AN ASSESSMENT OF A SERIES OF DE-EMBRITTLEMENT TREATMENTS ON A TURBINE BOLT MATERIAL

J.H. Bulloch & J.J. Hickey *

This paper describes a detailed study aimed at assessing the de-embrittlement or restoration of the toughness of steam turbine bolts that have suffered reverse temper embrittlement, RTE during service. It has been shown the toughness can be partially restored by certain heat treatments and where toughness restoration was achieved, it was significantly sensitive to phosphorus level. The re-embrittlement kinetics of de-embrittled bolts were dramatically faster than the initial embrittlement process and this together, with the limited extent of de-embrittlement at intermediate phosphorus levels, rendered a de-embrittling procedure somewhat dubious.

INTRODUCTION

The production of electrical power involves the usage of sizeable, highly stressed engineering structures at elevated temperatures. One such structure is a steam turbine which contains large steel bolts which, when exposed to certain temperatures, can suffer reverse temper embrittlement, RTE (1-3). Indeed RTE was recognised as a problem about a centuary ago (4).

The cost of a new set of turbine bolts is significant and hence any heat treatment which can de-embrittle or restore their toughness properties after a specific period of service is important and represents an attractive cost saving exercise. The present paper describes the effects of a series of de-embrittlement heat treatments on an embrittled Cr Mo V bolt which had seen some 120,000 hours of service at elevated temperatures.

Experimental Procedures

One embrittled Cr Mo V steel bolt from an "in house" embrittlement assessment programme (5) which had a composition of 1.3% Cr, 0.82% Mo, 0.28% V, 0.009% P and an average austenite

* Electricity Supply Board, Head Office, Dublin, Ireland.

grain size of 63 μm was selected for the de-embrittlement assessment; test coupons from this bolt were subjected to four de-embrittlement heat treatments via (i) a temper (680°C for 2 hours), (ii) a quench and temper (920°C for 1 hour, water quench + 680°C for 2 hours), (iii) an intercritical treatment (830°C for 4 hours) and (iv) a homogenization treatment (2 hours at 1300°C) followed by a quench and temper.

Test samples were taken from the four de-embrittled heat treated coupons and subjected to a series of heat treatments at 570°C. Such heat treatments simulated "in service" durations of 1500, 10,000 and 50,000 hours at 490°C using the Larson - Millar approach. In one instance, viz. the temper de-embrittled treatment, a sample was heat treated at 490°C for 1500 hours in an effort to assess the validity of the simulated 570°C treatments.

Standard Charpy specimens were machined from the de-embrittled and de-embrittled and simulation heat treated coupons, and transition temperatures, in terms of energy and fracture appearance were obtained. Selected samples were fractured "in situ" and subjected to analysis utilising a scanning auger microprobe, SAM; this analysis quantified the extent of grain boundary phosphorus segregation in terms of the average fraction of a monolayer of phosphorus.

Experimental Results

From the initial SAM analysis it was established that the embrittled bolt had an average grain boundary phosphorus monolayer of 0.34. Literature results (6,7) and data generated by the authors for a Cr Mo V steel are given in figure 1. From this figure it is evident that a significant relationship exists between the room temperature Charpy energy and the fraction monolayer of grain boundary phosphorus, i.e. phosphorus segregation.

The fracture appearance transition temperatures, FATT, of the embrittled and the various de-embrittled heat treated conditions, see figure 2, indicated that the de-embrittled FATT values were all lower than the embrittled FATT value of + 125°C with the temper and quench and temper treatments producing the largest degree of de-embrittlement.

The characteristics of the re-embrittlement kinetics of the various de-embrittled heat treatments are illustrated in figure 3 which portrays the various FATT values as a function of time at operating temperature, viz. 490°C. Also shown on this figure are other reported re-embrittlement data for a 2.15 Cr 1 Mo steel (8) and Cr Mo V steels (9, 10). This figure shows that in the case of the quench and tempered treatment the de-embrittlement benefits are lost after only 1500 hours as the FATT is increased to the value of the original embrittled bolt.

The temper treatment exhibited less of an increase in FATT after 1500 hours but the FATT value resided within the range for embrittled bolts viz., + 85 to + 125°C. Note that the FATT values at 1500 hours service for the real and simulated heat treatments for the temper de-embrittled treatment exhibited good commonality indicating that the simulated treatments at 570°C realistically portrayed the effects at 490°C for short service durations. For the temper and quench and temper treatments the FATT values at 1500 and 10,000 hours were similar while at 50,000 hours the FATT values exhibited a significant decrease.

