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FATIGUE AND FRACTURE PROPERTIES OF Co-Fe ALLOYS AT 150^0 C

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ABSTRACT

The results of a series of fatigue tests performed on two Co-Fe alloys at 150°C are reported. The ratio of the minimum to maximum load, R, in all tests was 0.1. Both materials behaved in a similar manner, with a fatigue limit (ie maximum stress to cause failure in 10^6 cycles) of 800 MPa (ie a stress range of 80 to 800 MPa). Following initiation, a short period of fatigue crack growth is followed by a fast fracture process. During fast fracture, the crack bifurcates; the bifurcation angles lie in the range 32° to 39°.

KEYWORDS

Fatigue, Co-Fe, Fast Fracture, Bifurcation.

INTRODUCTION

Cobalt iron alloys, are used in a wide variety of engineering applications, because they can be made with a combination of high mechanical strength and have a high level of magnetic saturation performance. In some situations, it is also necessary for these materials to operate at elevated temperatures and under variable loading conditions, such that fatigue must be considered as a possible failure mode. This paper contains the results of a series of tests performed on two Co-Fe alloys developed for use in a variable frequency generator for aeroengine applications. The materials, designated Rotelloy® 7 and Rotelloy® 8, were supplied by Carpenter Technology UK, as part of a DTI funded project managed by Lucas Aerospace.

TEST CONDITIONS, SPECIMEN GEOMETRY AND LOADING

The tests were performed on a 250kN Mayes, servo-electric machine, at 150°C. Chromel-alumel thermocouples (TL (70, type)) were attached to each specimen to control the temperature of the three zone furnace; the specimen temperature was held constant to within $\pm 1^oC$. The specimens were machined from 0.34mm thick (nominal) sheet; the other specimen dimensions are given in Fig 1. Because of the inevitable stress concentration features which results from the gripping arrangements, the waisted section at the centre of the specimen was included to ensure that fatigue failure would occur in the central, test section of the specimen, rather than at the grips or in the radii at the ends of the parallel sections of the specimens. Finite element analyses were performed to establish a suitable radius, r, for the "neck" section of the specimen; it was necessary to have as near to a uniform stress across the "neck" section as possible. The variation of the stress concentration factor, SCF, with r is indicated in Fig 2. A radius r = 50mm was chosen to simplify the manufacturing process and to ensure that a maximum SCF of 1.07 would occur. All fatigue tests were performed with a minimum load to maximum load ratio, R = 0.1.

TEST RESULTS

The results for the uniaxial fatigue tests are presented in Table 1 and are plotted in Fig 3. A schematic diagram of a typical fractured specimen is shown in Fig 4. It can be seen that the macroscopic fracture is characterised by a crack, of length a, which is perpendicular to the loading axis, followed by a bifurcation of the crack with bifurcation angle, θ_f. For those specimens in which the crack lengths, a, were clearly defined, the crack lengths were measured. Using published stress intensity factor data (1) together with the maximum load levels and crack lengths, a, estimates of the mode-I stress intensity factor, K_I, at which the bifurcation took place, were determined. The variation of the mode-I stress intensity factor, at bifurcation, with a/b for the two materials are shown in Fig 5, where b is the sample width. Also, the variations of θ_f with a/b for the two materials are shown in Fig 6.

From Fig 3 it can be seen that the two materials exhibit very similar fatigue behaviour. The results indicate that there is a fatigue limit at a maximum stress level of about 800 MPa (ie for stresses varying from 80-800 MPa). Hence, for maximum stresses less than about 800 MPa (with R = 0.1) more than 10^6 cycles is required to initiate a fatigue failure.

A scanning electron microscope (SEM) was used to investigate the fracture surfaces. Two distinct types of fracture surface were identified. Close to the crack initiation site near the edge of the specimen (see Fig 4), the fracture surface is flat and there are striations which indicate that a fatigue crack growth process is taking place; see Figs 7(a) and (b). For longer cracks, leading up to the bifurcation and beyond it, the surface is much more faceted and there are no striations, indicating that a fast fracture process is taking place as shown in Fig 7(c). Fig 7(d) shows a SEM view of the transition between the two types of fracture surface; this figure also shows that the transition is abrupt.

