The Effects of Carbides and Cavities on Creep Crack Growth in HK40 Steel

S. J. ZHU, J. ZHAO, F. G. WANG and Z. B. CAO
Materials Engineering Department, Dalian University of Technology, Dalian, Liaoning, PRC

ABSTRACT

Creep orack growth tests at 871°C have been performed on compact tension specimens of HK40 steel in different microstructures and cavity densities conditions. The skeleton shape carbide on grain boundaries has a higher resistance to crack growth than the blocky carbide. The cavities increase the creep crack growth rate by reducing grain boundary strength. With the increase of aging temperature, the difference of crack growth rate caused by the carbide shape and by the cavity density on grain boundaries becomes small. The secondary carbide size and distribution explicitly affect the crack growth behavior.

KEYWORDS

Carbide; cavity; creep crack growth; HK40 steel; reformer tube.

INTRODUCTION

The Creep properties of smooth specimens of a HK40 reformer tube used in petrochemical plant in the as-cast and serviced condition have been widely investigated (VanEcho etal., 1967; Persson and Waher, 1975; Zaghloul etal., 1977). As in many other practical engineering alloys the final creep fracture of HK40 is generally very brittle and does not just occur by the simple growth of cavities until they impinge upon each other and cover the bulk of grain boundary interfacial area. Instead, final fracture occurs by the brittle propagation of a few intergranular cracks which form by the growth and interlinkage of smaller cavities (Dunlop etal., 1978). It has been shown that longitudinal and circumferential cracks were formed in the matrix and the heat affected zones of welds when the tubes had been used for one third of their design life (Zhu etal., 1987). Therefore, the investigation on creep crack growth behavior of HK40 has been carried out.

The reformer tubes are serviced directly from as-cast condition. Because different parts from the top to the bottom of the tube have experienced different temperatures, the microstructures are different. Moreover, the reuse of some of tubes that have been replaced needs solution treatment at temperature higher than 1200°C for welding. Therefore, the research of the effects of aging and solution treatment on creep crack growth is significant for engineering practice.

This paper is concerned with the effects of intergranular and transgranular carbides on creep crack growth behavior by aging directly from the as-cast condition and after a solution treatment at 1250°C. Another two batches of material studied had previously undergone 57000 hours and 63000 hours of operating service in a reformer furnace so that the influences of cavities and secondary carbides on creep crack growth could be investigated. The interaction of grain strength and grain boundary strength is emphasized.

EXPERIMENTAL PROCEDURE

The materials investigated are commercially produced centrifugally cast tubes, which had an almost total columnar grain structure across the tube wall. The chemical compositions of the testing materials are shown in Table 1.

Table 1 Chemical Compositions of Materials (%wt)

Symbol	C	Cr	Ni	Si	Mn	P	S	Fe
A	0.47	24.91	21.14	0.87	0.84	0.017	0.013	balance
L	0.38	25.30	20.44	1.10	0.38	0.012	0.015	balance
B	0.36	25.73	20.04	1.02	0.38	0.015	0.019	balance

In Table 1, A is as-cast, L has a service history of 57000h at 840°C and B has a service history of 63000h at 840°C. The heat treatments of materials are shown in Table 2.

Table 2 Heat Treatments of Materials Tested

Symbol	State	Aging time (h)		
		800°C	871°C	950°C
A	as-cast	200	200	200
A(s)	1250°C x 2h	200	200	200
L	1250°C x 2h	200	200	200
B	1250°C x 2h	200	200	200

Constant-load creep crack growth tests were conducted on these materials using 9mm thick compact tension specimens at 871°C. The temperature was maintained within ±3°C. The shape and dimensions of the specimens are shown in Fig. 1. The specimens were oriented so that the crack ran in the actual crack propagation direction of the reformer tube.

Crack lengths were measured using a D. C. electrical potential drop technique in which a stabilized direct current of 4 amps was passed along the axis of the specimen. The microstructures were revealed by etching in

$3/4HCl+1/4HNO_3$ acids. Fracture surfaces were examined by the scanning electron microscope.

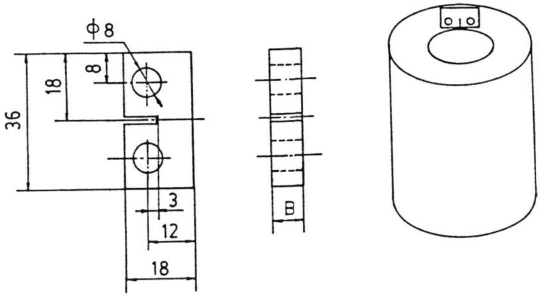

Fig.1--The orientation and dimensions of compact tension specimen.