Both the homogenisation and intercritical treatments exhibited good agreement in as much as they (a) showed a dramatic increase in FATT value of over + 70°C after only 1500 hours to levels that were appreciably higher than the original embrittled FATT value and (b) showed the same trend as those observed in the temper and quench and temper treatments at longer service durations.

Concluding Remarks

From figure 2 it can be seen that the extent of toughness restoration for the various de-embrittlement heat treatments is not very large being about 50°C, in terms of FATT for the temper and quench and temper treatments and only about 20°C for the other two de-embrittlement treatments. In an effort to establish if the present limited toughness restoration benefits were normal or otherwise a literature survey was conducted on temper de-embrittlement heat treatments on various steels and the results are portrayed in terms of bulk phosphorus content in figure 4. From this figure it is evident that in general the benefits of a de-embrittlement temper treatment, in terms of toughness restoration, are minimal at normal bulk phosphorus contents of 0.01 to 0.02%. It is also clear that the degree of toughness restoration is strongly related to bulk phosphorus content and that the change in FATT can be described as

$$\Delta \text{ FATT } (^\circ\text{C}) = C \sqrt{\% P} \qquad (1)$$

where C is a constant whose value is about - 300. It is evident from figure 4 that the present study data indicated a reduction in FATT which was about double that expected from the trend of reported results from the literature (8, 9, 11, 12).

From figure 3 it is clear that the re-embrittlement kinetics are about two orders of magnitude faster than the original "in service" embrittling process. The present data exhibited good commonality with other data from the literature. Note also that the coarse grained steels have (a) higher starting FATT values and (b) exhibited a greater degree of re-embrittlement at short service time durations. Both these observations can be readily explained in terms of the influences of grain size on FATT and the limited amount of grain boundary area available for phosphorus segregation in course grained structures respectively.

REFERENCES

1. Capus, J.M., "Temper Embrittlement in Steel", ASTM, STP 407, 1968, pp 3 - 19, Philadelphia, U.S.A.
2. Viswanathan, R, & Sherlock T.P., "Long Time Isothermal Temper Embrittlement in Ni Cr Mo V Steels", Met. Trans. 3, 1972, pp 459 - 467.
3. Schultz, B.J. & McMahon, C.J., "Temper Embrittlement of Alloy Steels", ASTM, STP 499, 1972, pp 104 - 116.
4. Howe, H.M., Proc. Inst. Mech. Eng., Jan - May, 1919, pp 405 - 412.
5. Bulloch J.H. & Hickey J.J., Unreported ESB Studies on Embrittlement in Cr Mo V Bolts, Aug. 1991 - May 1992.
6. McMahon, C.J., Gentner, D.H. & Vcisik A.H., Trans. ASME, 106, 1984, pp 66 - 70.
7. Viswanathan R, & Jaffee, R.I., "Toughness of Cr Mo V Steels for Steam Turbine Rotors", Joint Power Conf. Paper, ASME 82 - JPGC - PWR - 35 1982.
8. Qu, Z., & Kuo, H., Met. Trans. 12A, 1981, pp 1333 - 1337.
9. Cheruvu, N.S. & Novak, R.L., "Can a Temper Embrittled Rotor be Rejuvinated for Improved Service Life? - an Investigation", Joint Power Conf. Paper, Oct. 1989, Dallas.
10. Qu, Z. & McMahon, C.J., Met. Trans. 14A, 1983, pp 1101 - 1108.
11. Knight, R.F., Tyson, W.R. & Sproule, G.I., Metals Tech. 11, 1984, pp 272 - 279.
12. Dumoulin, P., Guttman, M., Foucault, M., Palmier, M., Wayman, M. & Biscondi, M., Metal Sci. 8, 1980, pp 1 - 15.

