INFLUENCE OF AGEING ON CREEP CRACK GROWTH BEHAVIOUR OF ROTOR FORGING AND CASING CASTING STEELS

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The creep crack growth (CCG) behaviour of the steam turbine rotor forging and casing steel has been studied in as received and aged condition. The chemical composition of the rotor steel is: 0.28%C, 1.27%Cr, 0.77%Mo, 0.35%V, 0.14%Ni, <0.01%S and<0.01%P and that of casing steel is: 0.19%C, 1.4%Cr, 1.4%Mo, 0.22%V, 0.14%Ni, <0.01%S and<0.01%P. The steels have been aged at 873°K for 3648 h so as to represent the simulated service exposed condition of the steel and characterize the creep crack growth behaviour if the crack initiates in the degraded material. For displacement rates ranging from 0.01-0.06 mm/h the C^* values have been found to vary from 0.004 - 0.0935 kg/mm/h in rotor steel and from 0.0118 - 0.1741 kg/mm/h at 813°K in casing steel, respectively. The crack growth rate has been found to be slower in the long term in aged casing steel as compared to the as received steel.

INTRODUCTION

In power plants, due to the complexity of the structures and the nature of the stress history during service, evaluation of initiation times for cracks is often difficult. Accurate prediction of the remaining life of the components, having crack like defects, from creep rupture data alone is not possible. At the end of predicted design life, cracks can develop at critical locations and can propagate in time due to creep and ultimately cause failure of the component. Crack location, orientation and size, determined during component inspection, can be used with the creep crack growth technology to estimate remaining life.

Linear elastic fracture mechanics (LEFM) has been used for a number of years in a calculation of permissible defect sizes with regard to failure by brittle fracture and fatigue. Recently, interest has developed in its possible applications to crack-like defects in a creep situation. Envisaging the problems encountered

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by the large power plant components such as steam turbine rotors and casings, the study on creep crack propagation behaviour was carried out. C^*, energy rate line integral, proposed by Landes and Begley (1) and Turner and Webster (2) was chosen. C^* parameter uniquely characterizes the crack tip stress and strain rate field for materials following a non-linear steady state creep law. C^* is defined as the power difference between two identically loaded bodies having incrementally differing crack lengths (1,3).

$$C^* = - \frac{\partial U^*}{\partial a}$$

Where U^* is the power or energy rate defined for a load P and displacement rate u by

$$U^* = \int_0^{\dot{U}} P \, d\dot{u}$$

The C^*-parameter has been effectively utilised by Saxena (4) for stainless steels and Gooch and Kimmins (5) for CrMoV steels. Many more studies on the CCG behaviour of CrMoV steels have been carried out because of their application in steam turbines. Nazmy et al (6) showed that C^* appears to be better than K_{IC} in correlating creep crack growth behaviour of this type of steel at 823^0K.

The creep crack growth testing has been carried out with an objective of utilising the present results to estimate the remaining life of an steam turbine components with cracks occurring during service. Testing has been carried out at 813^0K at 4 different stress levels by using single edge notch tension (SENT) type of specimens.

EXPERIMENTAL

Material

1CrMoV rotor forging and casing steels were taken in as received condition with tempered bainitic microstructure. The steels were aged at 873^0K for 3648h so as to represent the simulated service exposed condition equivalent to 2,00,000h at 813^0K as determined by Larson-Miller parameter. Specimens were machined from as received and the aged material. These specimens were given a 5 mm front and 0.5 mm deep side notches so that the crack front remains straight during crack growth.

Calibration and Standardisation

It was decided to adopt a remote method of measuring a growing crack at elevated temperature similar to the technique employed by Gilbey and Pearson(7). In this method an electric current is supplied to a metallic specimen. As the crack grows, the resistance of the specimen increases and the electric potential drops. The potential drop is calibrated for the equivalent crack lengths. Under the present study, 12 specimens each of both the steels were prepared with EDM cut fine artificial notches ranging from 1 to 12 mm. These specimens were loaded in the creep furnaces and a 10V a.c. current was supplied to the specimens. The potential drop across the crack (notch) was monitored at room temperature, 773, 813, 848 and 873^0K and the calibration plots were developed.

Experimental Procedure

Two methods of data generation for C^* are described in the literature; Constant displacement rate method and constant load method. Due to ready availability of creep testing machines, constant load test method was applied to characterize the creep crack growth behaviour. Constant load tests are conducted using dead weight type creep testing machines. The creep crack growth tests were conducted in specially built split type creep furnaces with a temperature control of $\pm 1^0$K. The extensometer for measuring the load line displacement was fixed outside the furnace on to the pull rods. A linear voltage differential transducer (LVDT) was fixed at the lower end. The crack length and the load line displacement data obtained through the crack meter and the LVDT, respectively were recorded through a personal computer using an analog to digital converter card. To determine the C^* values, data reduction technique as described in reference (1) and (4) has been employed.

