THE EFFECT OF TEMPERATURE UPON THE FATIGUE CRACK PROPAGATION BEHAVIOR OF ALLOY 625

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ABSTRACT

The fatigue crack propogation behavior of annealed Alloy 625 was studied in an air environment over the temperature range 24°-649°C. In general, crack growth rates tended to increase with increasing temperature. Two heats were studied, and the differences in behavior between them suggest a heat-to-heat variability. Characterization of stress ratio ($R = K_{min}/K_{max}$) effects was also done at a temperature of 538°C.

INTRODUCTION

Alloy 625 is often employed in applications where corrosion resistance at elevated temperatures is an important consideration. Many such applications involve cyclic stresses, and hence knowledge of the fatigue crack propagation (FCP) behavior may be necessary to verify the component lifetimes. The objective of this paper is to review the effect of temperature upon the FCP behavior of Alloy 625, as well as the effect of stress ratio at one elevated temperature.

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EXPERIMENTAL PROCEDURES

Two studies (1,2) have investigated the effect of temperature upon the FCP behavior of Alloy 625. In both cases, the material was in the annealed condition. The chemical compositions and mechanical properties* are shown in Table I and Figure 1, respectively. It will be noted that the yield strength does not change appreciably over the range 24°-649°C (75°-1200°F).

Reference 1 employed single-edge-notch cantilever-bend specimens (L-T orientation per ASTM E616) with width (W) and thickness (B) dimensions of 63.5 mm (2.5 in.) and 12.7 mm (0.5 in.), respectively. The Reference 1 tests were conducted at a cyclic frequency of 0.167 Hz and a stress ratio ($R = K_{min}/K_{max}$) of zero. Reference 2 utilized the ASTM E647 Compact Specimen design. Two specimen sizes were employed: W = 50.8 mm (2.0 in.) and W = 29.3 mm (1.15 in.). With the exception of a series of stress ratio effects tests which were conducted at a frequency of 6.67 Hz, the Reference 2 tests utilized a sinusoidal waveform at 0.667 Hz and a stress ratio of R = 0.05.

Reference 1 determined fatigue crack growth rates (da/dN) by graphically differentiating a plot of crack length versus cycles, while Reference 2 employed the "secant method" of ASTM E647. Both studies employed travelling microscopes to measure crack lengths optically on the specimen surfaces. In both cases, the tests were conducted in air-circulating furnaces.

RESULTS AND DISCUSSION

The results for the various temperatures studied over the range 24°C (75°F) to 704°C (1300°F) are shown in Figures 2-5. Each figure compares results from the two studies at similar temperatures. Taken as a whole, the results suggest the possibility of a heat-to-heat variation: with the exception of a test temperature of 427°C (Figure 3), the material of Reference 1 tends to exhibit lower FCP rates than that of Reference 2. This may be seen at the common test temperature of 24°C (Figure 3), and also in Figures 4 and 5 where the Reference 1 material at a higher temperature exhibits FCP rates similar to those of Reference 2 at a lower temperature. This is in spite of the somewhat lower cyclic frequency of the Reference 1 tests. Lower frequencies tend to promote higher FCP rates in solid solution-strengthened nickel-base alloys such as Alloy 600 tested in air at elevated temperatures(4). Heat-to-heat variations in FCP behavior are quite pronounced in some precipitation-strengthened nickel base alloys (5), but are not as pronounced in other solid solution-strengthened austenitic alloys such as the 300-series stainless steels(6). Comparing the chemical compositions (Table I) and the mechanical properties (Figure 1) of the two heats of Alloy 625 does not provide a clue as to the reason for the apparent heat-to-heat variability in FCP behavior.

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*The room temperature FCP results from Reference 1 were previously published in Reference 3, and the tensile properties were obtained from Reference 3.

