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MASTER

FATIGUE CRACK GROWTH CHARACTERISTICS OF NUCLEAR PRESSURE VESSEL GRADE MATERIALS

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HEAVY SECTION STEEL TECHNOLOGY PROGRAM

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

Fatigue Crack Growth Characteristics Of Nuclear Pressure Vessel Grade Materials

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Summary

The fatigue crack growth rate of pressure vessel grade materials is being studied in high temperature pressurized water. Initially, ultrasonic monitoring techniques were used to measure the crack growth in the 2T WOL specimens. However, utilization of ultrasonic monitoring techniques required fixing the test specimen to the test chamber head. It was concluded that because of the constrainment of the head, the stress intensity "K_{Ic}" at the crack tip was not well defined. As a result, the experiment was redesigned to utilize compliance calibration to experimentally measure rates of crack propagation.

Twelve (12) 2T WOL specimens fabricated from A533, Grade B, Class 1 base plate and weldment material were evaluated in PWR and BWR water environment. It was concluded that the water environment did not have an effect on the fatigue crack growth rate of the materials investigated.

Background

Using the fracture mechanics approach, the effect of an environment of high temperature primary reactor grade water on the fatigue crack growth characteristics of nuclear pressure vessel grade materials is being studied. The stress intensity concept of linear elastic fracture mechanics provides a parameter K which describes the stress situation at the tip of an existing crack. It has been shown that the cyclic range of the stress intensity factor, ΔK, is the controlling stress parameter which determines the fatigue crack growth rate. The crack growth rate da/dN of pressure vessel materials is being measured as a function of ΔK_I, the change in the stress intensity at the tip of the crack.

The fatigue crack growth data are being generated with 2T WOL (Wedge Opening Loading) specimens at 550°F in an environment (excluding irradiation) typical of Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR). The 2T WOL specimen is illustrated in Figure 1.

Tests are being performed on A533, Grade B, Class 1 steel (HSST Plate 02) and weld metal prepared by the submerged-arc, electroslag, and manual-arc processes. Material from the HAZ (heat-affected-zone) of the weldments prepared by the submerged-arc and manual-arc processes are also being studied.

A test chamber was designed and fabricated to operate at 550°F and 2000 psi. The test chamber was fabricated from stainless steel. The water was pumped from an auxiliary tank through the test chamber. Typical water chemistry is given in Table 1. Cycling rates were from 60 to 600 cycles per minute for a minimum of 100,000 cycles. Initially, the ultrasonic crack growth monitoring technique was utilized to measure the crack growth in the 2T WOL specimens. Use of ultrasonics as the chosen crack growth rate monitoring technique required that the test specimen be clamped to the lid of the test chamber. However, it was concluded that because of the constrainment of the chamber lid, the "stress intensity K_I" at the crack tip was not well defined. To correct this problem, the experiment was redesigned to utilize compliance (LVDT gauge) to measure the crack growth rather than the ultrasonic crack monitoring technique.

Experimental Results

Crack length "a" versus number of cycles "N" data were generated for twelve (12) 2T WOL specimens. In order to express the raw test data ("a" versus "N") in terms of fracture mechanics, the data were converted to the form of crack growth rate, da/dN versus the cyclic stress intensity range, ΔK. The crack growth rate was established by computing the slope between successive data points on the "a" versus "N" curve obtained by means of compliance (crack opening displacement). The ΔK values associated with a particular crack length, and in turn the corresponding crack growth rate was determined from the following expression:

$$\Delta K = K_{max.} - K_{min.} = Y \frac{P_{max.} \sqrt{a}}{BW} - Y \frac{P_{min.} \sqrt{a}}{BW}$$

