IN-VACUUM CYCLIC FATIGUE BEHAVIOR OF VANSTAR-7 AT ELEVATED TEMPERATURES

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ABSTRACT

Refractory metal alloys have been proposed for fusion reactor and space power applications because of their high temperature strength, low thermal stress properties, good compatibility with liquid metal coolants and radiation resistance. However, little is known about the cyclic fatigue properties which are important to some fusion reactor first wall systems that operate in thermal cycles. This paper presents limited results of in-vacuum cyclic fatigue tests on Vanstar-7 (9Cr–3Fe–Zr) at room temperature, 550 and 650°C. Miniature hourglass-shaped specimens were used with a gage diameter of 3.18 mm. The material was annealed 1 h in vacuum at 1400°C before machining, to produce an average grain size of ASTM No. 7. The specimens were stress relieved for 0.5 h at 1400°C after machining.

Tests were performed on a servocontrolled hydraulic testing system equipped with a vacuum chamber capable of pressures below 10^{-5} Pa. Specimens were heated by an induction heater, maintaining temperatures within ±2°C of the nominal temperature during the test. A diametral extensometer was used, but axial strain calculated via a strain computer was used for machine control. A fully reversed triangular wave function beginning with compression was employed at a strain rate of 4×10^{-3} s^{-1} for all low-cycle tests. High cycle testing was conducted initially in strain control but switched to load control after stable essentially elastic cycling was established.

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Figure 1 shows the cyclic fatigue life of Vanstar-7 tested in high vacuum at room and elevated temperatures. The room temperature curve represents a two-term power law relation between the total strain range and cycles to failure using a least squares method. The curves representing fatigue behavior at 550 and 650°C are drawn by eye inspection. Both are very similar with the 650°C being slightly lower than the 550°C one. A reduction in fatigue life was noticed at elevated temperatures relative to room temperature with a trend showing a factor of about two at 2% strain, which increased progressively to about 20 at 0.7% strain. Examinations of the micrographs of rupture surfaces indicated that grain boundary cracking around large particles rich in Zr, believed to be ZrC, might have been the fatigue initiation site which lowered the high temperature fatigue performance in the low strain range.

The Vanstar-7 data were compared to previously obtained vacuum fatigue curves for V—15Cr—5Ti, another first wall candidate alloy. The fatigue life was generally lower for Vanstar-7, as seen in Fig. 1. No specimens were tested at the extreme high-cycle end to determine the endurance limit strain range for Vanstar-7. But the data trend indicates that it would be much lower than that of V—15Cr—5Ti.

Comparison was also made between Vanstar-7 data and that of 20% cold-worked type 316 stainless steel at 550 and 650°C, respectively, as shown in Fig. 2. At the high strain range above 1%, the fatigue lives are about the same for both materials. However, at strain ranges below 0.8%, Vanstar-7

exhibited better fatigue life compared to the stainless steel by a factor of about 2 to 10 as the cyclic strain range decreases to 0.55%. On the basis of the above observations and more favorable thermomechanical stress behavior of vanadium-based alloys in general, it is clear that Vanstar-7 has potential value for fusion reactor applications.

