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EFFECTS OF AUSTENITIZING ON THE FRACTURE MECHANISM OF HARDENED HIGH CARBON STEEL

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Abstract

This paper aims at studying the effects of austenitizing on the fracture mechanism of hardened high carbon steel. The fracture behavior of hardened high carbon steel is dependent on the austenitizing treatment applied prior quenching and tempering. Steels austenitized below A_{cm} retain a dispersion of carbide particles that induce transgranular fracture. Austenitizing above A_{cm} dissolves all carbide particles resulting brittle and intergranular fracture.

1. Introduction

The ductility and toughness are the most relevant properties in terms of resistance to total failure as a result of overloading [1]. No standardized tests for the determination of ductility or toughness are in common use; often, data determined with different test methods are available, which makes them difficult to compare, and this can lead to confusion. The importance of ductility and fracture toughness for tool steel performance depends on the geometry of the tool [2]. In the case of un-notched specimens or specimens with smooth notches, the ductility and fracture stress are the relevant material properties; however, if sharp notches or cracks are present, fracture toughness is the most relevant property.

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The toughness depends on the hardness, and the hardening mechanism is different in as-quenched and fully-heat-treated tool steels. In the as-quenched tool, work-hardening and solid-solution hardening, mostly due to carbon in the solid solution, mainly affect the hardness of steel. Tempering leads to the precipitation of carbide particles and significantly decreases the carbon content in the solid solution and the dislocation density. The hardness of fully-heat-treated tool steels is therefore mainly affected by precipitates (secondary carbides or intermetallic phases) that cause precipitation hardening and, to small extent, solid-solution hardening. The work-hardening and grain refinement seem to play only a minor role.

The most reliable measure of toughness is the plain-strain fracture toughness. The minimum size of the specimens depends on the yield stress and the fracture toughness of the tested material. A fatigue crack of a defined length is propagated from a mechanical notch in the specimens ensuring that the notch effect is a maximum and equal for all tests. The same value of fracture toughness should be found for tests on specimens of the same material with different geometries and with a critical combination of crack size and shape and fracture stress. Within certain limits, this is indeed the case, and information about the fracture toughness obtained under standard conditions can be used to predict failure for different combinations of stress and crack size and for different geometries [3].

The microstructure of hardened high carbon steels and the surfaces of carburized steels provide excellent wear and contact pitting fatigue resistance for tool, bearing and gear applications. However, the same microstructural elements that produce high hardness also contribute to low toughness under conditions of tensile loading or bending. High carbon steels are susceptible to brittle fracture and also quench cracking during heat treatment. The hardening of high carbon steels consists of three heat treatment stages: austenitizing, quenching and tempering.

Each of these stages affects the distribution of the martensite, retained austenite and carbides that compose the final microstructure. This paper aims at studying the effects of austenitizing on the fracture mechanism of hardened high carbon steel.

2. Experimental Procedure

The chemical composition of high carbon steel is: 0.96%C, 0.41%Mn, 0.21%Si, 1.30%Cr, 0.01%P, 0.011%S and balance Fe. Circumferentially notched and fatigue-precracked K_{Ic}-test specimen) as shown in Fig. 1. Specimens were cut from cast plates and heat treated. The heat treatment consists of three stages viz: austenitizing, quenching and tempering as illustrated in Fig. 2. The heat treatment furnace is shown in Fig. 3. All the specimens were heated to different austenitizing temperatures to vary fracture toughness in the specimens, but the quenching and tempering treatments are same. The quenching was carried out in an oil bath and all the specimens were tempered to 175^0C. Two very different types of microstructure develop depending upon the relationship of austenitizing temperature to the A_{cm} of high carbon steel. Austenitizing below A_{cm} results in a dispersion of micro-sized carbide particles throughout the austenite while austenitizing above A_{cm} results in single-phase austenite.