Table I Chemical Compositions, wt pct

No.	C	Si	Mn	Cr	Ni	Mo	Al	Ti	Nb	Fe
1	0.03	0.20	0.07	21.9	62.1	9.0	0.14	0.26	3.55	2.67
2	0.03	0.33	0.10	21.0	62.7	8.5	0.17	0.24	3.50	3.46

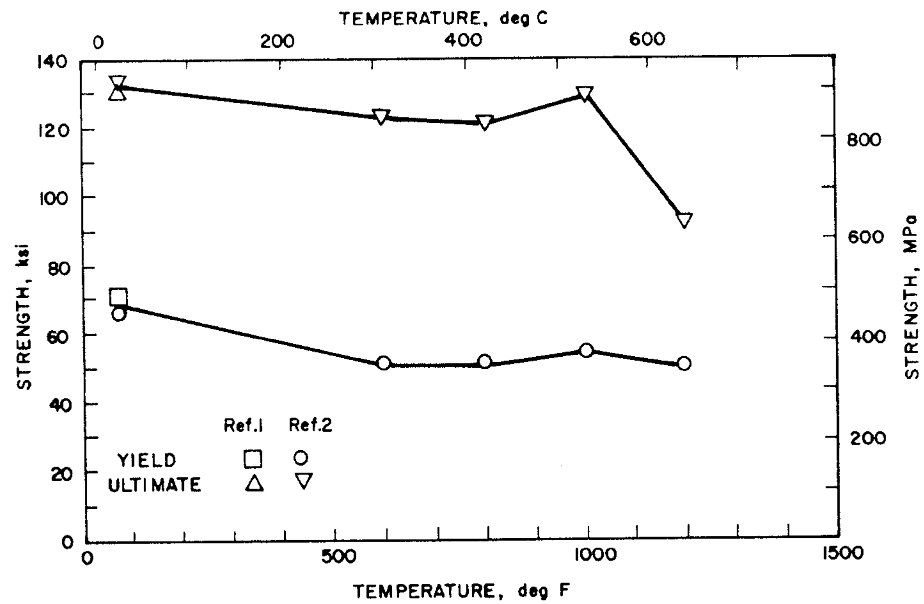

Figure 1. The effect of temperature upon the mechanical properties of annealed Alloy 625. The Reference 2 tests were conducted at a strain rate of 3 x 10^{-5} sec.$^{-1}$.

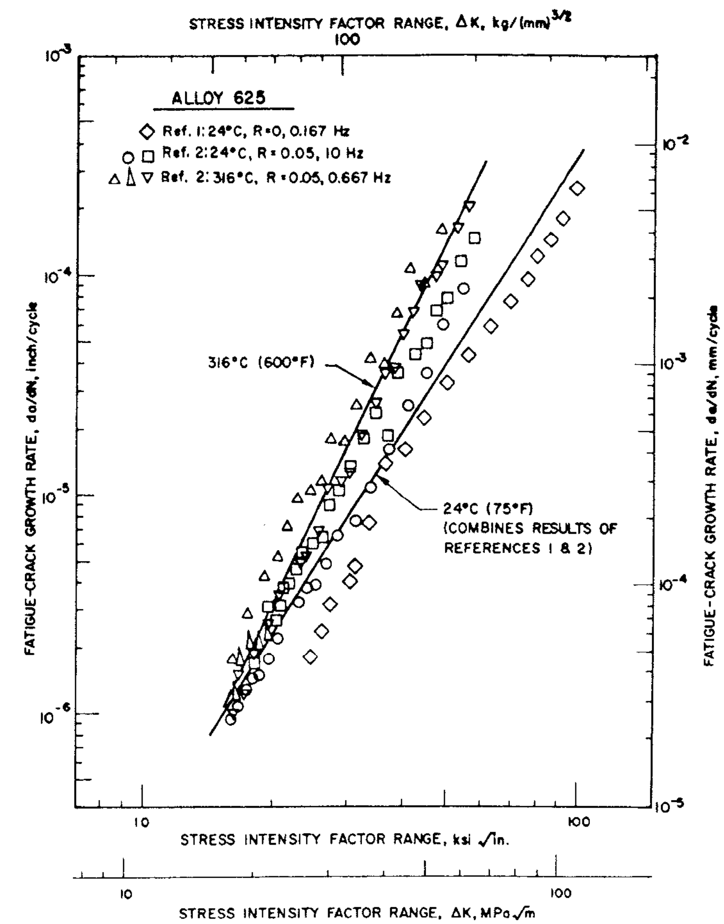

Figure 2. Fatigue crack propagation behavior of annealed Alloy 625 in air at 24° and 316°C.