where "a" is the crack length measured from the centerline of loading, Y is a compliance constant which depends upon a/W, W is the specimen width (see Figure 1), B is the specimen thickness, $P_{max.}$ and $P_{min.}$ are the maximum and minimum load per cycle. The results are presented in Figures 2, 3, 4 and 5. Figures 2 and 3 present the 550°F fatigue crack growth rate versus stress intensity factor range relationship for specimens fabricated from the base metal (HSST Plate 02). Figure 2 represents data generated in PWR water chemistry and Figure 3 data generated in BWR environment. The upper scatterband from similar data generated by Clark(1) with A533, Grade B, Class 1 base plate is also shown in Figures 2 and 3. The fatigue crack growth rate versus stress intensity factor range relationship for specimens fabricated from the weldment materials are shown in Figures 4 and 5. Figures 4 through 5 show that there is not an effect of water chemistry (PWR and BWR) on the fatigue crack growth rate of the materials investigated (base, weld metal and HAZ metal) for specimens fatigue at 600 cycles per minute. However, for tests performed at 60 cycles per minute in BWR water chemistry, the data fall outside Clark's scatterband at the low ΔK values. This anomalous behavior is probably related to the threshold level which is outside the realm of this experiment.

Conclusions

To date, the presence of nuclear reactor grade water environment (chemistry and pressure) for PWR and BWR was found not to have an effect on the fatigue crack growth of A533, Grade B, Class 1 steel base plate and weldments. Comparison of the results obtained for each material tested at 550°F and 600 cycles per minute indicated that the upper scatterband of the crack growth rate data for the base plate material at 75°F encompass all other data.

TABLE I

TYPICAL CHEMISTRY OF PROPOSED ENVIRONMENT (WATER)

(ppm)

	Pressurized Water Reactor	Boiling Water Reactor
Oxygen	<0.1	0.2 - 0.4
Chloride	<0.15	<0.2
Fluoride	<0.15	<0.1
Total Suspended Solids	<1.0	<0.2
Boron	0 - 4000 (2500)	
Solution pH	4.2 - 10.5 (5.1)	6 - 6.5
Electrical Conductivity	<1 - 40 - umhos/cm	<0.1 - umhos/cm
Hydrogen	25 - 35 cc (STR)/KG	0.03 - 0.05
Li (OH)	0.3×10^{-4} to 3.2×15^{4} molal	