The spacing of the striations (see Fig 7(b) for example), indicates that the fatigue crack growth phase is short compared with the initiation phase. Also, the fatigue crack lengths at the onset of fast fracture were generally in the range 0.15 to 0.3mm. This indicates (1) that, on the basis of an LEFM analysis, the fracture toughness K_{IC}, of the material is approximately 25 $MPam^{0.5}$. Using this value of the K_{IC} with a flow stress of 1000 MPa (2,3) leads to a crack tip plastic zone size of approximately 0.03mm. Although this is not insignificant compared with the crack length at the onset of fast fracture (0.15 to 0.3mm), it is small enough to ensure that it is reasonable to use K_{IC} = 25 $MPam^{0.5}$ as the fracture toughness to estimate the load bearing capacity of a component made from the Co-Fe alloys.

A detailed explanation of the fracture process will be the subject of a future paper. This will include an explanation of the relationship between K_{IC}, the bifurcation angle and the length of crack at the onset of branching.

CONCLUSIONS

- The fatigue limit for the alloys (with R = 0.1) is about 800 MPa.
- Fatigue initiation is followed by a relatively short period of fatigue crack growth.
- The K_{IC} for the materials is about 25 $MPam^{0.5}$.
- Following a short period of fatigue crack growth, fast fracture initiates, and the crack growths perpendicular to the applied stress axis.
- Crack branching occurs when the cracks have propagated to lengths in the range 0.5 to 1.5mm.

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REFERENCES

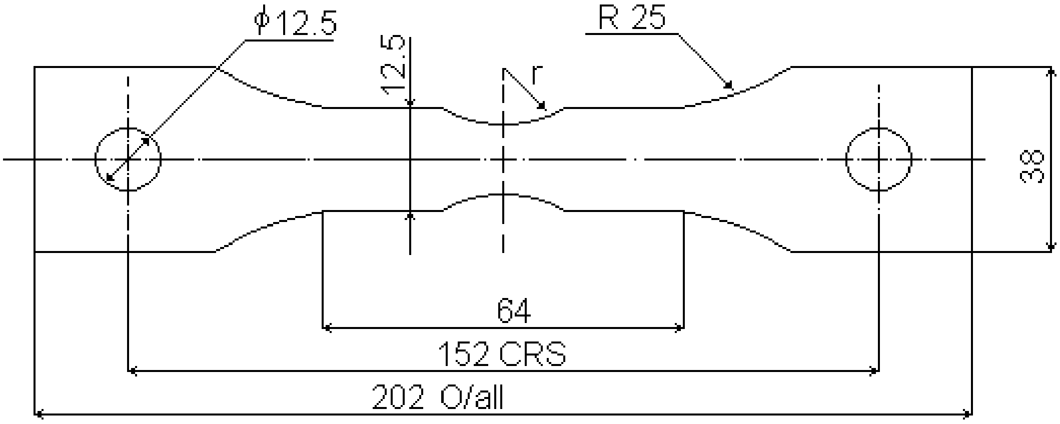
1. D P Rooke and D J Cartwright, "Compendium of Stress Intensity Factors", London, HM Stationery Office, 1976.
2. R V Major and W Gemmell, "Soft Magnetic Alloys Combining High Saturation and High Strength", Proceedings of conference on Soft Magnetic Materials 96, February 1996, San Francisco.
3. R V Major and V Samadian, "Physical Metallurgy and Properties of a New High Saturation Co-Fe Alloy", J Materials Engineering, Vol 11(1), 1989, pp 27-30.