RESULTS AND DISCUSSION

Carbide shape and size effects

In the as-cast condition, the microstructures are composed of eutectic carbides in an austenitic matrix supersaturated with carbon as shown in Fig. 2(a). During aging, carbides precipitate, first at and adjacent to grain boundaries, thereby revealing the cored cast structure as shown in Fig. 2(b). With increasing temperature, carbide precipitation becomes general throughout the matrix, the precipitated carbides tend to coalesce. Eutectic carbides also undergo changes during aging, but the changes in eutectic carbides occur at higher temperatures than the changes in the precipitated carbides.

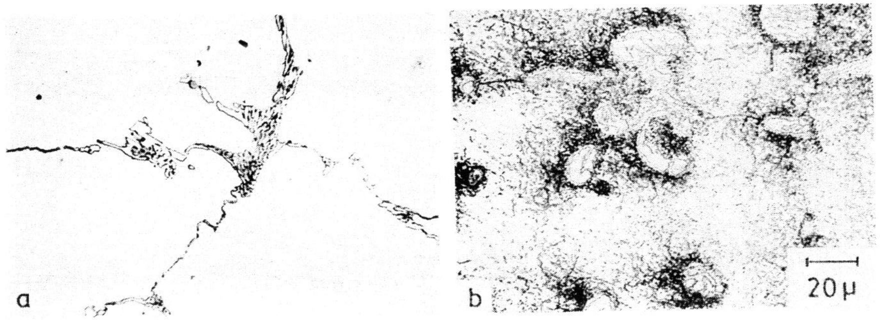

Fig.2--Microstructures as-cast and aged at 871°C for 200h.
(a) as-cast, (b) aged.

After a solution treatment, the eutectic carbides change from a skelton shape to a blocky shape (Fig. 3(a)). During aging, secondary carbide precipitates uniformly in the matrix (Fig. 3(b)). With increasing aging temperature, the diameter of the secondary carbides increases.

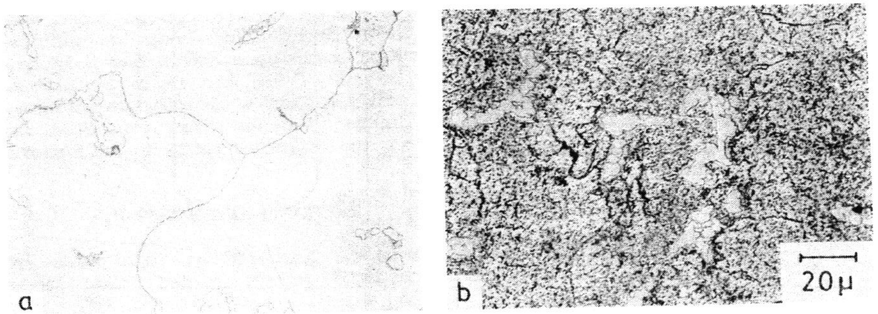

Fig.3--Microstructures as-solution treated and aged at 871°C for 200h after being solution treated. (a) as-solution treated, (b) aged.

The creep crack growth rate data for A and A(s) as a function of stress intensity factors are shown in Fig. 4. It can be seen that the creep crack growth rates in as-cast specimens are lower than those in solution treated ones and the creep crack growth rates in directly aged specimens are lower

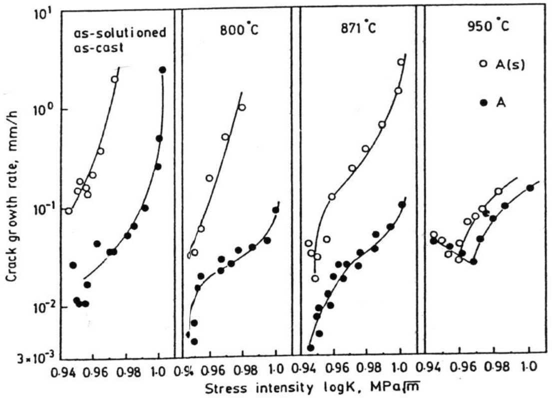

Fig.4--Effect of carbides on creep crack growth rate tested at 871°C in A and A(s).

than those in specimens aged after the solution treatment. This is because the skeleton eutectic carbides on grain boundaries should make boundary sliding more difficult and also increase the path for grain boundary diffusion. Both of these effects would be expected to inhibit crack propagation by retarding the formation of grain boundary microcracks ahead of the main

crack. Fig. 4 also shows that the difference of crack growth rates of A and A(s) at 950°C becomes small. The reason for this is that the skeleton eutectic carbide tends to a blocky shape with the increase of the aging temperature.