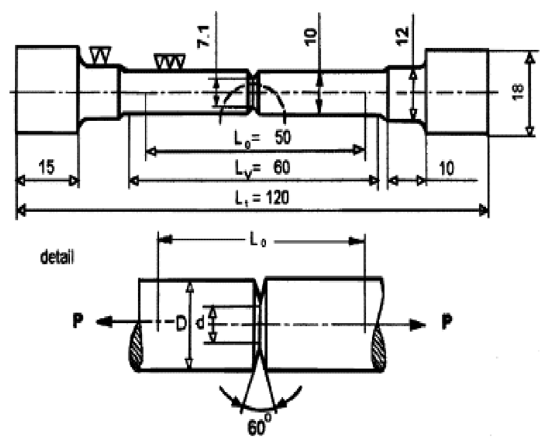

Figure 1. Circumferentially notched and fatigue-precracked K_{Ic}-test specimen. All dimensions are in mm.

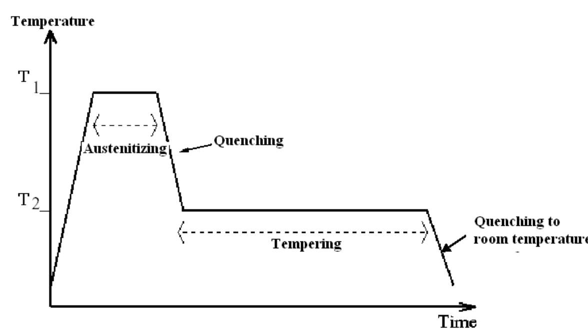

Figure 2. Heat treatment cycle.

Figure 3. Heat treatment furnace.

The fracture toughness is obtained from the following expression:

$$K_{\mathrm{Ic}} = \frac{P}{D^{3/2}}\left(-1.27 + 1.72\frac{D}{d}\right)$$

where P is the load at failure, D the outside diameter, and d is the notched-section diameter of the test specimen, i.e. the diameter of the ligament next to the crack. The above relation is valid as long as the condition $0.5 < d/D < 0.8$ is fulfilled.

Measurements of the fracture toughness were performed at room temperature using a universal tensile-test machine. The cross-head speed was 1.0 mm/min, which is the speed used for standard tensile-tests on specimens with a nominal test length of 100 mm. During the tests the tensile-load/displacement relationship until failure was recorded. In all cases, this relationship was linear, so confirming that fracture toughness expression was valid for the tests. The notched-section diameter d of each of the fracture surfaces was measured at magnification 3–10 times. Since the ligament could be somewhat elliptically shaped, this diameter was expressed as the arithmetic mean value of the diameters measured across each of the two axes of the ellipse [4].

3. Results and Discussion

Figure 4 shows the effect of variation of austenitizing temperature on the fracture toughness of the steel under study. The A_{cm} of this steel was found to be just below 950^{0}C. The dashed-line curve shows the fracture toughness associated with various dispersions of fine carbides in a matrix of fine martensite. The fracture surfaces of these specimens were transgranular, Figure 5, and were characterized by very fine fracture facets and very small microvoids around the undissolved carbide particles. Surprisingly, this type of transgranular fracture is associated with lowest fracture toughness.

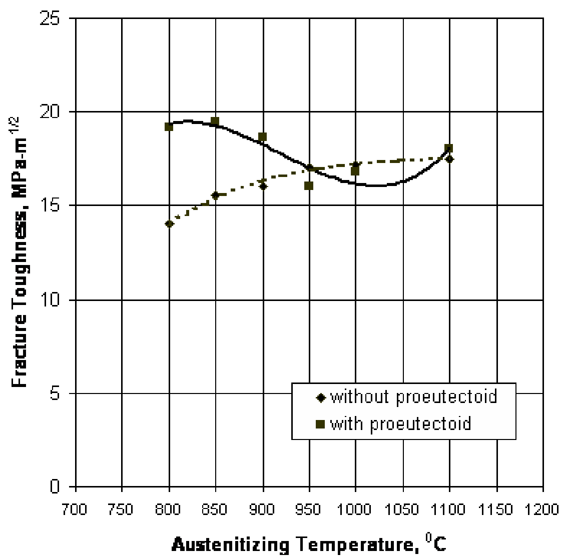

Figure 4. Variation of fracture toughness with austenitizing temperature.