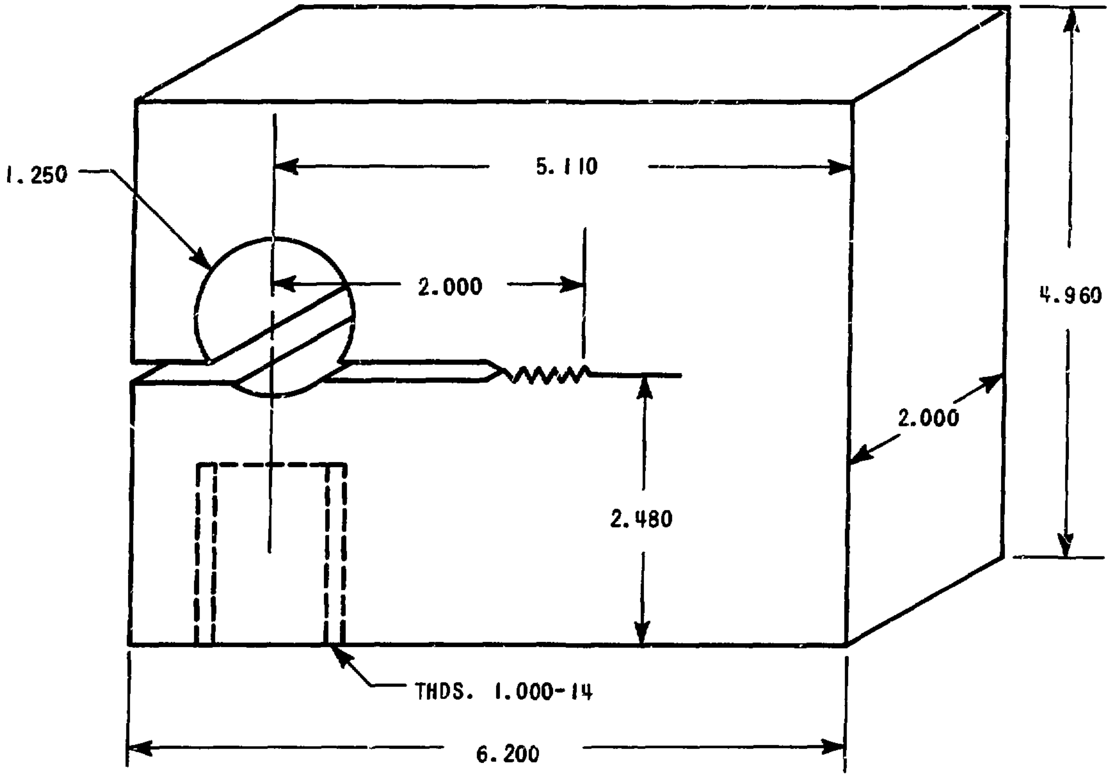

Figure 1. "2T" WOL Type Compact Fracture Toughness Specimen

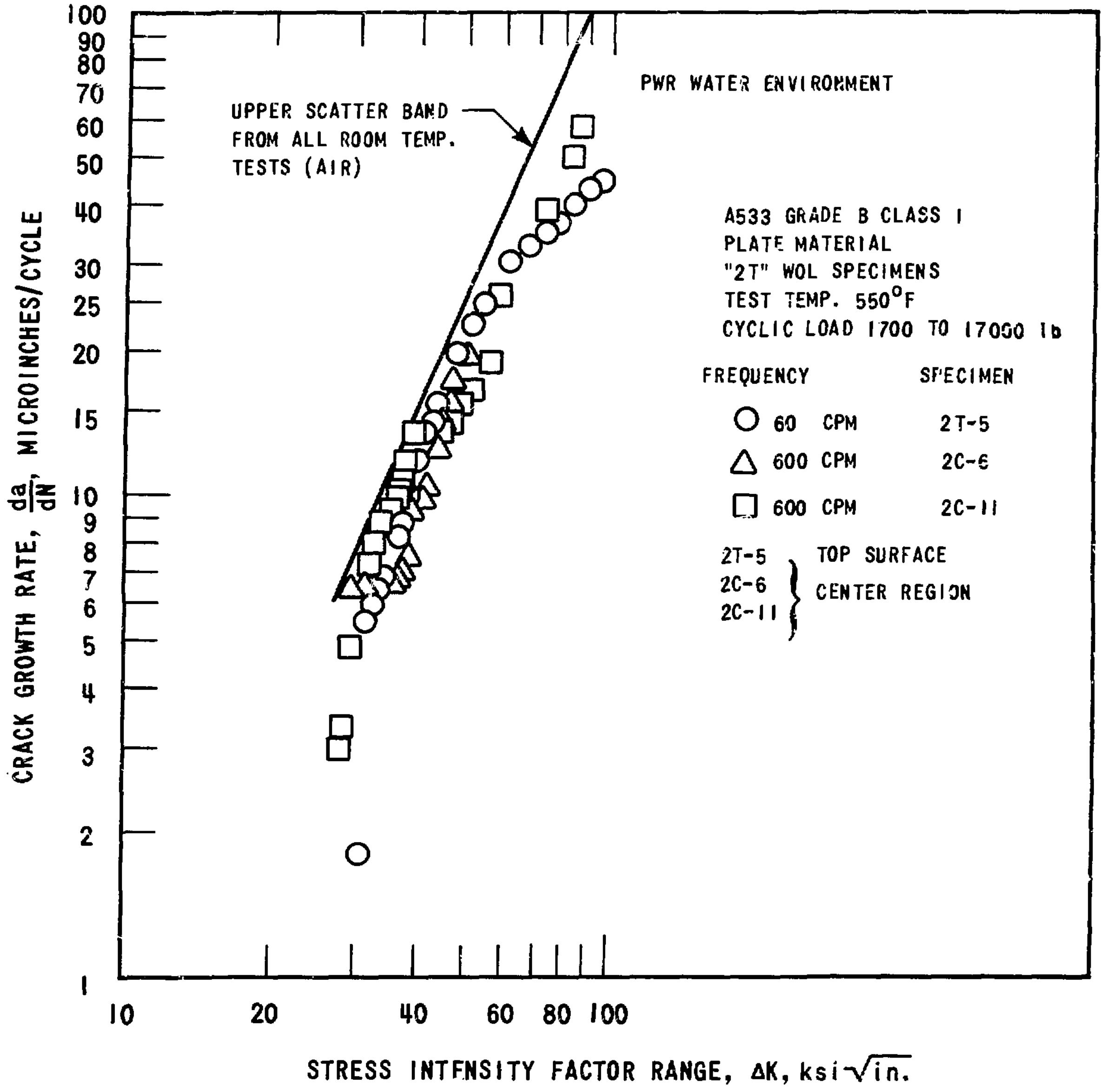

Figure 2. Crack Growth Rate as a Function of ΔK for A533 Grade B Class 1 Steel Plate in PWR Environment

