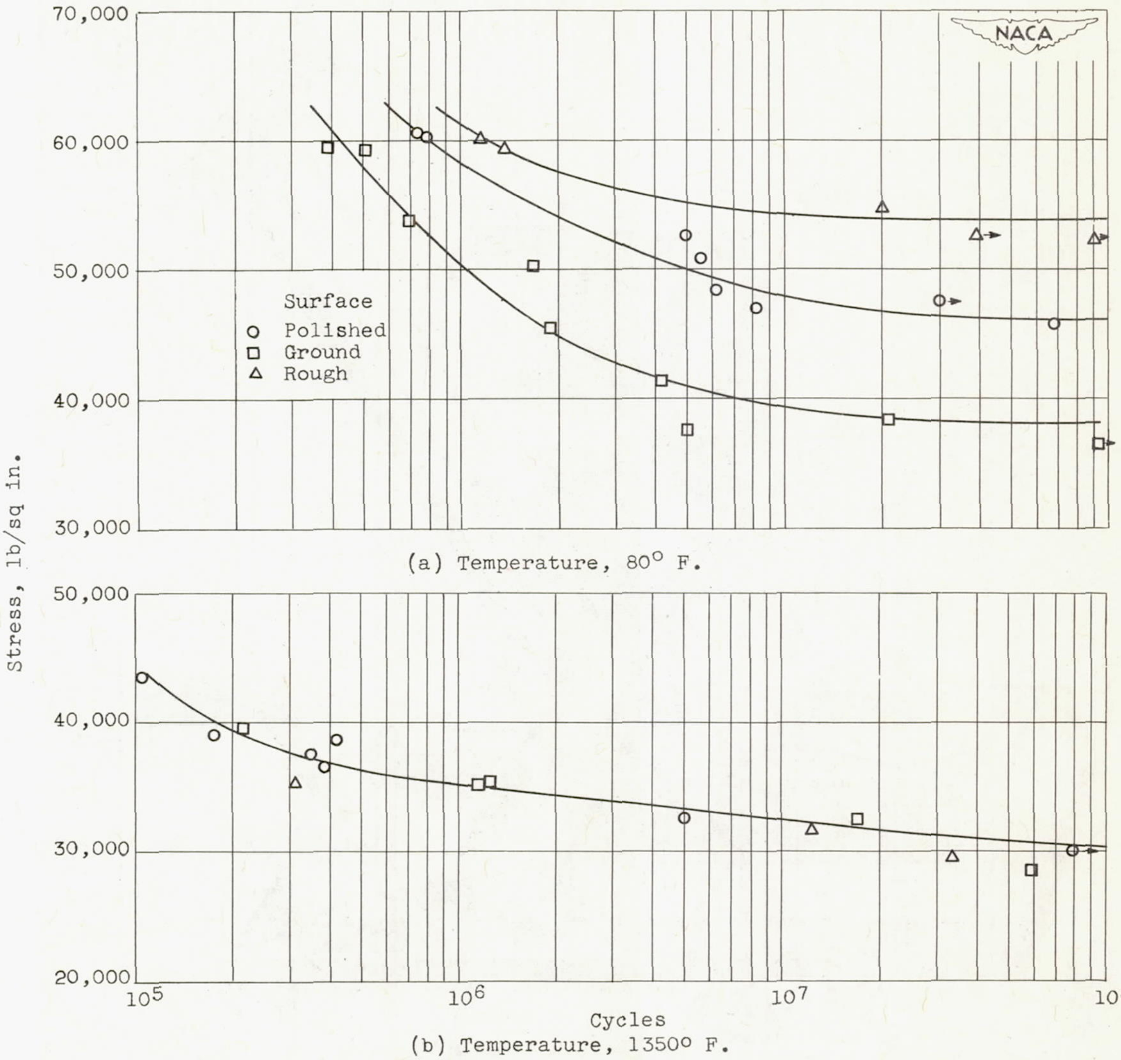


Figure 5. - Effect of surface treatment on fatigue properties of low-carbon N-155.