The continuous line curve of Figure 4 below 950^{0}C is associated with the presence of large undissolved proeutectoid carbides that formed at prior austenite grain boundaries on cooling from an earlier high temperature homogenizing treatment. These carbides spheroidized but were not dissolved during final austenitizing for hardening. Fig. 6 shows that the fracture followed these proeutectoid carbide networks. The austenite grain size produced by austenitizing below A_{cm} is quite fine and that it is only the proeutectoid cementite network that inherits the coarse, as homogenized austenite grain morphology. Figure 6 was taken from a fatigue precracked area of a compact tension specimen, the overload fracture surfaces from specimens with the undissolved proeutectoid carbide networks showed the same morphology.

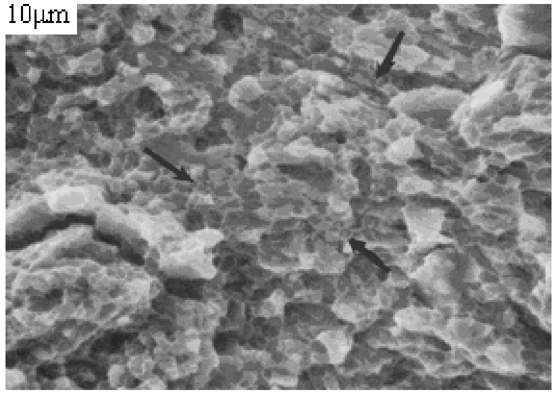

Figure 5. Overload fracture surface of a specimen austenitized at 800^0C Arrows pint to carbide particles.

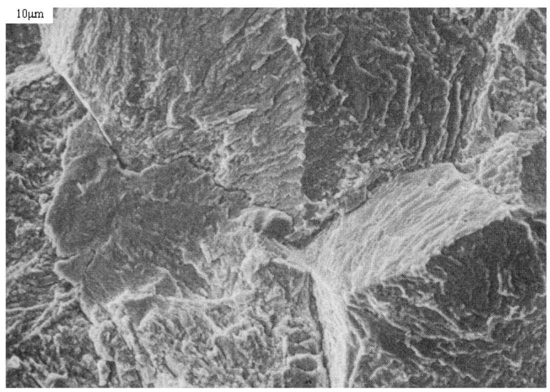

Figure 6. Intergranular fracture surface of a specimen containing a proeutectoid carbide network prior to austenitizing at 800^0C.

The specimens austenitized at 950^0C are fractured primarily along prior austenite grain boundaries, Figure 7. In specimens austenitized at higher temperatures transgranular fatigue precrack develops within the microstructure of an austenite grain. The initial crack path on loading is transgranular through a tougher mix of retained austenite and martensite. Eventually, the crack leaves the transgranular path and follows the austenite grain boundaries resulting in the brittle, intergranular fracture.

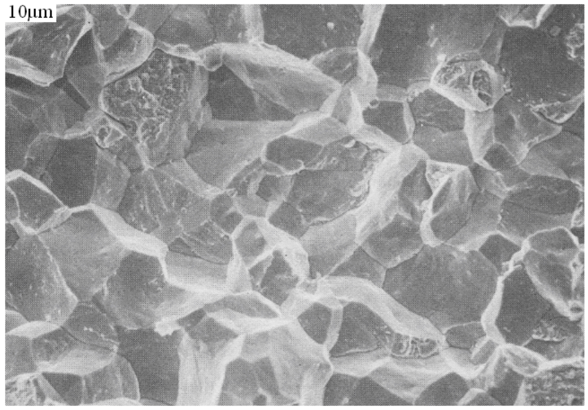

Figure 7. Intergranular fracture surface of a specimen austenitized at 1000^0C

4. Conclusions

The fracture behavior of hardened high carbon steel is dependent on the austenitizing treatment applied prior quenching and tempering. Steels austenitized below A_{cm} retain a dispersion of carbide particles that induce transgranular fracture. The best fracture toughness is associated with carbide distributions that cause transgranular crack propagation through martensite and austenite containing a minimum of micro-sized carbide particles. Austenitizing above A_{cm} dissolves all carbide particles resulting brittle and intergranular fracture with relatively low toughness during fatigue and/or overload conditions.

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