Table 1

Results of Fatigue Tests of Co-Fe Specimens

Spec. (2)	Max Stress ÷ UTS	Crack length (a) at bifurcation (mm)	(a/b)	K_I (MPam$^{0.5}$) at bifurcation (1)	Cycles to Failure
1a	0.85	0.93	0.930	65.68	2.04E+04+
2a	0.78	2.05	0.203	104.58	4.80E+04+
3a	0.71	1.85	0.183	87.21	9.86E+04+
5a	0.63				3.40E+06+ (run out)
6a	0.84	1.29	0.128	79.64	1.39E+04+
7a	0.77	1.39	0.138	76.94	4.67E+04+
8a	0.74	1.42	0.140	74.33	6.90E+04+
9a	0.70				3.40E+06+ (run out)
10a	0.63				3.40E+06+ (run out)
1b	0.84	0.60	0.060	50.09	2.81E+04+
3b	0.76	0.83	0.082	54.88	4.01E+04+
4b	0.74	0.96	0.095	67.79	6.57E+04+
5b	0.89	0.55	0.055	51.12	0.52E+04+
7b	0.92	0.73	0.072	61.77	1.15E+04+
8b	0.89	0.60	0.060	53.63	1.55E+04+
13b	0.63				3.40E+06+ (run out)
14b	0.68	0.71	0.070	44.54	6.27E+04+

(1) Based on assumed LEFM behaviour using the formulation presented in reference 1.
(2) "a" designates Rotelloy® 7 specimen
"b" designates Rotelloy® 8 specimen



Minimun Specimen Width = 10 mm (Nominal)
Thickness = 0.35 mm (Nominal)

Fig. 1 Co-Fe Fatigue Specimen

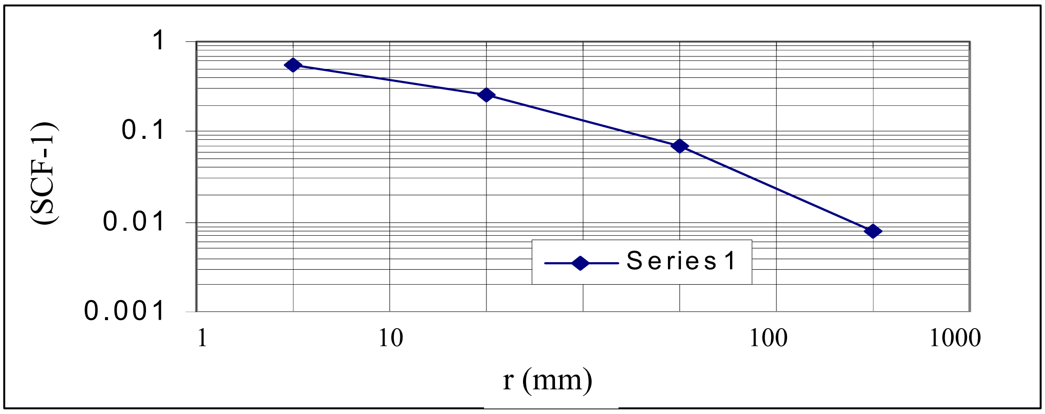


Fig. 2 Variation of SCF with r (obtained from FE Analysis)

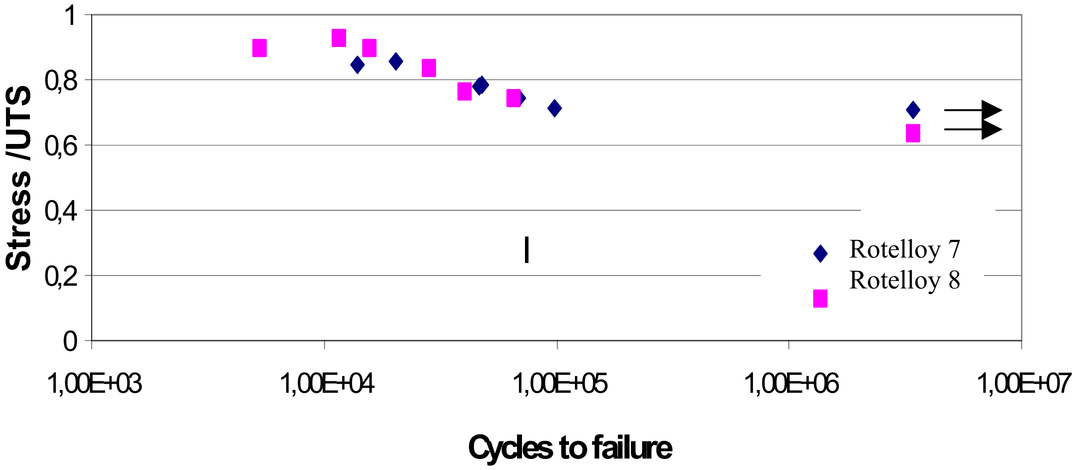


Fig. 3 Fatigue Data from Fe-Co Specimens (Rotelloy® 7 and Rotelloy® 8)