The creep rupture times versus aging temperatures are shown in Fig. 5. Since the creep crack growth rates of as-cast and directly aged specimens are lower, the rupture times are longer. The results of Wilson (1972) demonstrate that in a nickel-based alloy the more homogeneous deformation produced by coarser leads to longer rupture lives. Floreen (1975) has observed a similar beneficial effect of coarser in fracture mechanics samples. From Fig. 5, it can be seen that the secondary carbides affect crack growth properties. For solution treated specimens, the coarser the secondary particles are, the longer is the rupture time. However, for directly aged specimens the rupture time is longest at 871°C.

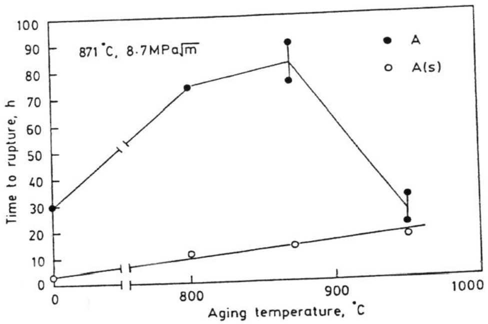

Fig.5--Time to rupture versus aging temperture in A and A(s).

The observation of the fracture surfaces of the specimens demonstrates that the fracture of all specimens is along columnar grain boundaries as shown in Fig. 6. For A(s), the coarsening of the secondary carbide increases creep

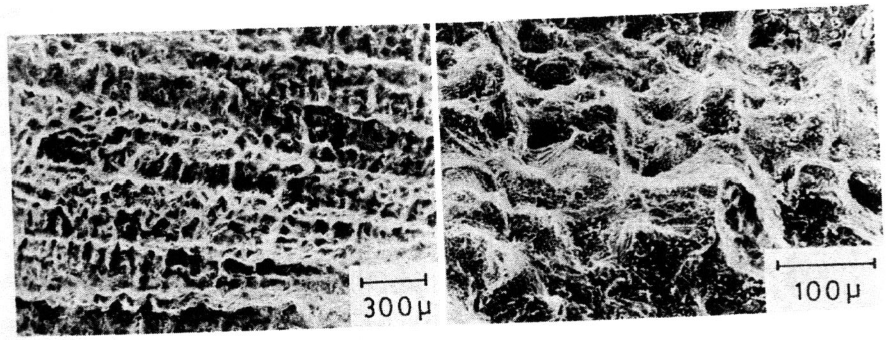

Fig.6--SEM showing fracture surface of intergranular creep crack propagation in A.

ductility and decreases the stress concentration in front of crack tip on grain boundary. As a result, the crack growth rate decreases and the rupture time increases, However, for A, the results are the same as for A(s) at temperatures lower than 871°C. Because the creep strength of the specimen aged at 950°C is too low to be compensated by a high ductility, the creep crack growth rate is high and the rupture time is short.

Cavity density and carbide size effects

Two methods have been employed to examine the amount of cavities in two serviced materials. The density is 7.785g/cm^3 for L as-solution treated and is 7.755g/cm^3 for B as-solution treated. The fracture surfaces at cryogenic temperature (-196°C) are shown in Fig.7. These demonstrate that B has more

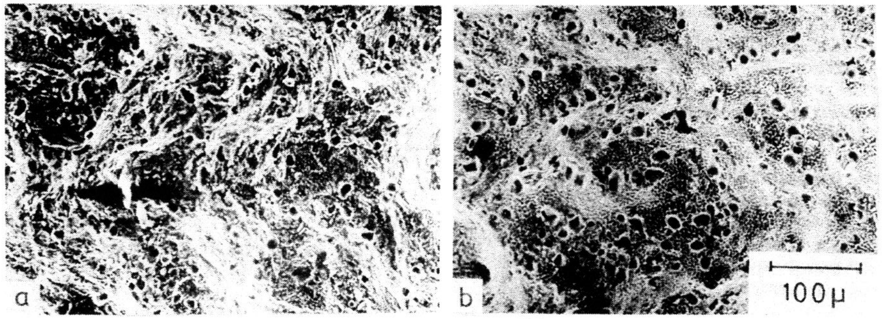

Fig.7--SEM showing cavities on grain boundaries in L and B. (a) L, (b) B.

