TOUGHNESS DEGRADATION OF TWO SETS OF CR-MO STEEL HIGH TEMPERATURE TURBINE BOLTS

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ABSTRACT

The present paper describes a reverse temper embrittlement, RTE, assessment of two series of CrMo turbine bolts which had experiences differing service times at operating temperatures of around 400°C. It was established that when RTE was identified (a) the condition was one of only partial embrittlement and (b) two distinct regimes, partial and non-embrittled were clearly identified on an average grain size, d, versus % bulk phosphorus plot. The interface between the two states of embrittlement could be described by a simple expression.

INTRODUCTION

As early as over four decades ago indicated that the segregation of tramp or impurity elements to prior austenite grain boundaries in low alloy steels caused a significant reduction in toughness. This phenomena is know as reverse temper embrittlement, RTE, and usually occurs upon slow cooling through, or isothermal holding, at temperatures within the range 300 to around 600°C. The present paper describes an embrittlement assessment conducted on two sets of turbine bolts, fabricated from a medium carbon Cr-Mo steel, which have experienced differing times at an elevated temperature of around 400°C.

EXPERIMENTAL PROCEDURES

A small metallographic section was removed from the non-critical keyway location from each bolt and after conventional metallographic preparation, the average grain size, d, hardness and full bulk chemical analysis were

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established. The accumulated strain that the bolts had gathered during service, however, could not be measured because original bolt length data was not available. The bolt embrittlement assessment was based on two criteria, viz, (i) full size Charpy Vee-notch, CVN, specimens, and (ii) auger electron spectroscopy, AES. Three Charpy impact criteria were adopted, viz, (a) the fracture appearance transition temperature FATT, (b) the 54J energy transition temperature, ITT_{54}, and (c) the room temperature fracture energy, RTCE.

RESULTS AND FINAL REMARKS

A typical fracture appearance characteristics for three bolt conditions, viz., non-embrittled, partially embrittled and embrittled (fully), as a function of temperature are given in Figure 1. Also in a number of instances the first stages of embrittlement were observed and this was defined as (i) the initial appearance of 5 to 10% brittle fracture or/and (ii) a Charpy energy of 80-90J at room temperature.

The relationship between average grain size and hardness level for both sets of bolts is given in Figure 2 where it is evident that hardness is not a reliable indicator of embrittlement.

The average austenite grain size for each individual bolt was plotted as a function of bulk phosphorus level and the trends for both sets of bolts are shown in Figure 3. This figure can be considered as an embrittlement estimate diagram, EED, which portrays two distinct regions, a partially embrittled and a non-embrittled regime which can be separated by a critical boundary which can be expressed by the expressions,

$$d \times (\%P) = C \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_ (1)}$$

(1)

where C has a value of 0.24 and 0.59 for service times of 176,000 and 60,000 hours respectively.

At face value it would appear that the difference in the embrittlement (being partial in nature) characteristics of the two sets of high temperature bolts was the direct result of service time duration, viz, the longer the time elevated temperature, the greater the amount of phosphorus segregation, and hence the propensity towards embrittlement is increased. However, when (a) the phosphorus segregation kinetics and (b) the embrittlement trends of CrMoV steels are considered, this apparent effect of service time on the degree of embrittlement observed in the present study was somewhat questionable.

The amount of phosphorus which concentrates at grain boundary locations and the rate at which this process occurred had been predicted by McLean (1) over thirty years ago and is based on solute segregation kinetics. The calculated trends of grain boundary P. segregation with time for varying bulk values is given in Figure 4. From this figure it can be seen that in the case of a 0.025% P steel at 400°C the grain boundary phosphorus levels $C^{P}_{(t)}$ at times of 60,000 and 176,000 hours were very similar, viz, 0.6 and 0.63 respectively. Recently the present author have demonstrated that accumulated strain during service at around 490°C for 122,000 hours had a strong influence on the level of reverse temper embrittlement of a series of CrMoV turbine bolts. Essentially increasing the average level of strain from 0.17% to 0.36% doubled the amount of embrittled bolts for an average grain size of around 30μm and 0.01% phosphorus (2).

Finally, it is suggested that the differences in the embrittlement behaviour of the CrMo bolts at varying service times was the result of differences in accumulated strain during service rather than as a direct result of service time. Unfortunately accumulated strain data could not be obtained as no original bolt length measurements were available. However, it is envisaged that the series of bolts with service times of around 176,000 hours would be expected to have absorbed more accumulated strain than those at 60,000 hours.

ACKNOWLEDGEMENT

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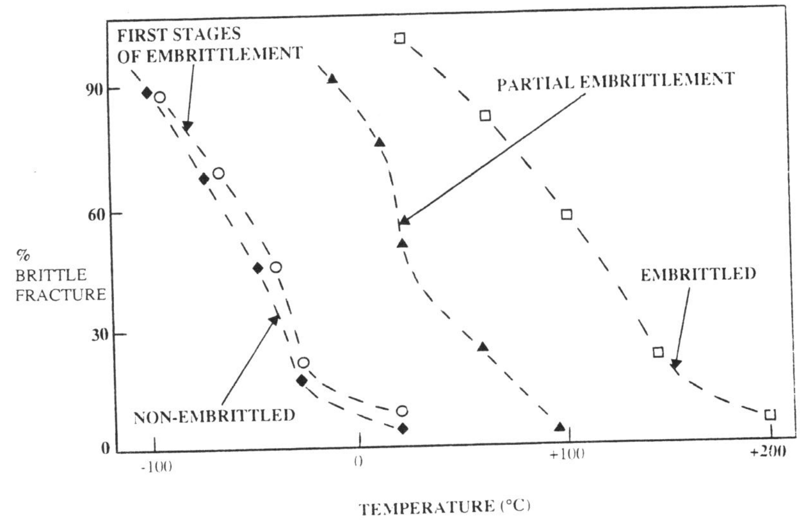

