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# Characterization and correlation of mechanical, microstructural and ultrasonic properties of power plant steel

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A B S T R A C T

In the present work 912% Cr tempered martensitic steel which is normally used in gas turbine-shrouds in electricity generation power plants was characterized through mechanical, microstructural and ultrasonic testing. The steel tested was in the as-received (virgin), artificially aged at 700 °C for three different periods of time namely 336, 840 and 1344 h, and retired from real operating conditions. The mechanical and microstructural test results were assessed and correlated with ultrasonic testing parameters. Artificial aging caused carbides to dissolute within the martensite–ferrite matrix and to coarsen and disintegrate at the prior austenite grain boundaries. Aging reduced the percentage of low angle grain boundaries and increased the average misorientation angle, both of which indicate the occurrence of static recrystallization. Energy dispersive spectroscopy elemental analysis identified that the dominant carbide types are $Cr_{23}C_6$ and VC, in which the former was mainly located at the prior austenite grain boundaries whereas, the latter was spread within the entire microstructure. Softening and the consequent loss in mechanical properties were detected as a function of prolonged aging times due to the accompanying microstructural phases and carbide dissolution which in turn were correlated with ultrasonic velocity and attenuation. The retired condition had the lowest strength, highest sound velocity and almost similar attenuation as that of the virgin which possessed highest strength and lowest sound velocity.

## 1. Introduction

Numerous components operating in electricity generation power plants generally suffer from degradation due to their long-term operation in high temperature. Hence, reliability and safety are crucial issues in the operation of these plants. This necessitates the assessment of the risk associated with material degradation through aging and consequently failure which implies to know the potential mechanisms of degradation and their accumulation. Therefore, in order to extend plant life safely at a minimum cost, it is important to monitor the material characteristics of the components under service, which manifests the need for non-destructive techniques (NDT) to be implemented. Characterizing material degradation in the high-temperature components using ultrasonic testing aided by microstructural and mechanical tests was the focus of numerous research works.

Kumar et al. [1] have characterized 9Cr–1Mo modified steel ultrasonically by subjecting it to a series of heat treatments consisting of soaking the steel for constant duration at different temperatures (1073–1623 K, 800–1350 °C) followed by oil quenching. Ultrasonic velocity and attenuation measurements were used for characterizing the microstructure obtained by various heat treatments. As the soaking temperature increased, the ultrasonic velocity decreased because of the increase in the volume fraction of martensite in the structure. There were sharp changes in the ultrasonic velocities corresponding to the lower and upper critical temperatures. This was attributed to the increase in the amount of martensite with the increase in soaking temperature, which is reflected also in the variation in hardness. The attenuation was found to decrease due to the increase in the amount of martensite which has lower attenuation. Furthermore, the ultrasonic attenuation was found to be at a minimum in the sample quenched from just above the *Ac3* (937 °C) temperature where the prior-austenite grain size was also at a minimum. After 1100 °C, attenuation increased sharply due to the rapid increase in grain size which is associated with the carbide dissolution. Heat treated steel 38Cr Mo Al was characterized using ultrasonic testing [2]. The treatment included three types, all of which started with austenitizing at 920 °C then either oil quenching, or oil quenching followed by tempering or air cooling. A good correlation was found between hardness and sound velocity. The quenched microstructure gave the lowest sound velocity which gradually increased with increasing the tempering temperature between 200–600 °C. The attenuation coefficient of quenched followed by tempering samples was lowest whereas normalized ones were highest. Earlier work [3] has correlated the mechanical properties with ultrasonic velocity and attenuation of lCr–1Mo–0.25 V steel. In addition to reference material, it was heat-treated by the artificially accelerated aging method at a constant temperature of 630 °C and four different durations. It was

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concluded that the ultimate and yield strengths as well as the Vickers hardness decreased whereas the elongation of the material increased as the aging time increased. Attenuation coefficient based on scattering increased as the degradation occurs due to the increase in aging which is accompanied by an increase in grain size and precipitates at grain boundaries. Another work [4] has studied the degradation mechanism of SUS 316-L where it was found that the change in microstructure between the virgin and the degraded material can be detected by an ultrasonic velocity which was correlated with the tensile strength. Vasudeven et al. [5] have characterized ultrasonically an isothermally annealed 20% cold worked-Ti-modified austenitic stainless steel (D9) using ultrasonic velocity measurement. This work showed that the variation in ultrasonic velocity is sensitive to the variation of aging time and also hardness. The aim of the present work is to correlate the microstructural and mechanical properties with ultrasonic measurements conducted on gas turbine-third stage shroud supplied from an international manufacturer. For the purpose of comparison, these shrouds were divided into five conditions, starting with the as-received (virgin), artificially-aged for three different aging times and finally a shroud that retired from real service conditions.