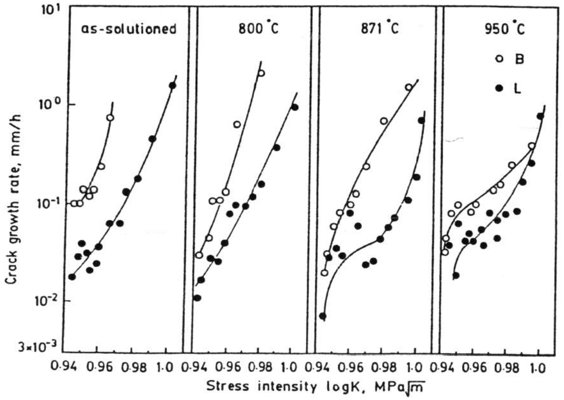

Fig.8--Effect of cavities and carbides on creep crack growth rate tested at 871°C in L and B.

severe creep damage. The changes of the microstructures of these two materials with aging temperatures are the same as A(s).

The creep crack growth rates as a function of stress intensity factor are shown in Fig.8. The rupture times versus aging temperatures are shown in Fig.9. The creep crack growth rates of B material with more cavities on grain boundaries are higher than those of L material, therefore the rupture times of B are short. Fig.10 reveals fracture surfaces of

creep and tension at room temperature for L material. They demonstrate that the amount and size of cavities on fracture surfaces are almost the same in two conditions. It is considered that cavities make the grain boundary area be reduced and therefore decrease creep rupture time.

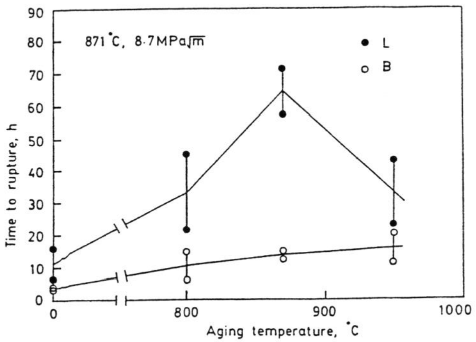

Fig.9--Time to rupture versus aging temperature in L and B.

From Fig.9, it can also be seen that for B material, the coarser the secondary carbide particles are, the longer the rupture time, but for L material, the rupture time is longest at aging temperature of 871°C. Because the rupture time deceases for L and increases for B by coarsening of the secondary carbides at 950°C, the difference of creep crack growth rates for L and B becomes small.

The results of Kobayashi et al (1985) show that creep crack growth rates decrease with the increase of grain strength for FA of higher grain boundary strength, and crack growth rates decrease and then increase with the increase of grain strength for WQ of lower grain boundary strength. From the comparisons of A and A(s) or L and B, the results demonstrate that the creep crack growth rates are low when grain strength is in accord with the grain boundary strength. If the grain boundary strength is high, the optimum resistance to crack growth is obtained with high grain strength.

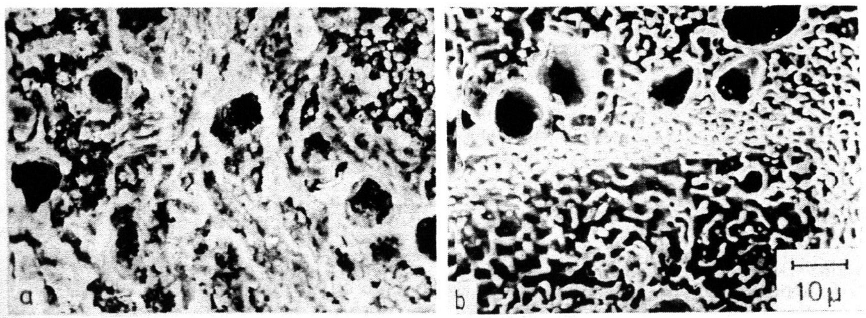

Fig.10--SEM showing surfaces of creep fracture and tension fracture at room temperature for L.

CONCLUSION

For HK40 steel, the skeleton shape carbides on grain boundaries have higher resistance to crack growth than the blocky carbides. The cavities on grain boundaries reduce the grain boundary area so that crack growth rates are high and the rupture times are short for B. The resistance to crack growth is the highest when the grain boundary strength is in accord with the grain strength determined by the secondary carbide particles.

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