RESULTS AND DISCUSSION

The crack growth and load line displacement data as a function of time are raw data. They are converted to crack growth rates and displacement rates. The displacement rates for various crack lengths are then plotted against four stress levels employed for testing. The area under these curves gives the power or energy rate, U^*, equivalent to the strain energy required to create two new surfaces by propagation of a crack. The negative slope of the U^* vs da/dt curves gives the desired C^* values for various displacement rates employed during the tests. The decrease in energy rate for an increment of unit length of crack defines the C^*-parameter. The C^* vs da/dt values for as received and aged steels are plotted in Figs.1&2. The relationship between da/dt (mm/h) and C^* (kg/mm/h) can be obtained from the plots. Following relationship for aged casing casting steel is derived at 813⁰K.

$$\frac{da}{dt} = 2.896\,(C^*)^{0.7783}$$

With the help of the above equation, the remaining life of the casing casting in aged condition can be computed. Assuming that the critical crack length of the casing is 20mm and the pre-existing crack length is 5 mm, the remaining life for the displacement rates of 10^{-3} and 10^{-4} mm/h is approximately 2241 h and 23,523 h at 813^0K. Similarly the other relationships obtained from the plots can be utilised for determining the remaining life of the components in presence of the cracks.

The cross-over of the curve for aged casing casting steel in Fig.2 can be explained by the fact that the life of aged casing steel improves considerably after around 50% consumption of design life (8). It happens due to precipitation of VC and Mo_2C. Intermixing of these carbides in later stages results in the formation of either (V,Mo)C or $(V,Mo)_2C$ (9). The material with this kind of precipitates forming in service or ageing shows an equivalent remaining life as compared to the as received material. Silcock (10) has shown that this type of precipitation preferentially takes place at dislocation network., thus hindering their movement by pinning action and introducing slow creep rate.

CONCLUSIONS

1. C^* values for displacement rates ranging from 0.01-0.06 mm/h have been found to vary from 0.004 - 0.0935 kg/mm/h in rotor steel and 0.0118-0.1741 kg/mm/h in casing steel, respectively.

2. Crack growth rate has been found to be slower in the long term in aged casing steel as compared to the as received steel.

SYMBOLS USED

a = crack length (mm)

C^* = energy rate line integral (kg/mm/h)

P = load (kg)

t = time (h)

U^* = energy release rate (kg mm/h)

u = displacement rate (mm/h)

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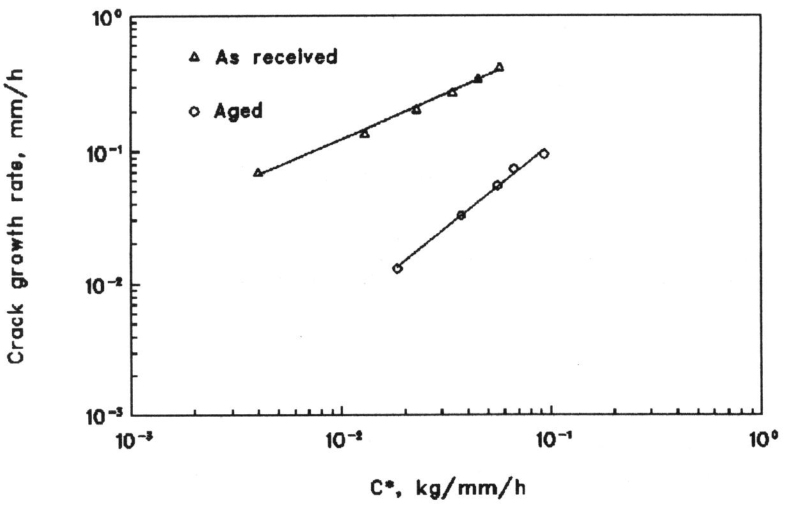

Fig.1 C^* vs crack growth rates for rotor forging steel

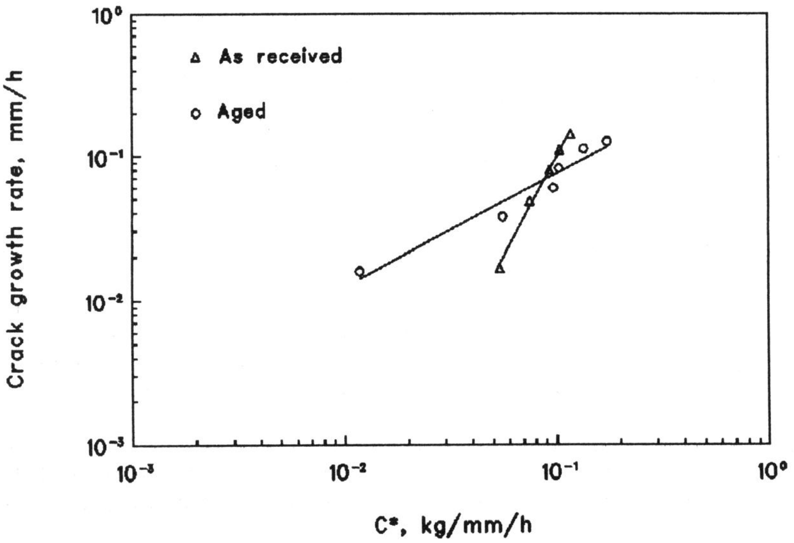

Fig.2 C^* vs crack growth rates for casing casting steel