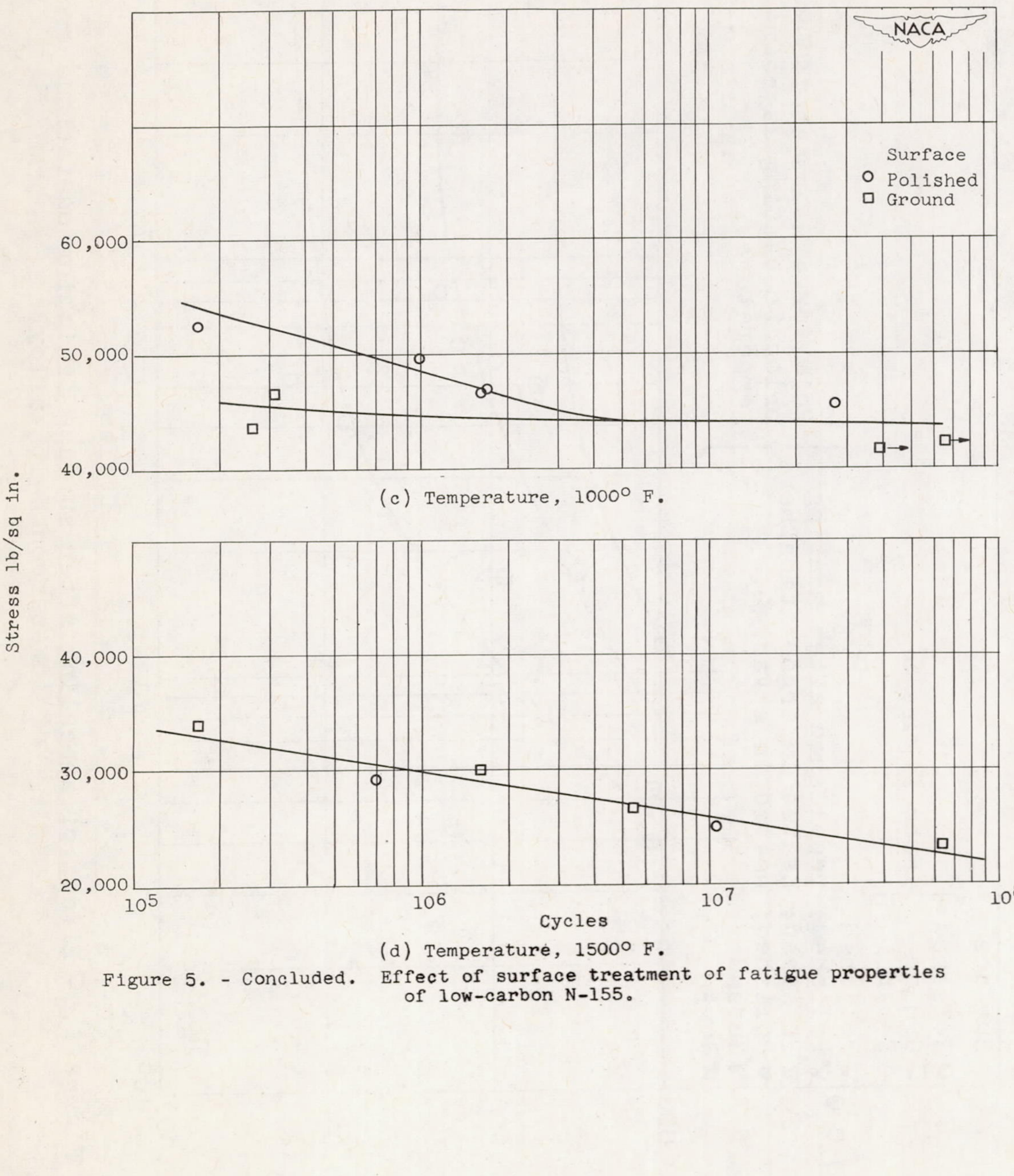


Figure 5. - Concluded. Effect of surface treatment of fatigue properties of low-carbon N-155.