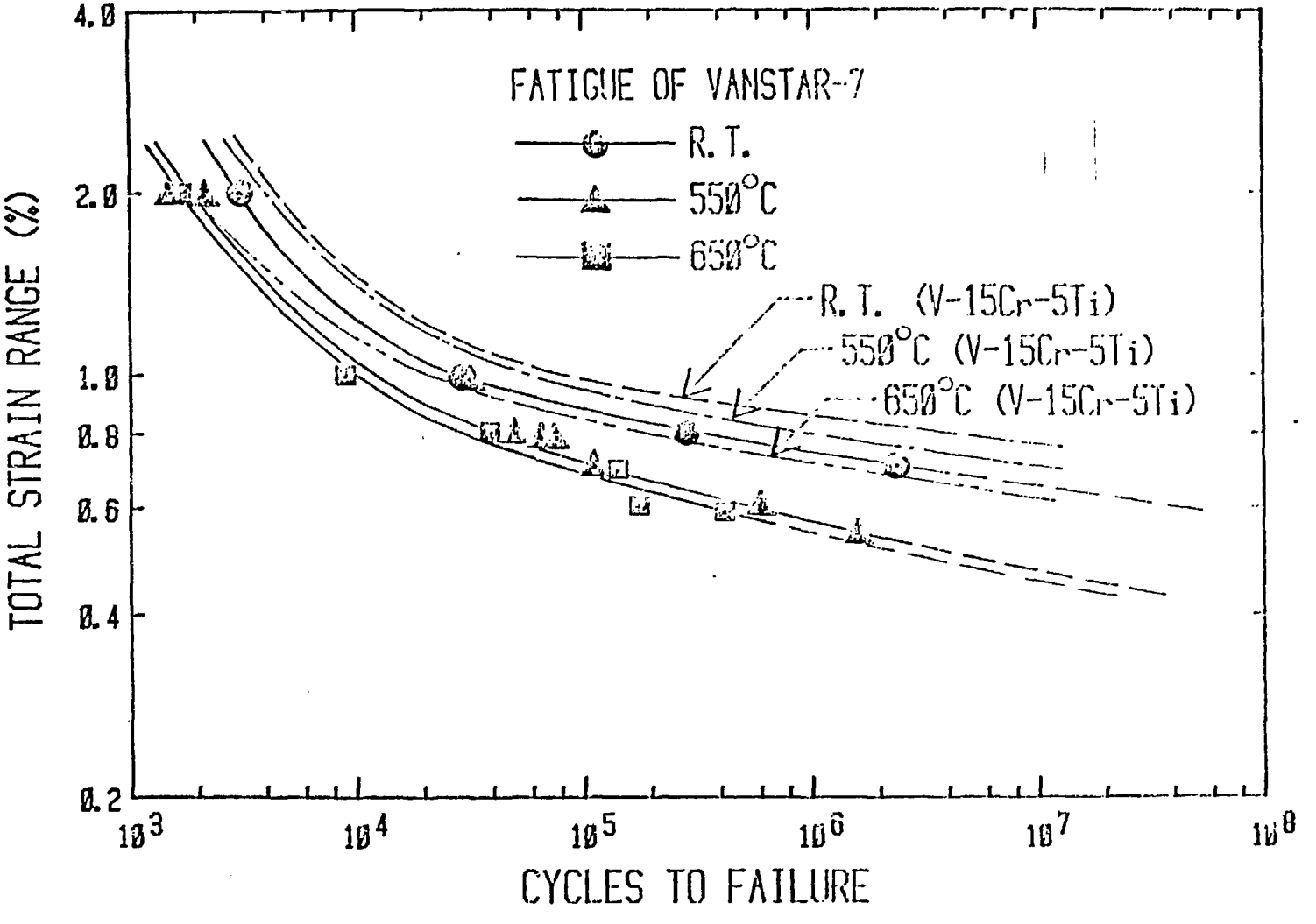

Fig. 1. Comparison of cyclic fatigue data for Vanstar-7 with previously obtained fatigue lifetime curves for V–15Cr–5Ti tested at 25, 550, and 650°C, respectively.

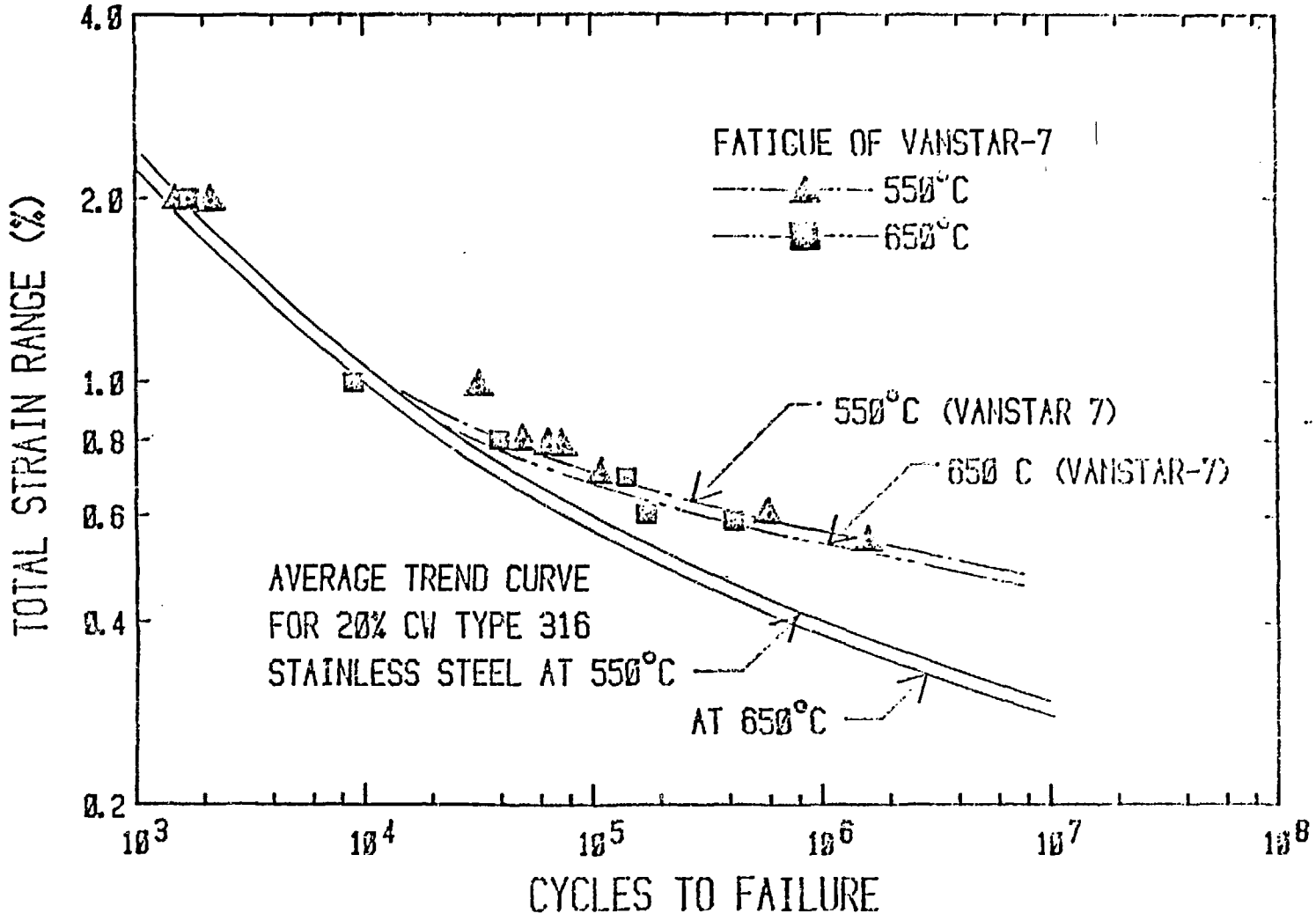

Fig. 2. Comparison of fatigue behavior of 20% cold-worked type 316 stainless steel and Vanstar-7 tested at 550 and 650°C, respectively.