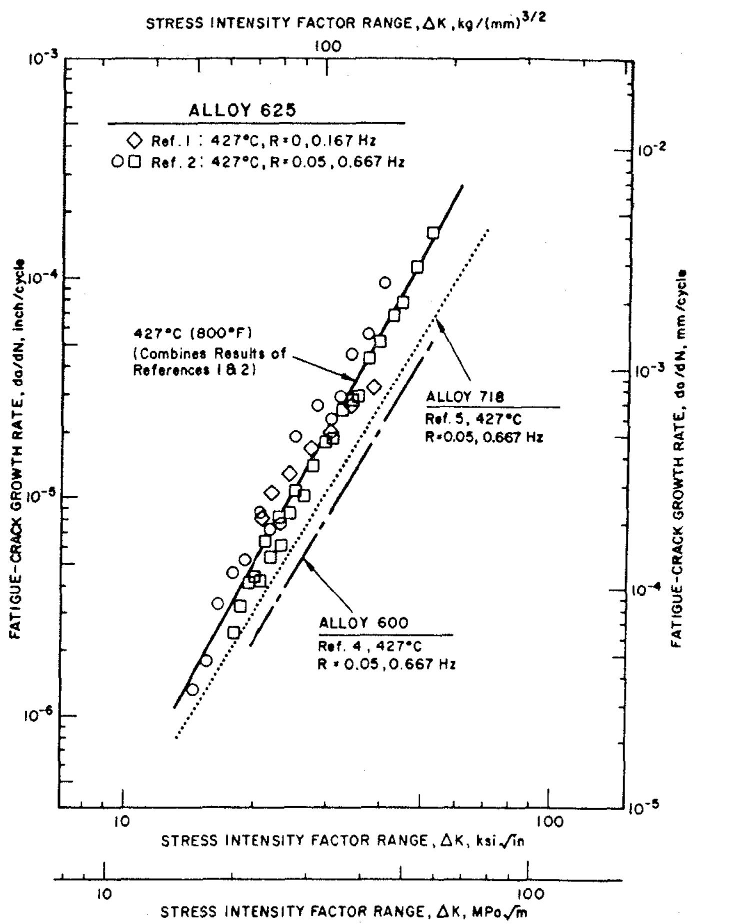

Figure 3. Fatigue crack propogation behavior of annealed Alloy 625 in air at 427°C.

