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TECHNICAL REPORT

DETERMINATION OF THRESHOLD VELOCITIES
AND CORRELATION OF HIGH-FREQUENCY
ENDURANCE LIMITS FOR LMFBR
HEAT-EXCHANGER MATERIALS

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SUMMARY

Jet impact erosion tests and high frequency fatigue tests were conducted for 2 1/4 Cr-1 Mo steel. Utilizing the relationship between the velocity of impact and the number of impacts to produce visible erosion, the threshold velocities were determined as 220 fps and 140 fps at 10^7 cycles and 10^8 cycles respectively. The relationship between the high frequency fatigue strength and the number of cycles to failure was determined at room temperature up to a maximum of 10^9 cycles. The high frequency endurance limit at room temperature was determined to be approximately 32,000 psi for 10^8 cycles. In addition, the ratio of high frequency fatigue strength to water hammer stress for erosion inception was also obtained as 2.75.

INTRODUCTION

In order to evaluate the magnitude of the erosion problems encountered in LMFBR heat exchangers, the design engineer needs

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for his design calculations basic experimental data correlating the threshold water hammer (impact) stress on the material and the high frequency endurance limit of the material. The program output for this experimental research study constitutes a material design chart relating the ratio between the high frequency endurance limit and the water hammer pressure of the material as a function of the number of cycles (impacts) at room temperature for 2 1/4 Cr-1 Mo steel.

Experimental Facility and Techniques The Jet Impact Erosion Facility

The jet impact erosion facility consists of a rotating disk driven by a variable speed motor capable of sustaining operation at 20,000 rpm. The rotating disk is capable of holding six specimens and rotates in the horizontal plane cutting two sets of 1/32 inch diameter vertical jets as shown in Figure 1. The erosion is caused by the impact of the test specimens on the solid jet at controlled speeds.

The High Frequency Fatigue Facility

The high frequency fatigue facility, Figure 2 consists of a piezoelectric ultrasonic transducer and associated power supply which is used to vibrate the tuned specimen. The

measuring instrumentation includes a high frequency power meter, a transducer for signal pick up, an oscilloscope, and a frequency counter. The frequency and amplitude of oscillations are monitored by the transducer pick-up which is located on the vibrating transducer assembly.

Determination of Threshold Velocities

Six test specimens were attached at three radial locations in the rotating disk described previously. This enabled the observation of two specimens at a preselected test velocity ensuring the reproducibility and reliability of the experimental observation. The test specimens were 3/8" inch in diameter. The observation of the specimens was adjusted to suit the test sequence in order to determine when denting or fracture occurred (i.e. frequent observations were taken at higher velocities where damage could be observed in a short time and the inverse for low velocities.) The observation consisted of removing a test specimen and of observing the surface exposed to liquid impact with 10 X magnification under side lighting which would make the initial indentations "stand out" when illuminated at the proper angle to the surface. The time taken for the initiation of permanent plastic indentations on the surface of the test specimen through this procedure was recorded for different test

velocities. The number of impacts were calculated from the number of revolutions during that time multiplied by two - the impacts per revolution. The relationship between the number of impacts to initiate erosion and the corresponding threshold velocity was plotted.

After the appearance of plastic dents on the specimen surface, this area of denting will continue to work harden as the test progresses, resulting in the fracture of small fragments of material from the surface.

Determination of High Frequency Endurance Limit

The underlying principle of the high frequency fatigue technique is the creation of longitudinal vibrations in a fatigue specimen designed to produce maximum uniaxial alternating strains at the nodal point at resonant frequency. These strains are further amplified by means of a well designed test specimen. The test specimen as shown in Figure 3 was designed by Thiruvengadam and is tuned for 20 KHz.

The maximum strains at the node of the fatigue specimen can be calculated from the following formula:

$$\epsilon = M \frac{2 \pi \xi}{\lambda}$$

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where ϵ = the strain amplitude at the node
 ξ = the displacement amplitude at the anti-node
 λ = the wave length in the material and
 M = Magnification Factor

The stress can be obtained by multiplying the strain with the modulus of elasticity. The frequency was accurately measured with a frequency counter and the time to failure was noted with the number of cycles to failure computed from the frequency.

RESULTS AND ANALYSIS

Correlation of Water Hammer Stresses with High Frequency Endurance Limits

Figure 4 shows the relationship between the velocity of impact and the number of impacts after which indentations were observed on the test material.

When a cylindrical column of liquid impinges on the surface of a material, the maximum stress developed at the point of contact by the impact ("water hammer" stress) is derived as:

$$\sigma_i = \frac{\rho_i C_i V_i}{1 + \frac{\rho_i C_i}{\rho_m C_m}} \quad [1]$$

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where

V_i = impact velocity

ρ_l = density of liquid

ρ_m = density of material

C_l = velocity of sound in liquid

and C_m = velocity of sound in the material.

For this investigation in which water was the test liquid and a common metal was the test material, the ratio is small compared to unity. Then the water hammer stress becomes:

$$\sigma_i = \rho_l C_l V_i \quad [2]$$

The values of $\rho_l C_l V_i$ were calculated for the data shown in Figure 4. The values of ρ_l and C_l for water were obtained from published literature.

The ratio of high frequency fatigue strength to the water hammer stress for erosion inception is shown in Figure 5 for the test material.

CONCLUSIONS AND RECOMMENDATIONS

Utilizing the relationship between the velocity of impact and the number of impacts to produce visible erosion, the threshold impact velocities were determined as 220 fps and 140 fps at 10^7 cycles and 10^8 cycles respectively. The relationship between the high frequency fatigue strength and the number of cycles to failure was determined at room temperature up to a maximum of 10^9 cycles. The high frequency endurance limit at room temperature was determined to be approximately 32,000 psi for 10^8 cycles. In addition, the ratio of high frequency fatigue strength to the water hammer stress for erosion inception was determined as 2.75.

As evidenced by the formation of oxide films, it appears that the 2 1/4 Cr-1 Mo steel could be considered corrosion prone. It would therefore be our recommendation that supplemental tests be conducted with pre-oxidized specimens. In conjunction with the temperatures associated with the LMFBR, we also recommend generation of high frequency fatigue data at high temperatures for correlation to threshold impact speeds of high temperature operation.

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REFERENCE

1. A. Thiruvengadam, S.L. Rudy, and M. Gunasekaran "Experimental and Analytical Investigations on Multiple Liquid Impact Erosion" NASA CR-1638, National Aeronautics and Space Administration, Washington, D.C., September 1970.

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FIGURE 1 - TEST SPECIMEN IMPACT ON LIQUID JET.

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FIGURE 2 - BLOCK DIAGRAM OF THE HIGH FREQUENCY FATIGUE TESTING APPARATUS.

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FIGURE 3 - HIGH FREQUENCY FATIGUE SPECIMEN
FOR 2 1/4 CR-1 Mo STEEL.

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FIGURE 5 - CORRELATION OF HIGH FREQUENCY FATIGUE STRENGTH TO THE WATER HAMMER STRESS FOR EROSION INCEPTION $\left(\frac{\sigma_a}{\rho c V} = 2.75\right)$