LEVEL IV ARO 13536.1-MS

(11)

AD A103574

PHASE INSTABILITY DURING FATIGUE OF STAINLESS STEEL

FINAL REPORT

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10 JULY 1976 - 31 AUGUST 1980

U.S. ARMY RESEARCH OFFICE
GRANT DAAG29 76 G 0278

DEPARTMENT OF METALLURGY
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A103574	3. RECIPIENT'S CATALOG NUMBER (1) Final rept.
4. TITLE (and Subtitle) (6) Phase Instability During Fatigue of Stainless Steel,		5. TYPE OF REPORT & PERIOD COVERED 10 Jul[redacted]976 – 31 Aug[redacted]80
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Carl J. Altstetter, Zafar Khan, Gary Schuster		8. CONTRACT OR GRANT NUMBER(s) (15) DAAG29-76-G-0278
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Metallurgy, University of Illinois at Urbana-Champaign		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (11)
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709		12. REPORT DATE Jan [redacted]981
		13. NUMBER OF PAGES 8
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 17		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fatigue, Austenitic Stainless Steel

Phase Transformation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This work is a comparative study of the fatigue crack growth rate (FCGR) of two austenitic stainless steels, AISI 301 and AISI 302. The objective was to determine how differences in the austenitic stabilities ~~(γ/α')~~ of the two steels would affect their respective FCGR's. Tests were run in argon, hydrogen, and a smaller number in air. In addition to determining the FCGR's, a number of other quantities were also measured using various techniques. The plastic zone size of some specimens was determined by using a microhardness tester and electron → cont.

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channeling data. The residual stress around the crack tip was measured using strain gages. The volume fraction of martensite was determined by measuring the magnetic permeability and by using quantitative metallography. The phase present along the path of the fatigue crack was determined by using glancing incidence electron diffraction.

Results from the work show that the relatively unstable AISI 301 stainless steel has a FCGR approximately 50 ~~percent~~ % lower than AISI 302 stainless steel when tested in argon or air at a low mean stress, less than 66 MPa. At higher mean stresses the FCGR's are equal. The plastic zone sizes of AISI 301 specimens are generally smaller than for AISI 302. The cause for the lower FCGR observed in the AISI 301 seems to be the residual compressive stresses that develop around the crack tip as a result of the martensite formation. Testing in hydrogen caused the FCGR of both steels to greatly increase with the AISI 301 being affected to a much larger extent. Glancing incidence electron diffraction showed that the fatigue crack preferentially followed the α' when tested in hydrogen. This indicates that the α' is being embrittled and is thereby causing the observed increase in FCGR.

Forward

This work is a comparative study of the fatigue crack growth rate (FCGR) of two austenitic stainless steels, AISI 301 and AISI 302. The objective was to determine how differences in the austenitic stabilities ($\gamma \rightarrow \alpha'$) of the two steels would affect their respective FCGR's. Tests were run in argon, hydrogen, and a smaller number in air. In addition to determining the FCGR's, a number of other quantities were also measured using various techniques. The plastic zone size of some specimens was determined by using a microhardness tester and electron channeling data. The residual stress around the crack tip was measured using strain gages. The volume fraction of martensite was determined by measuring the magnetic permeability and by using quantitative metallography. The phase present along the path of the fatigue crack was determined by using glancing incidence electron diffraction.

Results from the work show that the relatively unstable AISI 301 stainless steel has a FCGR approximately 50 percent lower than AISI 302 stainless steel when tested in argon or air at a low mean stress, less than 66 MPa. At higher mean stresses the FCGR's are equal. The plastic zone sizes of AISI 301 specimens are generally smaller than for AISI 302. The cause for the lower FCGR observed in the AISI 301 seems to be the residual compressive stresses that develop around the crack tip as a result of the martensite formation. Testing in hydrogen caused the FCGR of both steels to greatly increase with the AISI 301 being affected to a much larger extent. Glancing incidence electron diffraction showed that the fatigue crack preferentially followed the α' when tested in hydrogen. This indicates that the α' is being embrittled and is thereby causing the observed increase in FCGR.

Statement of the Problem

The present work examines the fatigue crack growth rates, (FCGR's), of two austenitic stainless steels (AISI 301 and 302), in argon and hydrogen atmospheres. These two stainless steels were selected because their chemical compositions are similar, but different enough to give significant differences in austenitic stability. The objectives of the project were as follows:

1. Determine how a phase transformation affects the FCGR's of the stainless steels in argon.

2. Determine if the FCGR's are affected by gaseous hydrogen and explain any observed differences.

There were a number of reasons for doing these experiments. It has long been known that a deformation induced-transformation can have a beneficial effect on the monotonic mechanical properties of a metal--examples of this are TRIP steels and marmem metals. Thus, it seems quite reasonable to expect that under some conditions a phase transformation could decrease the FCGR of a metal. A number of studies have examined the effects of a phase transformation on the fatigue properties of different alloys, and the results are varied, indicating a need for further study and clarification. A full discussion of the previous work in this field was collected in a literature survey.

