Effect of Austenitising Temperature on Creep Fracture of a 12CrMoV Steel

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ABSTRACT

Creep rupture properties and fracture behaviour of a commercial purity 12CrMoV steel at 500, 550 and 600C in various microstructural conditions of austenitisation in the temperature range of 1080 to 1250C, typical of those found in heat affected zones (HAZ), have been determined and reported in this paper. Rupture lives varied from about 700h to 39500h. The formation of delta ferrite (around 8%) at grain boundaries when austenitised at 1250C, is found to inhibit grain growth. Austenitising at 1250C produced higher rupture lives and lower ductilities as compared to other conditions, when creep tested at 550C. Scanning electron microscopic (SEM) studies indicated that the fracture mode in this condition was intercrystalline predominantly. Creep fracture at 500 and 600C ocurred in a ductile dimple mode in the steel austenitised at 1250C. At 600C, a tendency for embrittlement is noticed in the steel austenitised in the intermediate range.

KEYWORDS

12CrMoV steel, austenitising temperature, creep rupture lives, rupture ductility, creep fracture.

INTRODUCTION

12CrMoV steel is extensively used in power generating equipment for large capacity integral turbine rotors, conventional turbine blading, reheater and superheater tubing for super critical steam conditions. The high temperature properties of this steel have been well established and documented (Hede *et al.*, 1969; Irvine *et al.*, 1964). A comprehensive treatise dealing with the properties, applications and fabrication problems of this group of steels is available (Briggs *et al.*, 1965). During welding, the parent metal close to fusion boundary near the weld pool develops high temperature regions because of weld thermal cycles and becomes fully austenitic. It is well known that in such regions grain coarsening occurs. Long term high temperature behaviour of such regions has to be established for deciding safe working life of the plant from the creep fracture point of view. This paper describes results of creep rupture tests of a commercial purity 12CrMoV steel carried out at 500, 550 and 600C at three different stresses.

EXPERIMENTAL PROCEDURE AND RESULTS

Materials and Heat Treatments

Chemical composition of the steel is given in Table I. Heat treatment details and the results of the grain size

Table I. Chemical Composition

Major Element, wt%						
C	Si	Mn	Cr	Mo	V	Ni
0.160	0.33	0.53	12.8	0.78	0.29	0.26
Minor Element, ppm						
S	P	Sn	As	Sb	Cu	Al
130	150	40	55	<10	400	120

Table II. Details of Heat Treatment and Grain Size

Code	Heat Treatment	Average prior austenite grain size, um
A	Austenitise at 1080C, 1h, oil quench, temper at 730C, 1h, air cool	60
B	Austenitise at 1120C, 1h, oil quench, temper at 730C, 1h, air cool	140
C	Austenitise at 1150C, 1h, oil quench, temper at 730C, 1h, air cool	195
D	Austenitise at 1200C, 1h, oil quench, temper at 730C, 1h, air cool	425
E	Austenitise at 1250C, 1h, oil quench, temper at 730C, 1h, air cool	84

measurements are shown in Table II. Metallographic specimens prepared from the heat treated steel were mechanically polished, etched and observed in an optical microscope. The optical micrographs are shown in Figs.1a to 1e.

Stress Rupture Testing

Cylindrical specimens of 7.98mm dia and parallel lengths of 23.8mm were machined from the heat treated rounds and creep rupture tested in air at 500, 550 and 600C under constant load corresponding to initial stress of 31, 20 and 14 kg/sqmm respectively. Automatic lever adjusting type uniaxial stress rupture testing machines with the temperature control better than $\pm$2C over the entire gauge length of the specimens were used for this purpose.