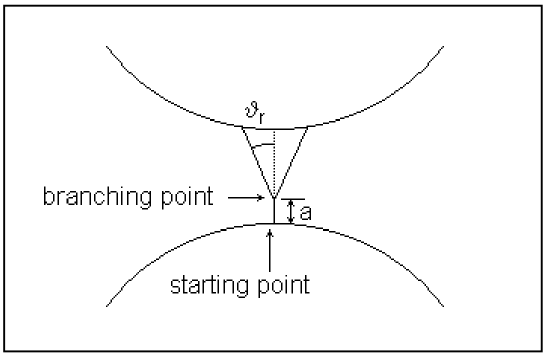


Fig. 4 Schematic Diagram of the fracture showing the bifurcation

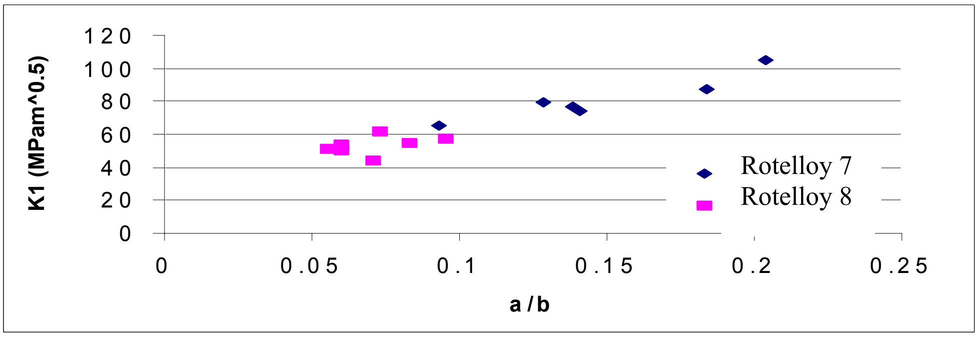


Fig. 5 K_1 at bifurcation for Fe-Co specimens based on LEFM assumption

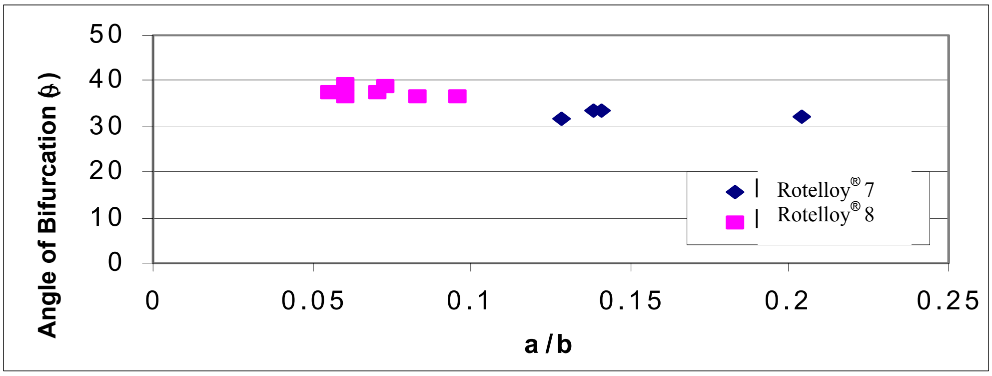


Fig. 6 Bifurcation angles ϑ_f obtained from the Co-Fe specimens

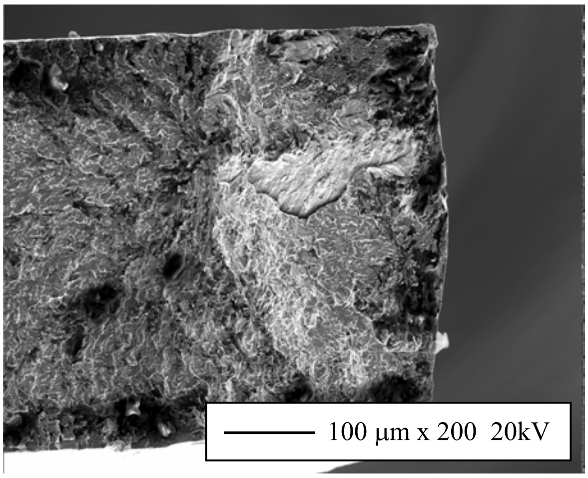