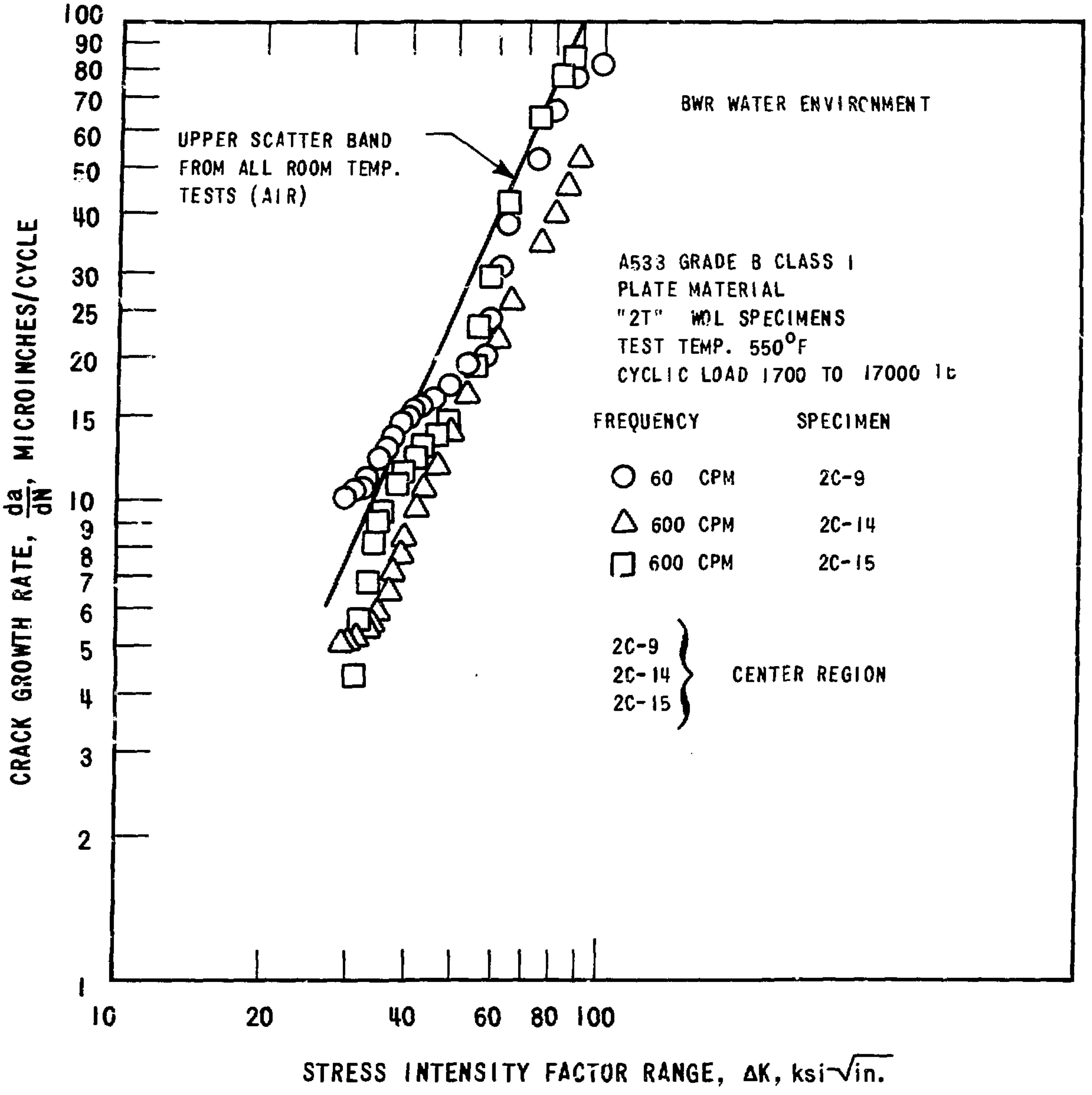

Figure 3. Crack Growth Rate as a Function of Δ K for A533 Grade B Class 1 Steel Plate in BWR Environment