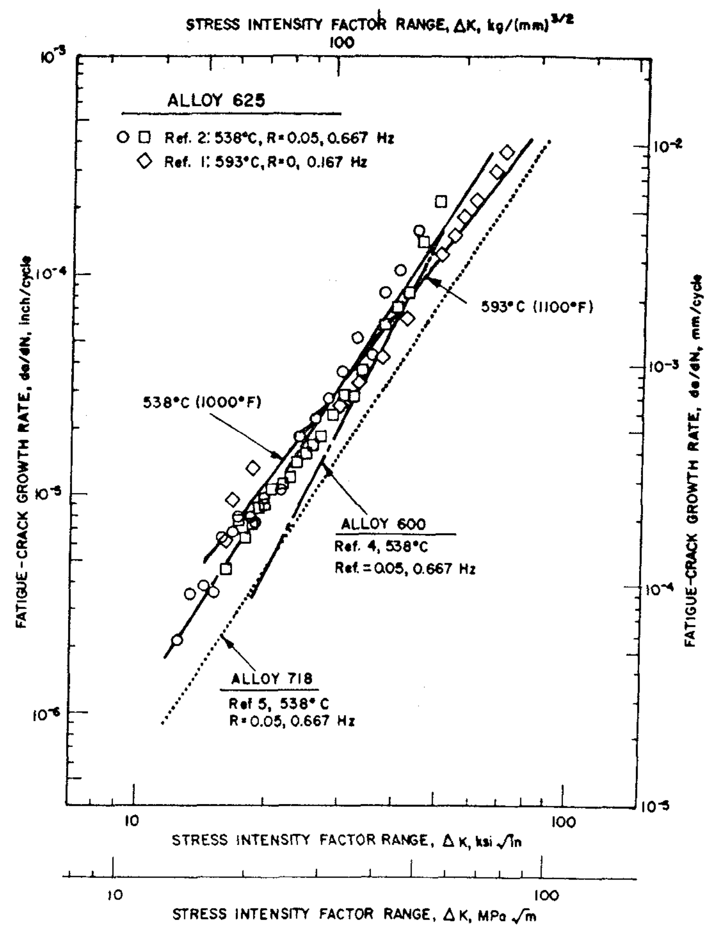

Figure 4. Fatigue crack propogation behavior of annealed Alloy 625 in air at 538° and 593°C.

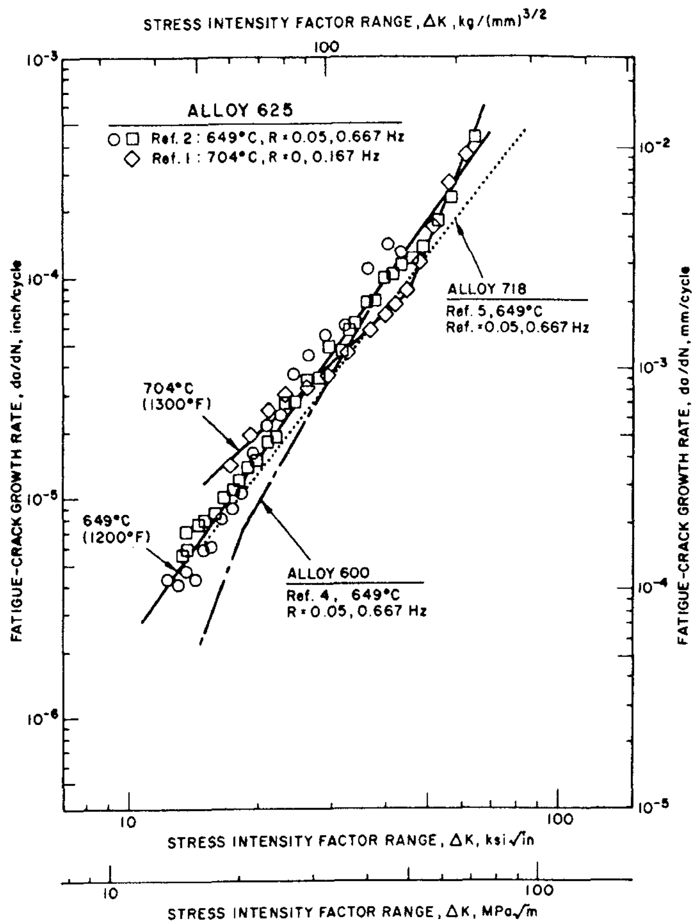

Figure 5. Fatigue crack propagation behavior of annealed Alloy 625 in air at 649° and 704°C.