Fig. 7(a) Low magnification micrograph of fatigue crack initiating at the curve of the sample

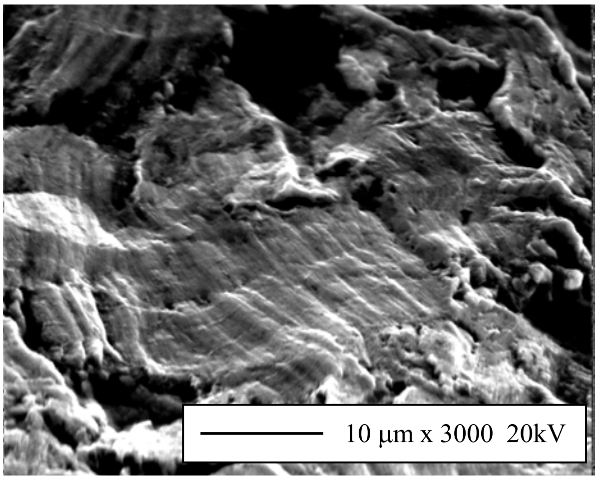


Fig. 7(b) High magnification micrograph of produced on fatigue fracture surface

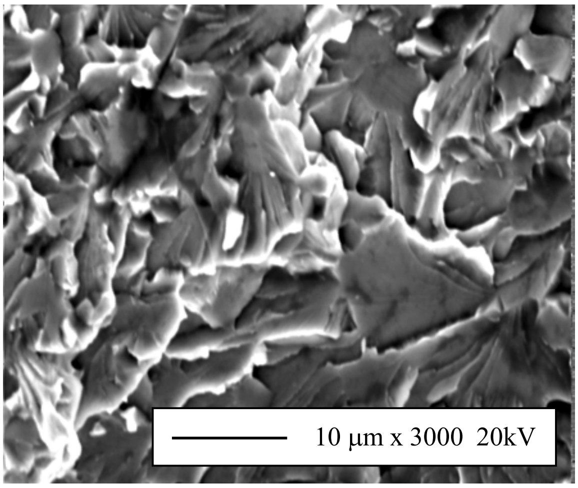


Fig. 7(c) Brittle facets on the fast fracture surface

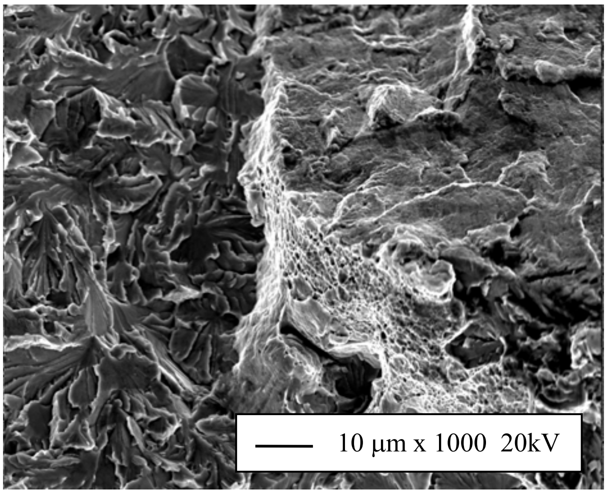


Fig. 7(d) Transition zone between fatigue and fast fracture surfaces