Results of creep rupture tests are given in Table III. The stresses at the three tempratures were so chosen that creep

Table III. Results of Creep Rupture Testing

Temp.	Stress	A		B		C		D		E	
C	Kg/sqmm	tr	El	tr	El	tr	El	tr	El	tr	El
500	31	2300	22	25607	27	39410#	2*	1685	19	4788	24
						26827#	2*	**			
550	20	3623	22	10152	27			12117	17	23699	12
		3692	20					20262	24	21154	10
								15192	22		
600	14	3380	27	714	26	3734	9	2573	14	2560	23
				835	23	1797	11	2987	8	2513	27

tr: rupture time, h
El: rupture Elongation, %
: test interrupted
* : elongation on interruption
**: test is being repeated

fracture would occur in a normal heat treated steel in about 3000h. Normal heat treatment for such composition is austenitising at 1080C, oil quenching and tempering at 730C. At 500C, the steel in heat treatment condition A through E, in general, has shown appreciable ductility. Rupture life for intermediate range of austenitising temperatures at 1120 and 1150C (B and C) has been noticed to be higher than for other three conditions. At 550C, except for condition A, the steel in all other conditions has exhibited far higher rupture lives than expected, highest being for the condition E. Rupture ductility is the lowest for condition E while for other conditions it is in appreciable level. At 600C, except for condition B, the rupture life is comparable with the expected one and the rupture ductility has been observed to be lower for the intermediate conditions C and D.

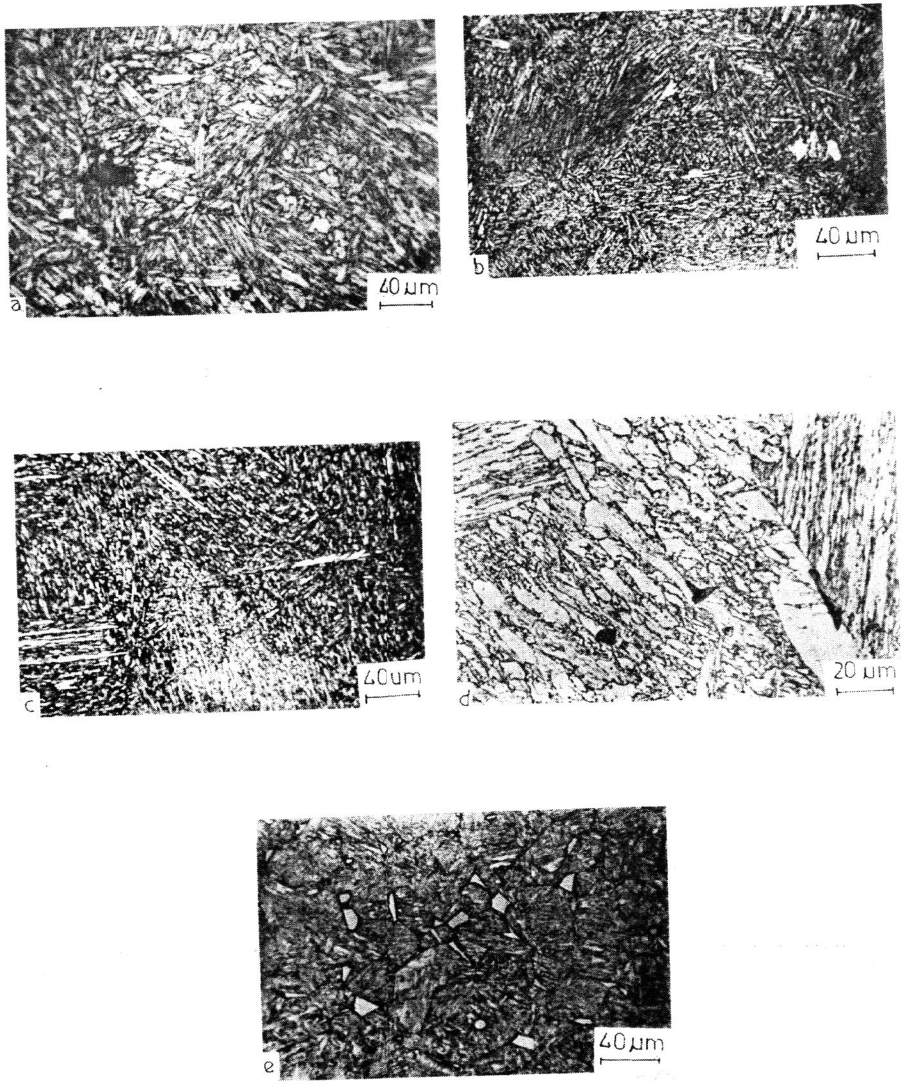

Fig.1. Optical microstructures of oil quenched and tempered 12CrMoV steel at differet austenitising temperatures