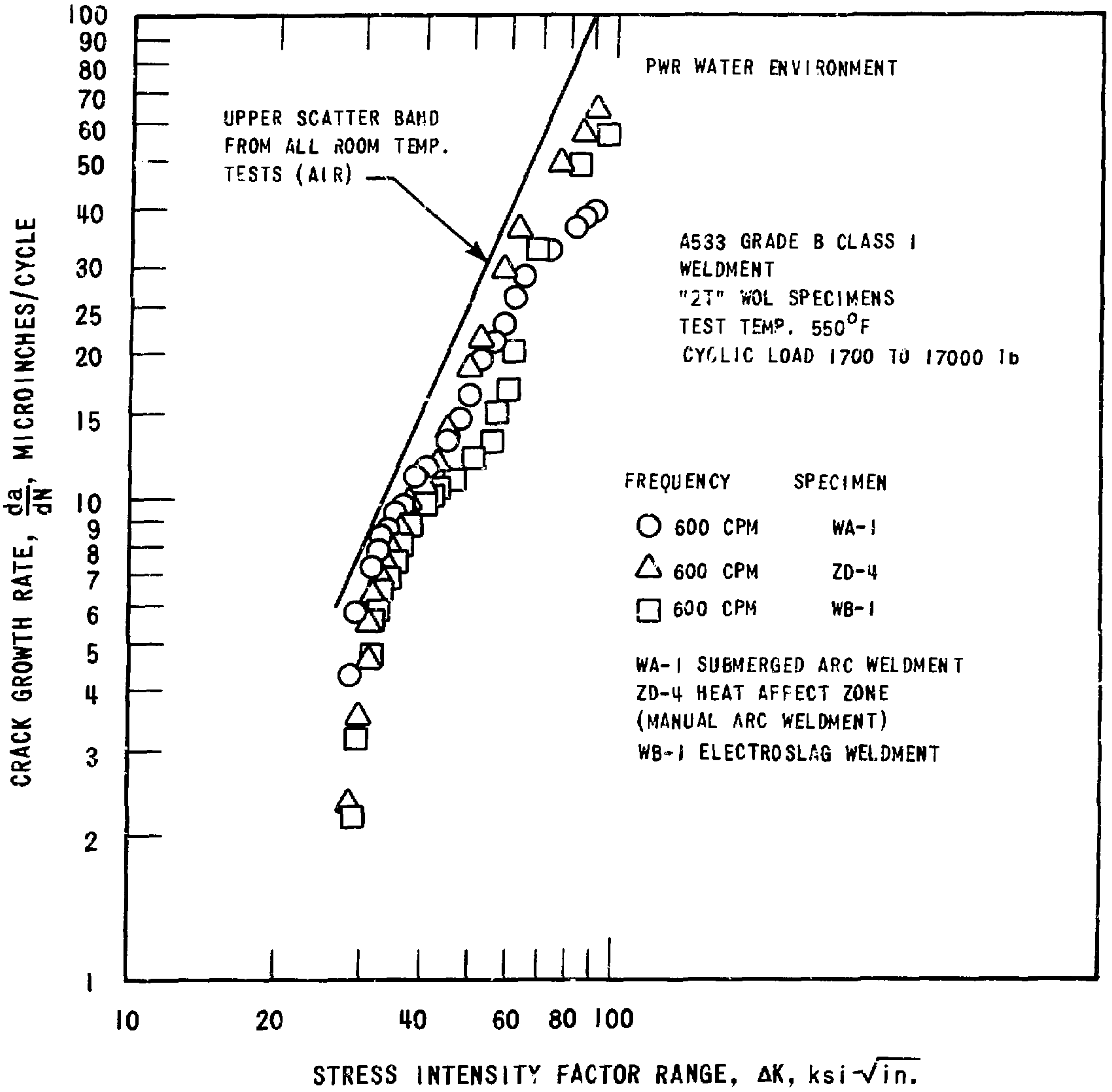

Figure 4. Crack Growth Rate as a Function of ΔK for A533 Grade B Class 1 Weldment Material in PWR Environment