## 2. Materials and methods

The as-received (virgin) shrouds having the chemical composition in wt.%: C: 0.328; Cr: 11.55; Ni: 0.196; Mn: 0.256; Si: 0.505; V: 0.0831; and Ti: 0.012, belonging to the 9–12% Cr-martensitic–ferritic steel, normally used in various power plant applications, are used in this study. These shrouds were subjected to accelerated aging at 700 °C in an electric resistance furnace for different durations namely 336, 840 and 1344 h. In addition to these materials and for the purpose of

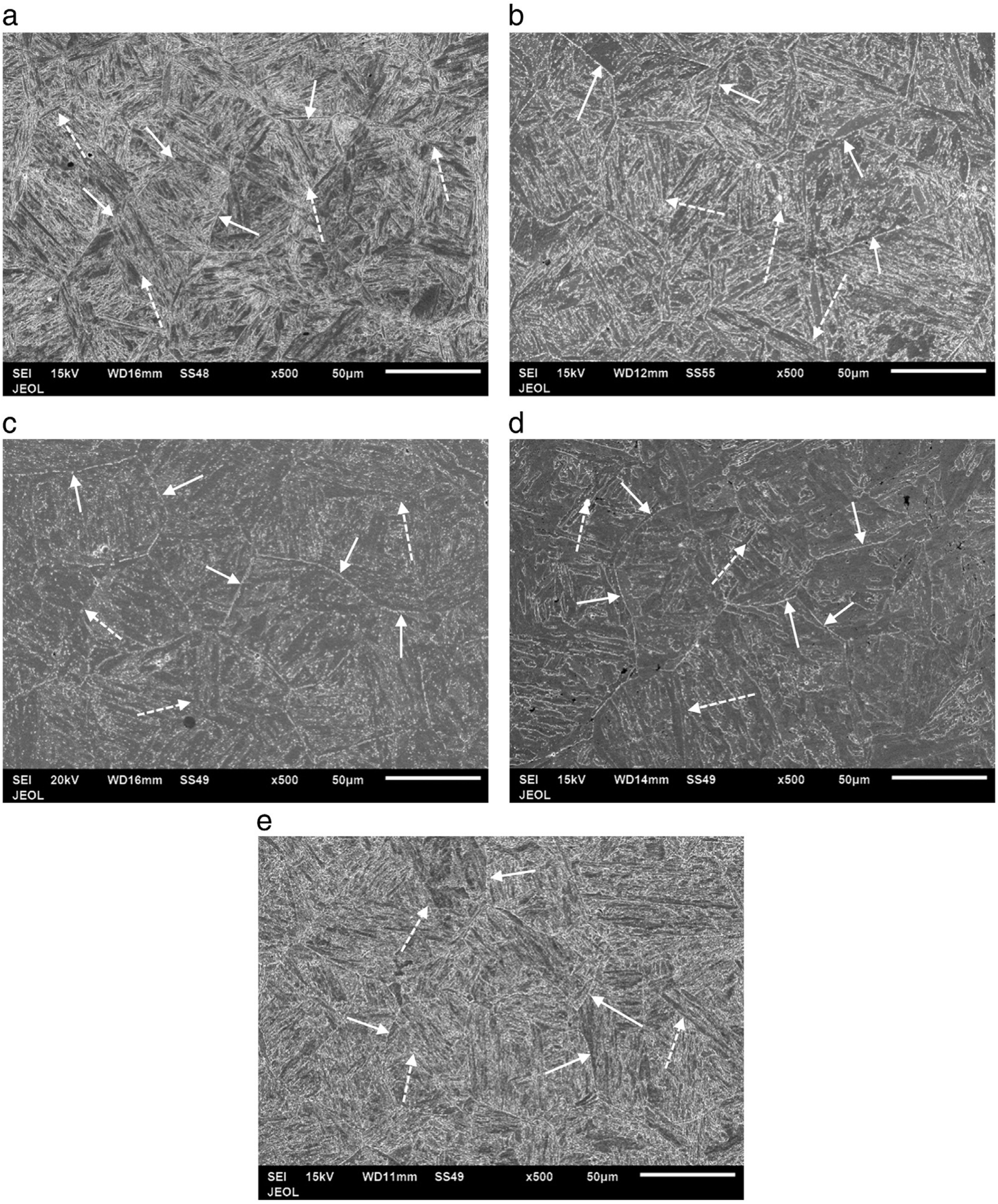

**Fig. 1.** Martensitic ferritic microstructure showing the prior austenite grain boundaries for different conditions: a) 0 h (virgin); b) 336 h; c) 840 h; d) 1344 h and e) 21,000 h (retired) Note: Solid arrow points: prior austenite grain boundaries; dotted arrow points: block boundaries.