CORRELATIONS OF FATIGUE CRACK GROWTH RATE PARAMETERS AT CRYOGENIC TEMPERATURES*

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The fracture mechanics approach to the evaluation of fatigue crack growth behavior provides a rationale for material selection as well as design criteria against fatigue failure. For this reason, the materials industry includes fatigue crack growth studies in the materials design and characterization process for a wide variety of component--e.g., aircraft components, nuclear hardware, marine structures, piping, and bridges. Over the past few years, the fatigue crack growth studies at the National Bureau of Standards (NBS) have been used to characterize a wide variety of cryogenic structural alloys and their welds. This work has been spurred by developments in energy-related fields and by magnetic fusion energy programs. This paper summarizes the observed correlations of fatigue crack growth rate parameters of selected materials at room and cryogenic temperatures in terms of the exponent, m, in the Paris equation, $da/dN = C(\Delta K)^m$, where da/dN is the fatigue crack growth rate in mm/cycle, ΔK is the stress intensity range in $MPa\sqrt{m}$, C and m are material constants.

MATERIALS

The materials studied include ferritic steels [1-4], wrought AISI 300 series stainless steels [5-12], and austenitic steel welds with various welding processes and filler metals [12-17]. The AISI 300 series stainless steels are commonly used Fe-Cr-Ni alloys. The austenitic steel weld data include data on welds of the AISI 300 series stainless steels, as well as

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Table 1. Summary of regression statistics for data of Fig. 1.

	Ferritic Steels	AISI 300 Series Stainless Steels	Austenitic Steel Welds
slope	-1.468	-1.527	-1.474
σ*	0.109	0.0753	0.0646
intercept	-3.749	-3.884	-4.247
σ*	0.507	0.272	0.291
R**	0.966	0.946	0.970

*σ: standard deviation
**R: correlation coefficient; R = 1 implies a perfect correlation

additional Fe-Cr-Ni-Mn, Fe-Cr-Mn, and Fe-Cr-Ni alloys. The testing media are laboratory air, liquid nitrogen, and liquid helium for test temperatures of 295, 76, and 4 K, respectively. The data considered pertain to constant amplitude fatigue loading with a stress ratio equal t 0.1.

The majority of the data collected were obtained in the laboratories of NBS using compact specimens or bend specimens [2-4,6,7,9-11,13-17]. Additional relevant data [1,5,8,12] were included in the analysis for comparison and confirmation. For details of specimen preparation, material compositions and treatment, it is necessary to refer to the original publications.

RESULTS AND DISCUSSION

The Relation Between C and m

It has been shown that there is an empirical linear relation between log C and m for structural steels at room temperature [18,19]. This stud extended the correlation to ferritic steels, AISI 300 series stainless steels, and austenitic steel welds at cryogenic temperatures. The result are shown in Fig. 1. Least-squares regression analyses have been performed for each of the three sets of data of Fig. 1, and the regressio statistics are summarized in Table 1. The results indicate that there is a definite linear relation between log C and m for the materials studied.

A linear relation between log C and m has the following implications. (1) The two constants (C and m) in the Paris equation are not independen and reduce to one constant (C or m) for a specific class of material. (2) Materials with higher values of m have a better fatigue crack growth resistance than those with lower m values in the lower half of the stress intensity range where the Paris equation applies, or vice versa at the higher stress intensity range.

However, it should be pointed out that different materials with same m values and different C values have been observed [20] and the empirical relation between log C and m should be treated as a trend rather than a rule.

The Relation Between m and Fracture Toughness and Yield Strength

The results of m vs. fracture toughness and m vs. yield strength are plotted in Fig. 2. Figure 2a shows that the value of m is independent of fracture toughness at fracture toughnesses greater than 90 MPa$\sqrt{m}$. Below 90 MPa$\sqrt{m}$, high values of m are observed. The high values of m in low fracture toughness specimens can be attributed to the concurrent occurrence of monotonic fracture, such as cleavage or intergranular fracture, with fatigue crack growth [20].