a: 1080C, b: 1120C, c: 1150C,
d: 1200C, e: 1250C

Fractographic Examination

All the specimens fractured in creep testing have been cleaned in mild acetic acid, dried in acetone and examined in a stereo scanning electron microscope for fractographic analysis. The results indicate that specimens whose rupture elongation was below 14% fractured in an intercrystalline mode with a few ductile regions consisting of dimples. It is observed that the steel in condition A and B fractured under all the test conditions by a ductile dimple mode exhibiting well defined dimples. At 550C, the steel consisting of grain boundary delta ferrite, fractured in a brittle intercrystalline mode. The steel in all other conditions of heat treatment fractured in a ductile dimple mode under creep rupture testing at 550C. At 600C, the steel in condition C and D has fractured exhibiting a mixed mode of brittle intercrystalline facets and ductile dimples, while in condition E at 600C, the steel has fractured by a ductile dimple mode. Typical SEM fractographs for conditions A through E are given in Figs.2a to 2e.

DISCUSSION

Weld thermal cycles produce the effect of increased austenitising temperatures in the parent steel adjacent to fusion zone. An increase in austenitising temperature causes grain growth and higher amounts of carbides go into solution. It also results in introduction of delta ferrite at grain boundaries. Upon cooling to room temperature, higher grain size steel produces martensite of morphology different from the other parent metal regions that did not undergo such thermal cycles. Higher amounts of carbides dissolved at increased austenitising temperatures, usually, reprecipitate in much finer form and in greater amounts, causing increased creep rupture lives and lower rupture ductilities. It is reported that delta ferrite has no effect on longitudinal rupture strength but reduces the transverse rupture strength (Briggs et al., 1965). It is also reported that delta ferrite, enriched in elements such as Mo and W becomes stronger over long periods of testing due to the formation of Fe Mo or Fe W type Laves phases. These findings have also been confirmed in a recent report (Shaw et al., 1987).

A good amount of ductility exhibited by the steel in all its conditions at the test temperature of 500C is perhaps due to relatively lower extent of grain boundary cavitation observed in the metallographic studies of longitudinal sections cut from the creep ruptured samples. Since cavitation is a diffusion controlled mechanism (nucleation and growth), it is expected that at a relatively lower temperature and higher stress levels, extent of cavitation shall be lower.

In the intermediate range of austenitising (1120 to 1200C), the steel showed a significant tendency to strengthening without becoming embrittled when tested at 500 and 550C except in case of steel austenitised at 1200C and tested at 500C for which the test is being repeated. The increase in strength levels, is perhaps because of increased dissolution of vanadium carbide