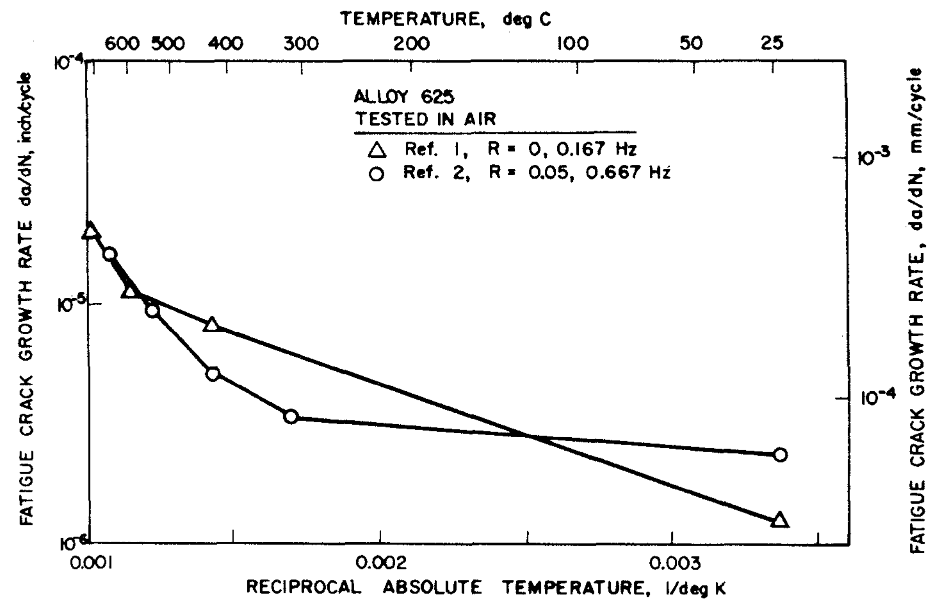

Figure 6. Arrhenius plot of Refs. 1 and 2 crack growth rates taken at $\Delta K = 22$ MPa $\sqrt{in}$ ($\Delta K = 20$ ksi $\sqrt{in}$).

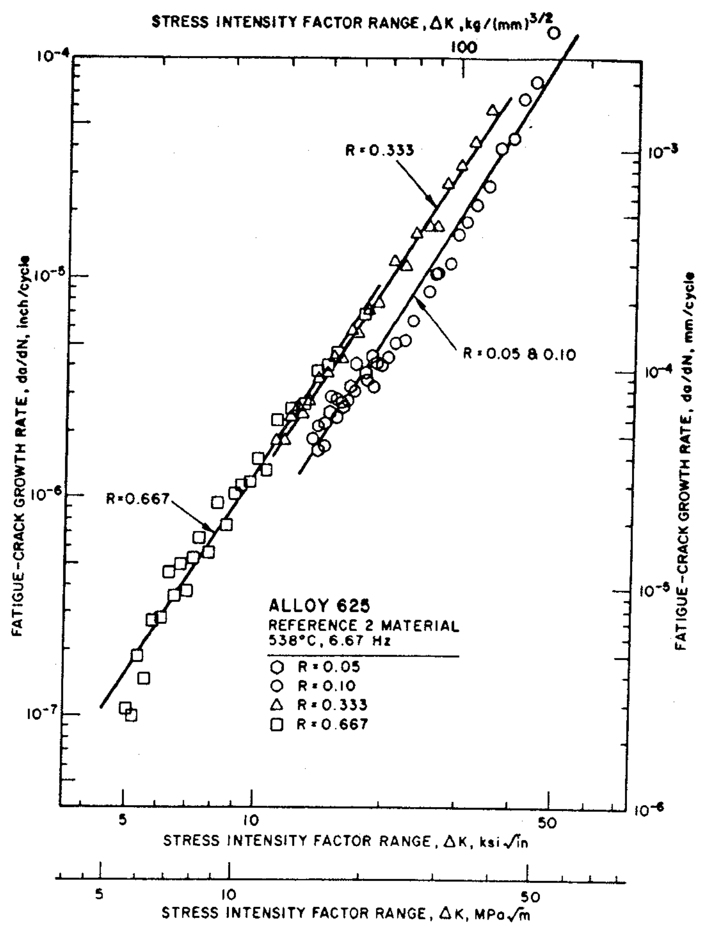

Figure 7. The effect of stress ratio upon the fatigue crack propagation behavior of annealed Alloy 625 in air at 538°C.

