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A SURVEY OF STRAIN-CYCLING DATA
ON
TYPICAL ARMY-REACTOR VESSEL
MATERIALS

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THERMAL AND MECHANICAL STRAIN CYCLING OF DUCTILE MATERIALS

A survey of the strain-cycling literature has been made by the Metallurgy Unit of NPED. The purpose of this survey is (1) to fulfill requirements of Subtask 6.5 "Strain Cycling Specimen Development" of Task 6, "Radiation Damage to Pressure Vessels," and (2) to compile data on plastic strain fatigue of Army reactor vessel materials under conditions of thermal or mechanical strain. Such data - on unirradiated materials - will serve as a basis of comparison for similar tests to be run by the Naval Research Laboratory on irradiated materials to determine the effect of irradiation on plastic strain fatigue.

The data available is rather limited, but it touches on a variety of materials. Those most applicable to the present program are the stainless steel Type 304 and the low-carbon steel Type A-201. Type 304 steel has been used as cladding material on all of the Alco-built Army reactor vessels, and Type A-201 is a low-carbon steel similar in chemical composition to Type A-212 steel which was used as the base material in the SM-1 reactor vessel. Data on other materials such as aluminum, copper, titanium, and nickel are presented principally as back-ground information to indicate the similarity of results on a wide range of metals and to illustrate some general observations on plastic strain fatigue.

A method of testing developed by Coffin was used to obtain the data on thermal-strain cycling. The samples used for this procedure are thin-walled (.020/.040 in.) tubes with flanged ends. These tubes are rigidly clamped to heavy plates at each end. The plates in turn are anchored in such a way as to prevent thermal expansion and contraction when the specimen is subjected to cyclic temperature changes.

In this manner, the samples are subjected to cyclic longitudinal stresses arising from the end constraint. A similar procedure with only minor modifications was followed by Carden, Sodergren, and Majors. Details of the apparatus and testing procedures are contained in reports by these investigators. (1) (2) (3) (7)

The mechanical load cycling data presented are from observations of both cyclic bending and longitudinally stressed specimens. Details of these testing procedures are contained in reports by Gross and Stout, (4) Tavernelli and Coffin, (5) and Anderson and Waldron. (6)

In all cases, the plastic strain range has been defined as the total strain per cycle minus the elastic strain per cycle. This value can be calculated by use of observed stress values, as indicated by Coffin, Gross, and Stout; or it may be taken from a stress hysteresis loop as measured by Carden and Sodergren and Majors.

The investigators have presented their data in graphic form, plotting plastic strain range versus cycles to failure. The results were compiled and are presented in the accompanying graphs. In Fig. 1, mechanical load cycling data on stainless steel Type 304 and low-carbon steel, Type A-201 are presented. Figure 2 presents mechanical load cycling data on a number of materials, both ferrous and non-ferrous. Figure 3 compares thermal cycling and mechanical cycling of stainless steel Type 304, of nickel, and of titanium.

Figure 1 presents data on materials of principal interest in the Army reactor vessel program. Figure 2 is presented to illustrate a point first noted by Coffin and Tavernelli; namely, that a plot of the Plastic Strain Range versus Cycles to Failure on logarithmic coordinates generally gives a straight line with slope equal to $-1/2$. This relationship apparently holds true for a variety of materials

over a wide temperature range and tested either mechanically or thermally.

For comparison of mechanical and thermal cycling as presented in Fig. 3, the conditions of testing were as follows:

<u>Material</u>	<u>Mechanical</u>	<u>Thermal</u>
Nickel-A	525°F	525°F
Titanium-75A	575°F	575°F
Stainless Steel Type 304	Room Temperature	1300°F Mean Temperature

It should be noted that in all cases the thermal plastic strain curve falls considerably below the corresponding curve of mechanically tested specimens.

From design standpoint, if the above observed relationships hold true for a number of irradiated as well as unirradiated materials, this information must be considered in the design of a structure. A portion of the desired information on irradiated materials will be supplied by Naval Research Laboratory. The proposed testing method, however, involves mechanical cycling only; and this fact must be taken into consideration when applying such data. The data presently available on unirradiated material indicates that thermal cycling causes failure in fewer cycles than mechanical cycling. Therefore, since most of the cycling over the life-time of a reactor vessel is of a thermal nature, the design should be appropriately conservative when it is based on mechanical strain data. The need for additional information on thermal plastic strain fatigue is apparent from the data presented here; and since fatigue properties discussed are of prime importance in the design of a reactor pressure vessel, this need should serve as a basis for future investigations.

Fig. 1

Mechanical Load Cycling Data on Stainless Steel, Type 304 and Low-carbon Steel, Type A-201

Fig. 2

Mechanical Load Cycling Data on Ferrous and Non-ferrous Materials

Thermal and Mechanical Cycling
Nickel, Titanium, 304 Stainless
Plastic Strain Range
VS.
Cycles to Failure

----- Mechanical Cycling
----- Thermal Cycling
Ni & Ti data from Majors
Stainless data from Carden,
Sodergren, & Atomic International

Cycles To Failure

Fig. 3
Comparison of Thermal Cycling and Mechanical Cycling of
Stainless Steel, Type 304, Nickel, and Titanium

BIBLIOGRAPHY

1. L.F. Coffin, Jr., and R.P. Wesley, "Apparatus for Study of Effects of Cyclic Thermal Stresses on Ductile Metals," Transactions ASME, August 1954
2. A.E. Carden and J.H. Sodergren, "The Failure of 304 Stainless Steel by Thermal Strain Cycling at Elevated Temperature," ASME Paper No. 61-WA-200
3. H. Majors, Jr., "Thermal and Mechanical Fatigue of Nickel and Titanium," Transactions ASM, 1959
4. J.H. Gross and R.D. Stout, "Plastic Fatigue Behavior of High Strength Pressure Vessel Steels," "The Welding Journal," Volume 34, 1955, Research Supplement, pp 161-165
5. J.F. Tavernelli and L.F. Coffin, Jr., "A Compilation and Interpretation of Cyclic Strain Fatigue Tests on Metals," Transactions ASM, 1959
6. W.E. Anderson and C.R. Waldron, "High Temperature Strain Fatigue Tests with a Modified Direct Stress Fatigue Machine," Atomic International Report No. NAA-SR-4051, September 1959
7. L.F. Coffin, Jr., "A Study of the Effects of Cyclic Thermal Stresses on a Ductile Metal," Transaction ASME, August 1954