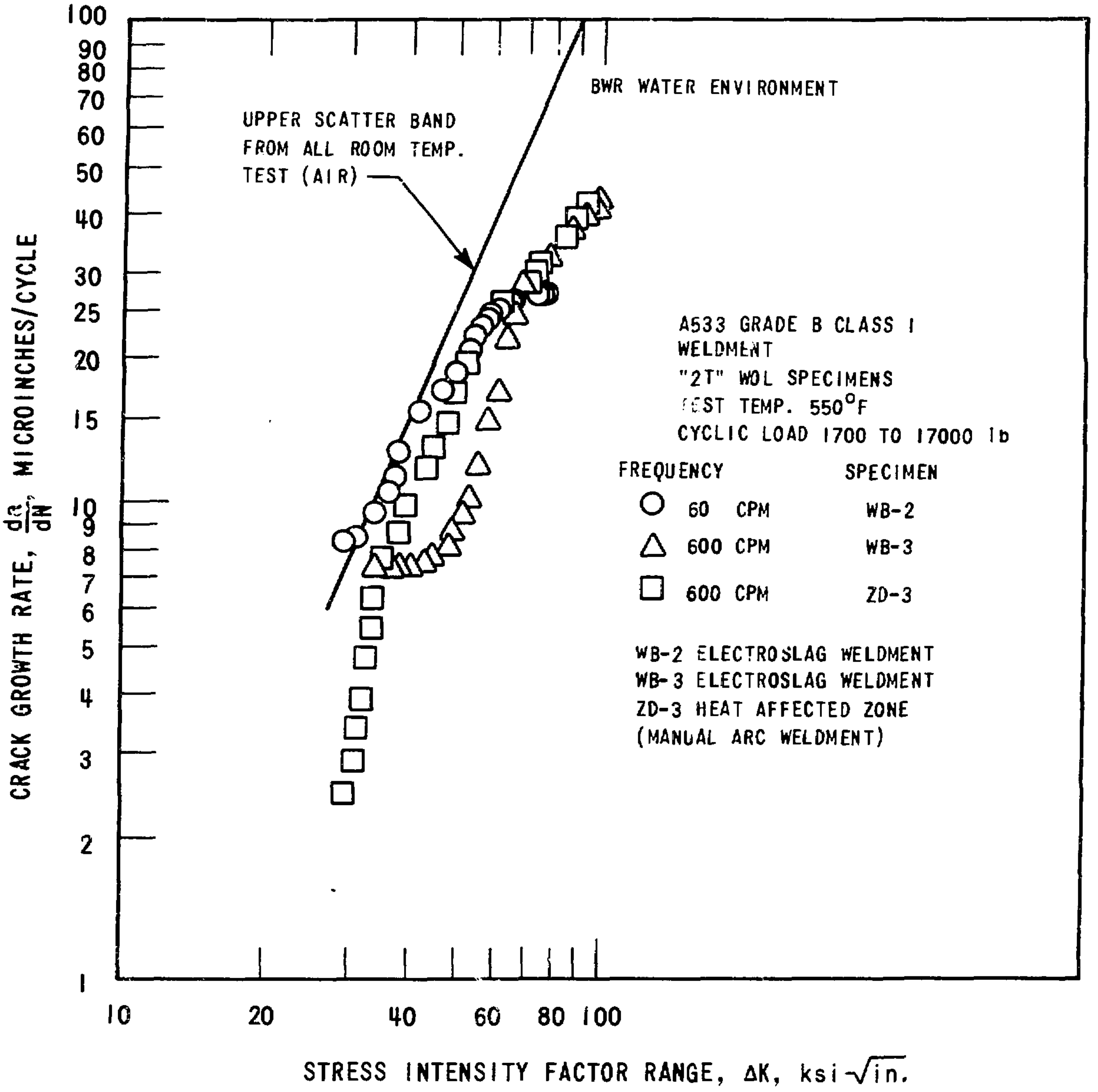

Figure 5. Crack Growth Rate as a Function of ΔK for A533 Grade B Class 1 Weldment Material in BWR Environment

References

1. W. G. Clark, Jr., ASME Paper 70-PVP-24, "Fatigue Crack Growth Characteristics Of Heavy Section ASTM A533 Grade B, Class 1 Steel Weldments".