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BIMONTHLY PROGRESS REPORT NO. IV

THERMAL-SHOCK INVESTIGATION

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Project M949

AIR RESEARCH AND DEVELOPMENT COMMAND, U.S. AIR FORCE
CONTRACT AF 33(038)-21254; E.O. NO. 605-227 SR-3a

January, 1952

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OBJECT

The object of this research is to evaluate optimum design of test specimens and criteria which will permit correlation of thermal-shock data with performance of the material in the form of turbine buckets.

SUMMARY

Reproducibility tests have been run on several specimens of type 347 stainless steel. S-816 alloy has been tested in the setup used for testing stainless steel and in a setup with increased air flow. No definite conclusions can yet be drawn as to reproducibility with either material.

INTRODUCTION

Previous experiments have shown that stainless steels of types 304 and 347 as well as Inconel are cracked relatively easily by thermal shock. Not enough data are available on Haynes-Stellite 21 alloy to compare its performance with that of other alloys. This period of research was concerned chiefly with S-816 alloy and type 347 stainless steel. This report covers the period October 11, 1951, through December 11, 1951.

APPARATUS

The air supply has been modified to provide a more constant rate of air flow over the test cycle by introducing an accumulator tank about three feet from the air nozzle. The accumulator yields a higher average rate of air flow over the test cycle. The piping between the accumulator and the solenoid valve, located just upstream of the nozzle, was enlarged in order to reduce friction losses. A photograph of the test setup is shown in Fig. 1.

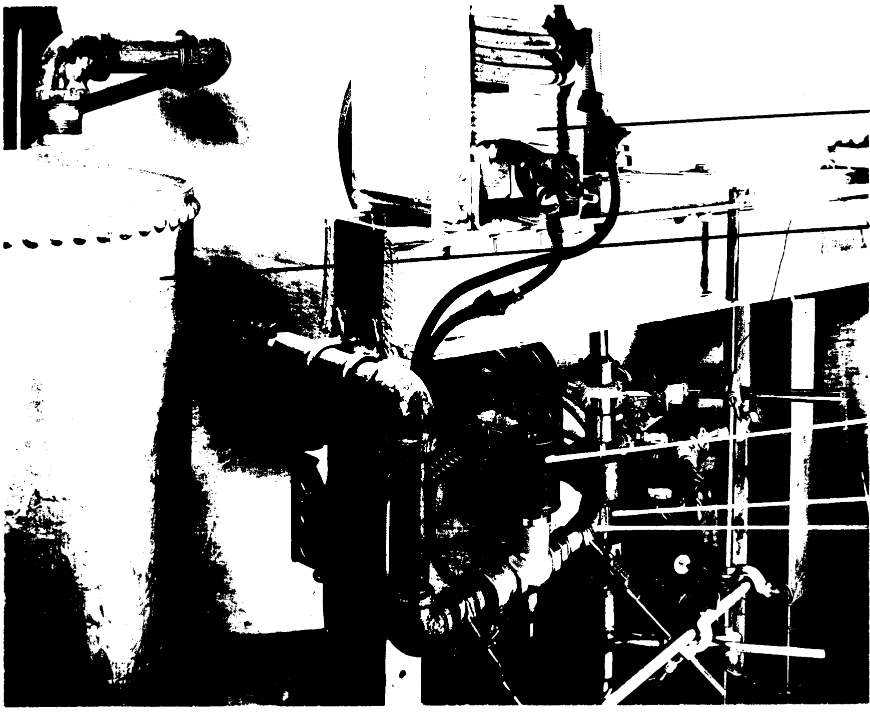


Fig. 1. Test Setup.

A schlieren apparatus has been set up in order to indicate the character of the air stream and the velocity of the air flow.

Installation of controls for a second unit has been started.

RESULTS AND DISCUSSION

Reproducibility Tests on Stainless Steel:

A number of tests on type 347 stainless steel were run, as indicated in the test log at the end of the report, at 1600°F maximum cycle temperature without axial load. Seven specimens of triangular cross section failed at 1800 to 3200 cycles. The test conditions were the same during all tests except that these specimens were of two different edge thicknesses. No correlation was noted between number of cycles to failure and edge thickness.

As yet, it is difficult to determine whether this reproducibility of the number of cycles to failure is satisfactory. If the behavior of alloys in thermal shock is considered to bear some similarity to results of fatigue tests, sufficient data might yet yield the hypothetical results shown in Fig. 2. By "severity" is meant effectiveness in producing cracking in a given material by thermal shock. The degree of severity may be altered by changing the air blast, as by changing the mass rate of air flow or changing the temperature of the air.

In Fig. 2, severity A would yield a relatively small scatter among results of reproducibility tests; severity B would yield widely differing results, even with excellent experimental techniques; severity C might be such as to cause some specimens to fail and not others. It will be recalled that early tests were less drastic than condition C, inasmuch as cracking was not obtained. It is consequently believed that more data are required at a single temperature before conclusions can be drawn as to the quality of the reproducibility obtained.