FIGURE 1 THE CHARPY FRACTURE APPEARANCE - TEMPERATURE TRENDS OF THE Cr-Mo STEEL BOLTS

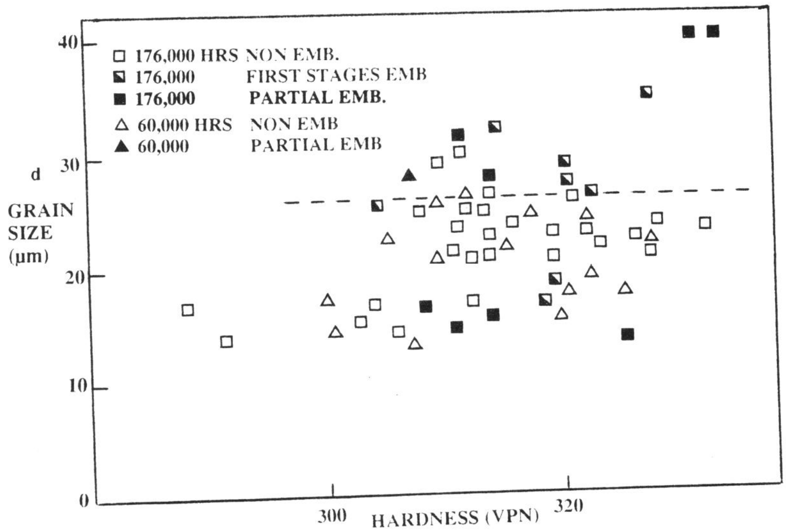

FIGURE 2 THE RELATIONSHIP BETWEEN MICROSTRUCTURE HARDNESS AND GRAIN SIZE FOR BOTH SETS OF Cr-Mo STEEL BOLTS.

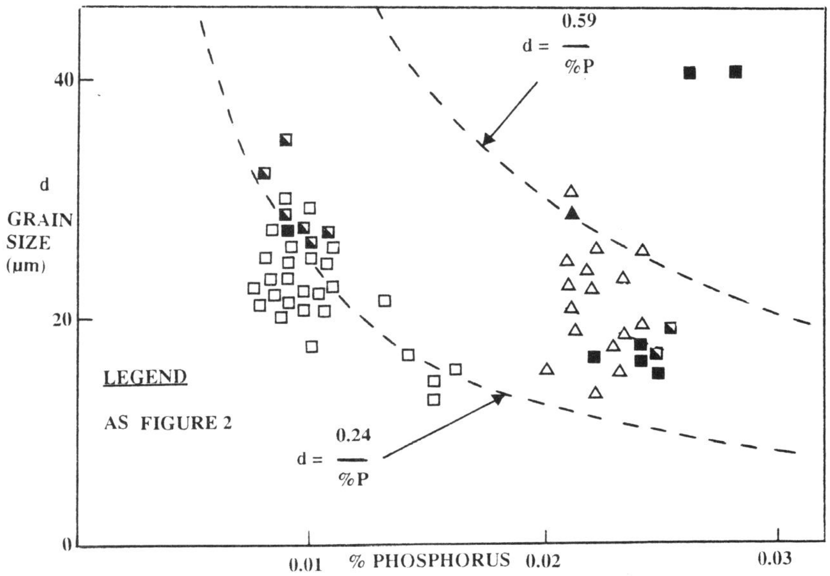

FIGURE 3 THE RELATIONSHIP BETWEEN GRAIN SIZE AND BULK PHOSPHORUS LEVEL FOR BOTH SETS OF Cr-Mo STEEL BOLTS.

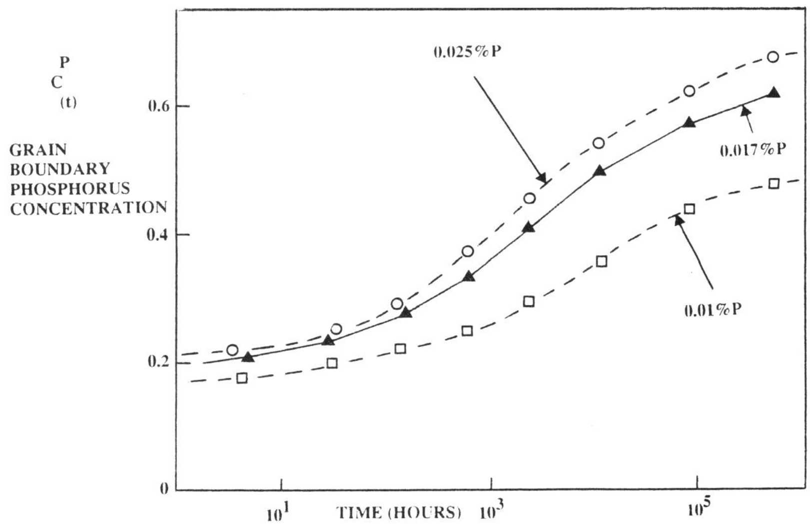

FIGURE 4 THE RELATIONSHIP BETWEEN GRAIN BOUNDARY PHOSPHORUS CONCENTRATION AND TIME AT 400°C