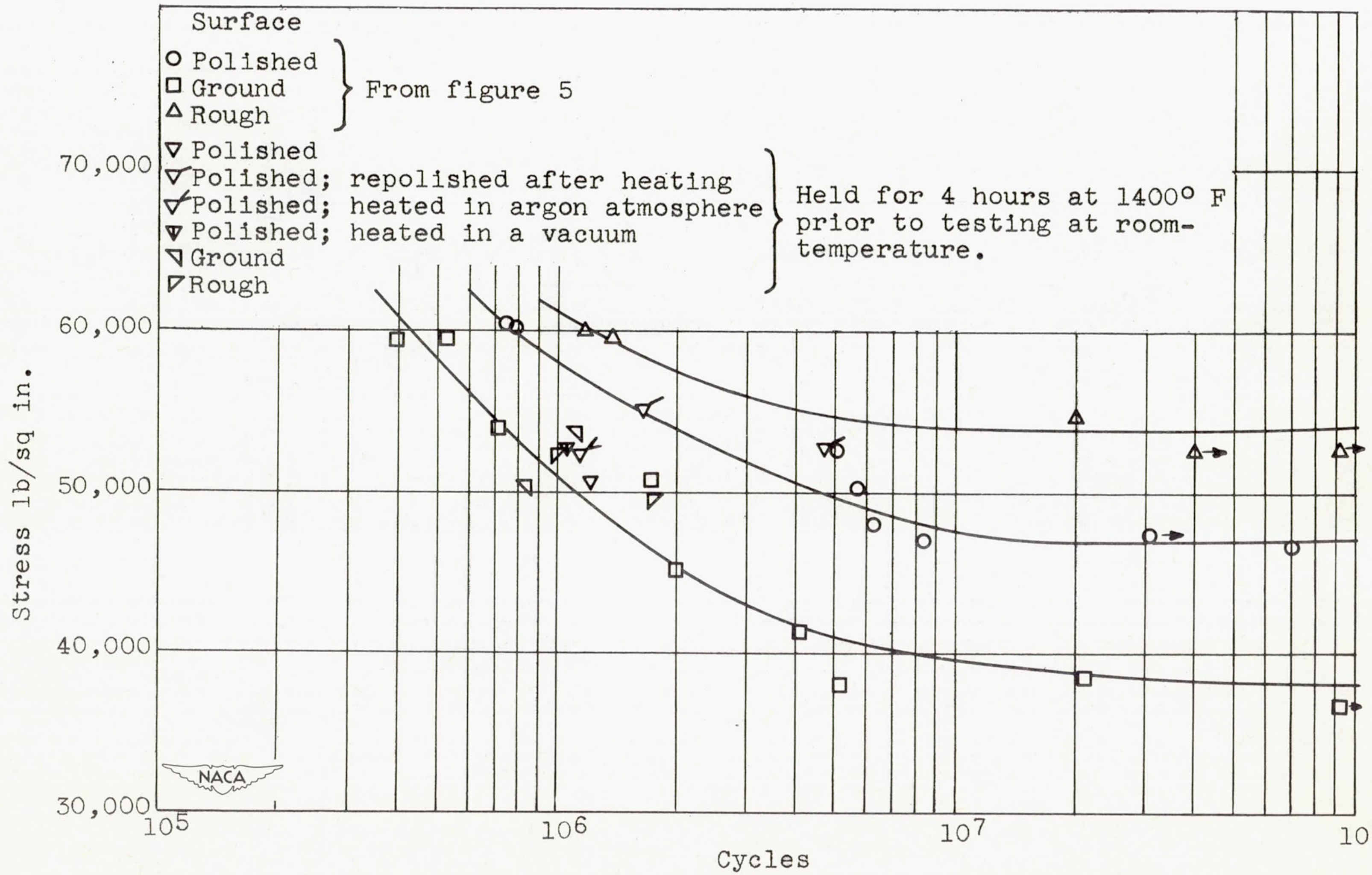


Figure 6. - Effect of annealing after surface finishing on fatigue properties of low-carbon N-155 alloy.