Initial Results With S-816 Alloy

In an effort to determine the extent to which S-816 alloy is susceptible to cracking under thermal stress superposed on mechanical stress, a specimen was loaded with a static stress corresponding to a stress-rupture life of about 100 hours at 1600°F. Necking occurred at 1425 cycles, however, and the load was reduced gradually during the test to maintain constant stress. The specimen fractured after a total of 2657 cycles at a maximum cycle temperature of 1500°F. The type of failure obtained is shown in Fig. 3. Although no cracks were seen in the specimen at the last observation prior to fracture, the appearance of the fractured specimen indicates that cracking did not begin at the corners of the triangular cross section.

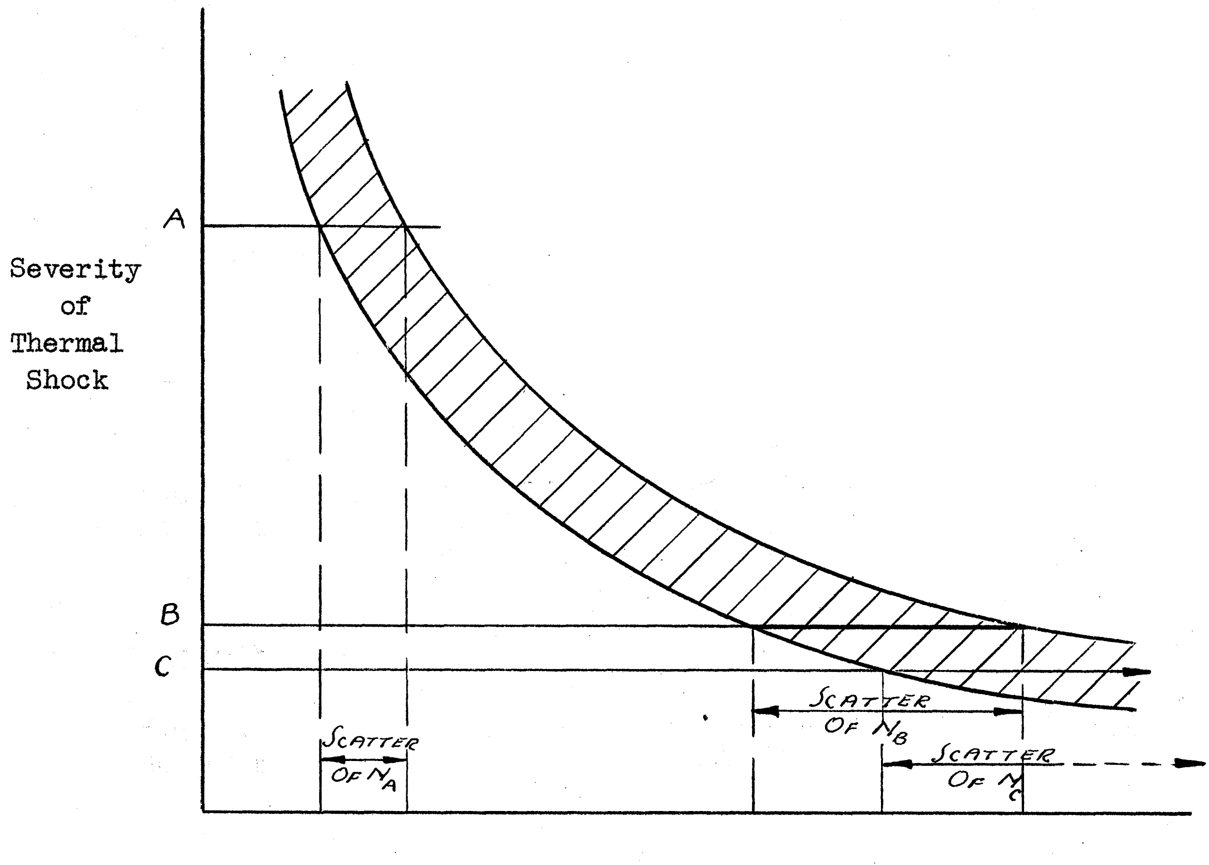


Fig. 2. Hypothetical relationship between severity of thermal shock and number of cycles to failure.

A second S-816 specimen was loaded with a smaller stress and tested for 5108 cycles at 1500°F without failure. At this point the temperature was raised to 1600°F and at 10,000 cycles the temperature was increased to 1700°F and held at this temperature for the remainder of the test. Some creep and necking occurred at the higher temperatures and the static load was removed. Increase of the maximum cycle temperature produced deformation due to the thrust of the air blast, but no cracking occurred.

The excessively long test time required by the S-816 alloy indicated that the air blast was not sufficiently severe for this material. The severity may be placed at C (see Fig. 2), or even lower for S-816.

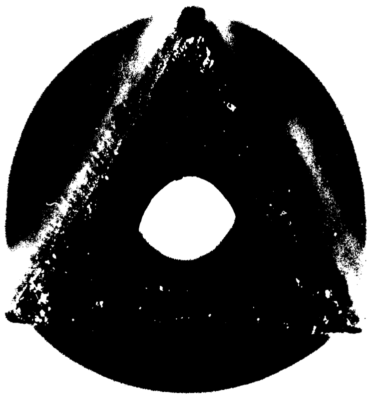


Fig. 3. Cross-section of thermal-shock specimen of S-816 alloy, failed by fracture. Areas of thinner oxide film are blue, at the corners of the triangle.