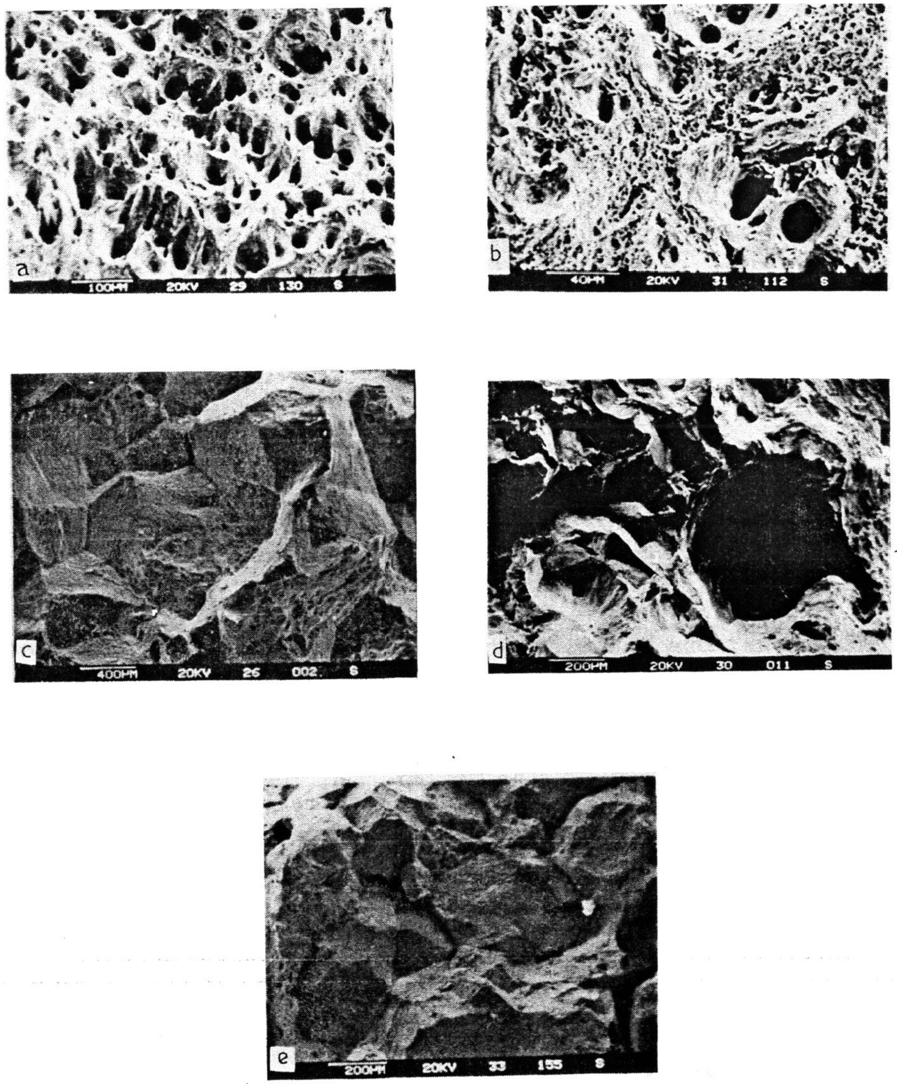

Fig.2. SEM fractographs of 12CrMoV steel creep ruptured at 500, 550 and 600C

a: A, 500C, 2300h; b: A, 600C, 3380h
c: E, 550C, 23699h; d: C, 600C, 3734h
e: D, 600C, 2987h.

and its subsequent precipitation in a finer form. At 550C, the steel containing delta ferrite has exhibited rupture life much higher than the one in other conditions of austenitising but at the same time became embrittled as could be seen from a totally intercrystalline creep fracture (Fig.2c). Formation of Laves phase of Fe Mo type is assumed to be responsible for the increased rupture life; confirmatory X-ray diffraction tests of the residues extracted by anodic dissolution from these specimens are in progress. The increase in rupture life and intercrystalline mode of creep fracture observed at 550C in the steel containing grain boundary delta ferrite of our work, however, is in contrast with the work reported recently in which it was found that presence of prior austenite boundary delta ferrite biased the fracture toward the transgranular mode but had little effect on crack growth rates (Gooch, 1982).

The steel in all its conditions of austenitising, when tested at 600C showed rupture lives close to the expected life of 3000h within $\pm$20% scatter band, allowed for creep rupture data. Tendency for embrittlement as revealed by predominant intercrystalline mode of fracture (Figs.2d and 2e) in the steel austenitised in the intermediate range of temperatures at 1150 and 1200C needs to be further examined. The steel containing grain boundary delta ferrite when tested at 600C did not produce strengthening effect similar to the one noticed at 550C testing. This is because stable Laves phases responsible for strengthening are perhaps not forming at 600C.

CONCLUSIONS

1. At 500C of creep rupture testing, the steel austenitised in the intermediate range of temperatures except for 1200C exhibited higher rupture lives than the expected. Rupture ductilities are appreciable at this temperature and fracture occurred in a ductile mode exhibiting well defined dimples.

2. At 550C of creep rupture testing the steel austenitised at 1250C and as a result containing grain boundary delta ferrite exhibited higher rupture lives and lower rupture ductilities. Fracture occurred mostly by intercrystalline mode. Intermediate range of austenitising (1120 to 1200C) produced higher rupture lives and appreciable ductilities. Fracture under these conditions occurred by a ductile dimple mode.

3. At 600C of creep rupture testing, all the austenitising conditions produced rupture lives close to the expected life of 3000h. Rupture ductilities in the intermediate range of austenitising (1150 and 1200C), however, have been found to be lower and the fracture occurred mostly by an intercrystalline mode.

4. X-ray diffraction of the carbides extracted from the creep ruptured samples, currently in progress shall perhaps explain some of the observations made in this work.

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