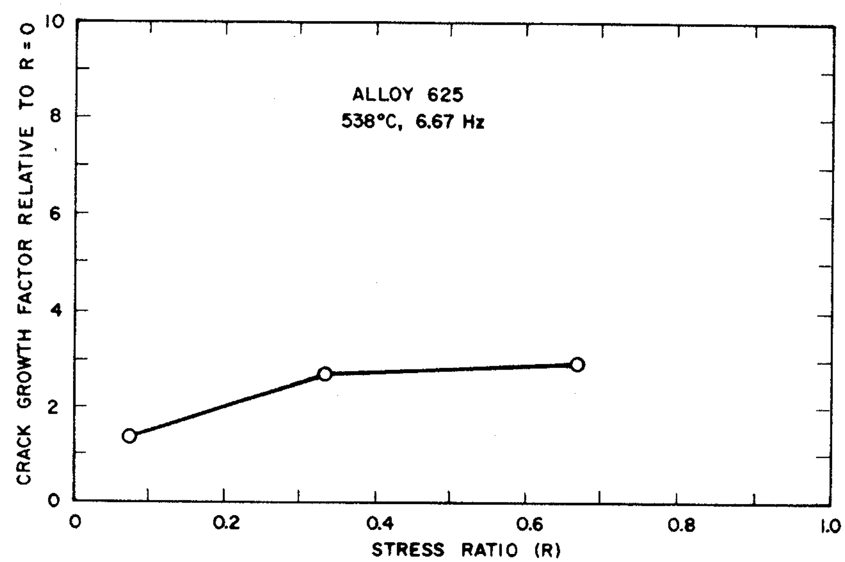

Figure 8. Stress ratio effect (normalized to R = 0) for annealed Alloy 625 in air at 538°C.

It was mentioned previously that two different specimen sizes were employed in the Reference 2 study. The larger size specimen (W = 50.8 mm) results are plotted in Figures 2-5 as a square data symbol. Comparing those data with those for the smaller specimen size confirms that, as long as the remaining ligament criterion of ASTM E647 is met, there is no effect of specimen size upon the FCP behavior.

Comparing the FCP rates for the various temperatures plotted in Figures 2-5 shows that, in general, FCP rates increase with increasing temperature. As discussed earlier, there are a few exceptions where the Reference 1 material exhibits slightly lower FCP rates than the Reference 2 material at a lower temperature. However, the general trend of crack growth rates increasing with increasing temperature still holds, and is also observed in most alloys tested in an air environment (4,5,7). The effect of temperature may also be seen in the Arrhenius plot of Figure 6. Two distinct slopes, one at lower temperatures and the other at higher temperatures, may be seen and that is suggestive of two different mechanisms. Similar trends in an Arrhenius Plot for Type 304 stainless steel may also be seen in Reference 7.

The results from Reference 2 for Alloy 625 are compared in Figures 3-5 with results for Alloy 600 and Alloy 718 tested at the same temperatures, cyclic frequency, and stress ratio. In general, FCF rates in Alloy 625 are equivalent to, or higher than, FCP rates in the other two nickel-base alloy tested under the same conditions.

Fatigue crack growth experimental studies are often, as a matter of convenience, conducted at stress ratios (R) close to zero. However, actual structural applications often involve nonzero stress ratios. Therefore, a small survey of stress ratio effects was conducted on the Reference 2 material at 538°C (1000°F). The results, plotted in Figure 7, show a modest effect of stress ratio over the range $0.05 < R < 0.667$, with FCP rates at a given ΔK increasing with increasing R. The nearly parallel slopes of the curves at the different stress ratios allow the construction of a simple ratio of R effects. Figure 8 plots such a factor that has been normalized relative to the behavior at $R = 0$. For example, FCP rates are approximately a factor of three higher at $R = 0.667$ than at $R = 0$. Note, however, that the stress ratio effects tend to saturate at higher values of R. Stress ratio effects are often associated with crack closure(8), and crack closure effects tend to decrease as R increases.

SUMMARY AND CONCLUSIONS

The results of two studies on the effect of temperature upon the FCP behavior of annealed Alloy 625 were reviewed in this paper. Major conclusions from these studies are summarized below:

- In general, FCP rates in Alloy 625 tested in an air environment increase with increasing temperature. This same trend is noted in most other alloy systems.

- The results of these two studies suggest the possibility of heat-to-heat variability in FCP rates in Alloy 625. The reason(s) for such variability is presently unknown.

- These results confirm that, if the remaining ligament criterion of ASTM E647 is met, there is no effect of specimen size upon the FCP results.

- At a given value of ΔK, FCP rates tend to increase with increasing values of R. This trend, however, diminishes at higher values of R, and this is believed to be due to the decreasing influence of crack closure at higher values of R.

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