Enlarged Air-Supply System

The air supply was altered in an effort to increase the severity of the air blast. Pressure measurements had indicated that supply-line friction caused a serious reduction of the available pressure measured at the entrance to the nozzle. Adding a 4-cubic-foot tank and increasing the pipe size to the inlet of the solenoid valve gave a higher average pressure upstream of the nozzle. The intensity of the sound increased to the extent that it may be necessary to construct a muffler. Flow is definitely supersonic outside the nozzle, as indicated by schlieren observations.

Later Tests on S-816 Alloy

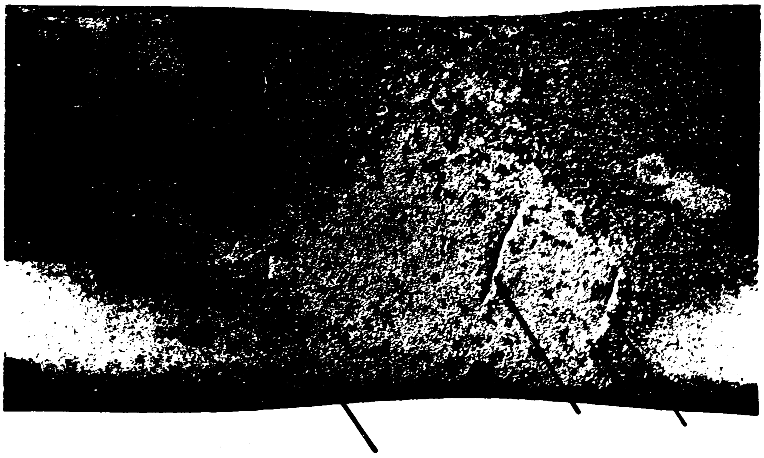
The test on the second S-816 alloy specimen was resumed. At the end of 20,179 cycles a crack was observed at mid-length of the specimen near the cooled edge. Fig. 4a is an enlarged photograph of the test section of the specimen at the end of the test. The smaller cracks on either side of the middle crack were discovered after the test had been halted. The specimen was then broken in bending to reveal the progress of the crack.

Temperature Measurement

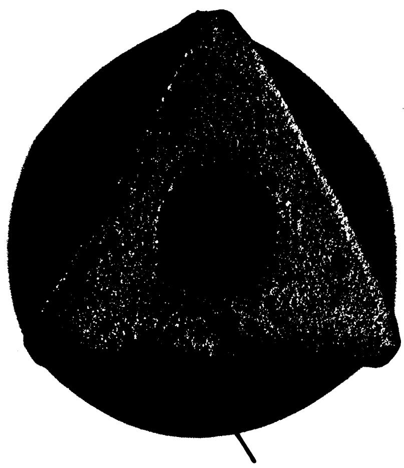
The use of a thermocouple inside the specimen is undesirable because of occasional cracking through the thin wall at the hole, and because a thermocouple located in the interior of the specimen senses a temperature different from that at the surface. Furthermore, the drilling of the thermocouple hole in materials such as S-816 is seriously delaying procurement of specimens of the harder alloys. The use of a total-radiation-type pyrometer is being investigated.

Summary of Results

Tests have been continued on reproducibility and on different materials during this period.



a) Photograph of flat side of specimen showing cracks (arrows).



b) Cross section of specimen after breaking at middle crack by bending, showing crack (arrow).

Fig. 4. Thermal-shock specimen of S-816 alloy, failed by cracking.

KEY TO LOG

Column (2)

	Arrow indicates direction and location of cooling jet; cooling medium is air unless otherwise stated.
W	Cooling medium is water.
.045	Width of cooled edge, inches.

Column (3)

M	Thermal-shock cycle manually controlled.
1500/5	Automatic cycle control; maximum temperature, °F, and length of cooling period, seconds.
P1800	Dead load, 1800 lbs.
10/100	Starting with stated maximum temperature, maximum temperature was increased 10°F after each 100 cycles.
40.5K	Reversed-bending (rotating-beam) fatigue tests; maximum stress, 40,500 psi.
to 1800	Maximum temperature held constant after 1800°F was reached.

Column (4)

A	Air cooling for stated number of cycles.
W	Water cooling for stated number of cycles.
no symbol	Air cooling for stated number of cycles.

Column (5)

O	No failure visible.
F	Fracture.
C	Cracks.
G	Grooves.

Column (6)

B	Specimen warped due to thermal strains.
A0.14	Area of cross section, square inches.
T300/1600	Heat treated before testing 300 hrs at 1600°F.

KEY TO LOG (cont.)

Column (6) continued.

G1500	Grooved first appeared at 1500 cycles.
O.H.	Stated maximum temperature was exceeded due to mal-function of control unit.
B.T.	Broke through to thermocouple hole.
40.5K 82000	Previously subjected to 82,000 cycles at 40,5000 psi.
R	Reproducibility test.
N	Specimen formed a neck.
+100/5108	Temperature increased 100°F at 5108 cycles.