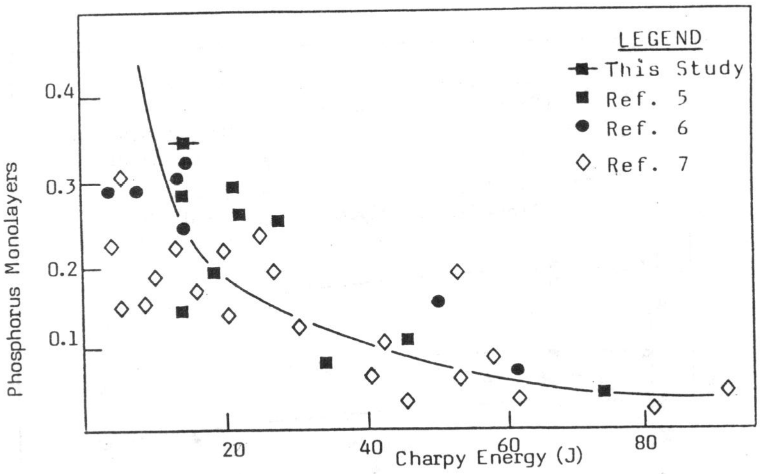

Figure 1: Phosphorus Segregation - Charpy Energy Trend for Various Steels

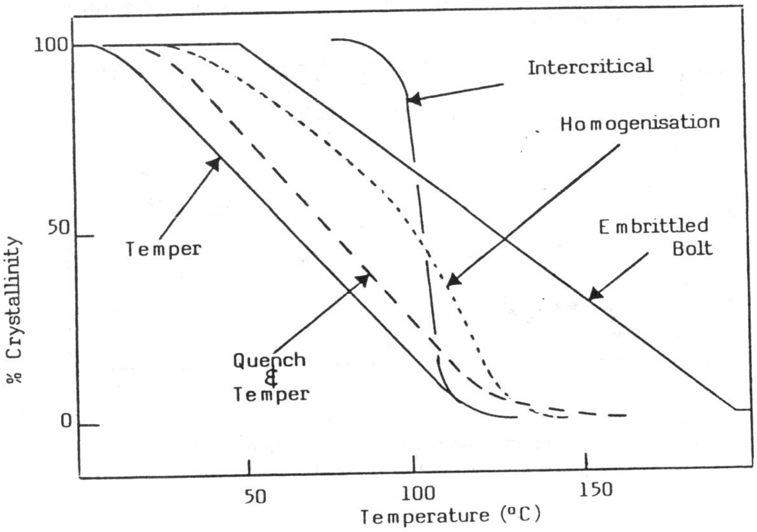

Figure 2: Transition Curves for Embrittled & De-embrittled Conditions

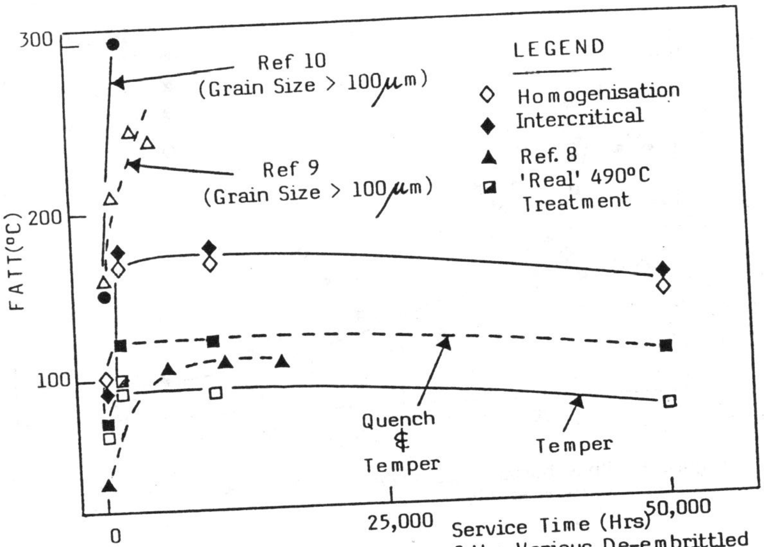

Figure 3: Re-embrittlement Kinetics of the Various De-embrittled Conditions

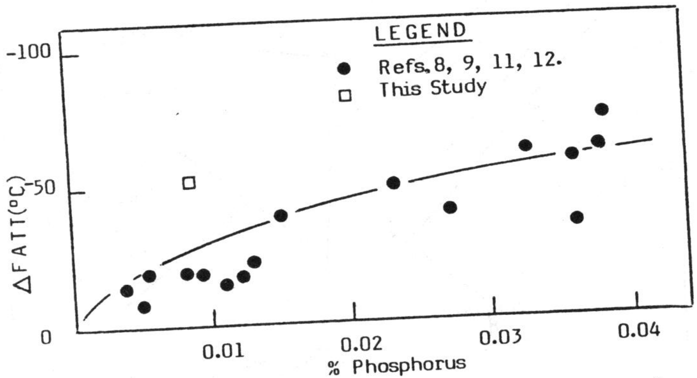

Figure 4: The Temper De-embrittlement Characteristics of Steels as a Function of Phosphorus Level