There were also good reasons to study the influences of hydrogen on the FCGR's. It is generally known that martensitic steels are embrittled by hydrogen. In recent years it has also been shown that even completely stable austenitic steels can be embrittled. The latter has led some researchers to conclude that martensite is not necessary for embrittlement and may not, by itself, be responsible for the embrittlement, even when it does occur. Thus, there exists some controversy over the role of martensite in the hydrogen embrittlement of stainless steels. Results from the present work should help to clarify this role. Again a discussion of past work in this area is given in the literature survey.

This research is readily justified. First, because results of FCGR measurements and tests on the environmental effects of hydrogen can be immediately applied to practical engineering problems. It has been estimated that between 80-90 percent of metal failures in practice arise from fatigue. Hence, there is an obvious need for data characterizing the fatigue properties of materials under various conditions. Second, the research should lead to a better fundamental understanding of the effects of a phase transformation on the FCGR's of metals. This knowledge could ultimately result in the design of materials that have superior fatigue properties.

Summary of the Results

The following gives a summary of the results and conclusions of this work.

Argon and Air Tests

1. At low mean stresses, annealed AISI 301 has a FCGR 25 to 50 percent lower than 302. This difference vanishes at higher mean stresses.

2. Work hardening prior to testing reduces or eliminates the differences in FCGR between the steels.

3. The plastic zone size is smaller and the amount of strain hardening is greater for AISI 301 specimens as compared to 302. The reason for this difference appears to be due to the relatively large amount of α' that is formed in type 301 steel during load cycling.

4. Work hardening prior to testing results in an overall increase in the hardness of the steels as would be expected. However, cold worked type 302 tends to work soften during load cycling, AISI 301 does not show a similar tendency.

5. Residual stress measurements in the region around the crack tip show that the highest residual stresses occur in type 301 specimens cycled at low mean stress. The type 302 specimens have smaller residual stresses and both steels have smaller values as the mean stress is increased. The

reason for this appears to be that the higher mean stresses cause the specimens to yield along their entire width, thus removing any constraint. At lower mean stresses the deformation is localized to the region near the crack tip. Type 301 steel transforms to a much greater extent and the accompanying volume expansion causes the higher residual stress. The difference in residual stress levels seems to best explain the smaller FCGR observed for the unstable 301 steel at low mean stresses.

Hydrogen Tests

1. Hydrogen increases the FCGR of the unstable steel from 50 to 500 percent and for the stable steel from 25 to 100 percent, depending on the mean stress.

2. The magnitude of the effects of cyclic loading in H_2 gas is less for low ΔK's.

3. Prior deformation can reduce the effects of hydrogen by stabilizing the microstructure.

4. Hydrogen tends to localize the deformation for both steels, as indicated by smaller plastic zone sizes. A result of this decreased deformation is an approximate 50 percent reduction in the bulk α' for AISI 301 and a 25 percent reduction for AISI 302.

5. SEM pictures show that type 301 specimens tested in H_2 in the annealed or prior deformed state both show a more crystallographic fracture surface as compared to tests run in Ar; the difference is most dramatic for the annealed case. The fracture surfaces of type 302 specimens tested in H_2 appears unchanged from those tested in Ar.

6. Glancing incidence electron diffraction shows that the crack exclusively follows the α' for 301 stainless steel specimens tested in H_2 as compared to a mixed path for argon tested specimens. Fatigue cracks in 302 were observed to follow a mixed path when tested in both H_2 and Ar. Results seem to indicate that in the case of 301 the α' plays the role of the embrittled phase. There is no evidence that the hydrogen is increasing the tendency for localized α' formation.

Publications and Technical Reports

The following work under ARO sponsorship has appeared in print since the inception of this grant.

G. Franke and C. Altstetter
Low Cycle Fatigue Behavior of Mn/N Stainless Steels
Met. Trans. 7A (1976) pp. 1719-1727.

In preparation:
G. Schuster and C. Altstetter
Hydrogen-enhanced Fatigue Crack Growth
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Proc. of Int. Conf. on Effect of Hydrogen on Behavior of Materials, Jackson Hole, 1980.

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Met. Trans. A.

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ASTM Conf. on Quantitative Measurement of Fatigue Damage, Dearborn, Mich.

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Fatigue of Cold Worked Austenitic Stainless Steels
Met. Trans. A.

Scientific Personnel:

R. Bianchetta, M.S. 1976
Z. Khan, M.S. 1978
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G. Schuster, Ph.D. 1981
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