As shown in Fig. 2b, the value of m is independent of yield strength except that in high yield strength specimens the scatter in m becomes more pronounced.

The Relation Between m and Material Type

Examination of Fig. 1 has shown that there is a temperature effect o m for ferritic steels when temperature decreases from 295 to 76 and 4 K, but not for AISI 300 series stainless steels and austenitic steel welds. The effect of temperature in ferritic steels relates to the effect of fracture toughness on m, as mentioned in the previous section. Ferritic steels are b.c.c. metals that exhibit ductile-to-brittle transitions when temperature decreases sufficiently. At low temperatures, ferritic steels become brittle (low fracture toughness), and this produces high m values. No temperature effect on m is observed in AISI 300 series stainless steel and austenitic steel welds because these f.c.c. metals do not exhibit ductile-to-brittle transitions as temperature is decreased from 295 to 4 K.

Fig. 1 also indicates that the AISI 300 series stainless steels have least spread in m values and the austenitic steel welds have a higher average m value than the AISI 300 series stainless steels do (4,43 vs. 3,57).

CONCLUSION

The following conclusions can be drawn from the present study:

1. There is a linear relation between log C and m in the Paris equation for the cryogenic structural alloys and welds studied.
2. The value of m is independent of fracture toughness and yield strength of the materials except in low fracture toughness materials; in the latter case, m increases as fracture toughness decreases below 90 MPa$\sqrt{m}$.
3. There is a temperature effect on m for ferritic steels but not for austenitic steels; low temperatures tend to yield higher m values for ferritic steels.

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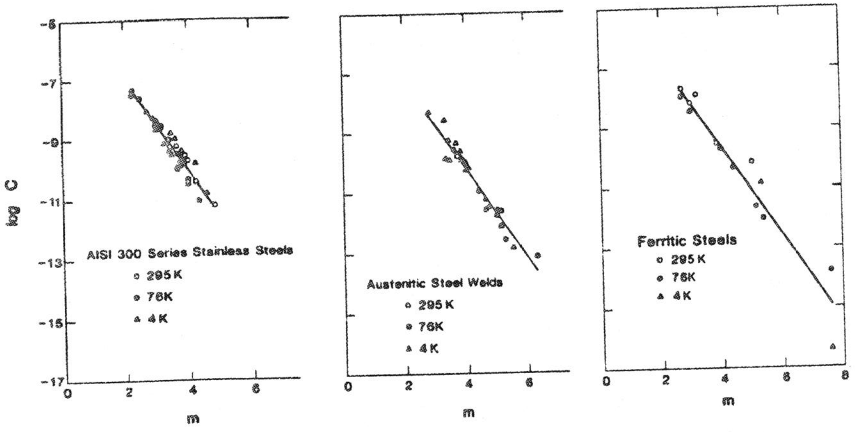
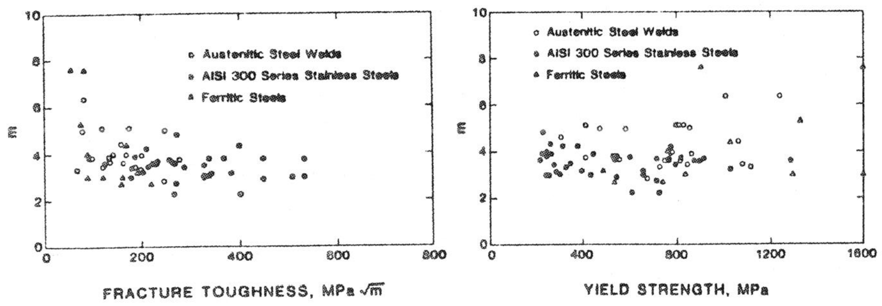


Fig. 1. Relation between logC and m.



(a)

(b)

Fig. 2. Relation between m and fracture toughness (a) and yield strength (b). Note: fracture toughness were converted from J-integral which was obtained from the single-specimen test technique.