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Investigating the Effects of a Heat Treatment on Microstructure of an Ultrahigh Carbon Steel through SEM and *In Situ* CLSM studies.

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Without special thermomechanical processing and/or chemical additives, ultrahigh carbon steels (UHCS, 1 - 2.1 wt% C) develop an extensive network of brittle carbides. The network carbides can serve as initiation sites and propagation pathways for cracks. Thus, the high volume fraction of interconnected carbides will greatly reduce toughness/ductility, but does result in very good abrasion resistance. As a consequence, UHCS have been successfully used in rolling mills at least as far back as 1913 despite their brittleness. In the years following the discovery in the early 1970s that UHCS could be made superplastic, there has been significant progress in making them usable for many more applications through break-up of the carbide networks [1]. An important question is whether network breakup can only be accomplished through heavy mechanical deformation or additives. For some applications these methods are not feasible, and an alternative would be desirable.

We have been investigating the novel possibility of accomplishing significant hardening and carbide network breakup solely through heat treatment by studying as cast and heat treated samples of a commercial centrifugally cast UHCS mill roll alloy, AS-100. Industry has known for some time that heat treatment near the austenitizing temperature will significantly improve the hardness and toughness of this alloy; a spheroidization mechanism was originally suspected. Scanning electron microscopy (SEM) studies of the microstructure show that heat treatment causes many apparently equiaxed carbides to appear homogenously in the microstructure (Figure 1a). These carbides have no apparent orientation with the parent matrix and thus have been termed “idiomorphic” carbides, following the Dubé classification system modified for cementite by Aaronson [2]. Examination at higher magnification reveals that pearlite post heat treatment is still lamellar, though in many regions it is significantly distorted (Figure 1b), indicating that the new carbides are not a result of pearlite spheroidization. Quantitative analysis of SEM images confirms that the heat treatment reduces carbide network connectivity and volume fraction, and also decreases pearlite lamellar spacing. Measured hardness values scale well with the inverse square root of lamellar spacing (Figure 2), indicating that a Hall-Petch hardening mechanism is in operation.

Video recorded during *in situ* confocal laser scanning microscopy (CLSM) has revealed that the apparently idiomorphic carbides nucleate and grow well above the eutectoid temperature, accompanied by shrinkage of the network carbides (Figure 3). Conditions for idiomorphic carbide nucleation and growth are not currently understood, so the extent to which they may be precipitated in the microstructure—and hence the potential of pure heat treatments to break up the network—is not known. *In situ* CLSM indicates that they begin to appear quickly within the austenitizing temperature regime, and there is potential to determine temperature regions for optimal precipitation and growth. High magnification *ex situ* SEM studies of samples produced inside the confocal microscope complement the CLSM video footage, allowing for quantitative analysis of effects of various heat treatments on idiomorph size and volume fraction, network connectivity, and pearlite lamellar spacing. Thus we believe that a heat treatment can be optimized for this alloy to increase toughness by breaking up the carbide network above the eutectoid temperature, and increase hardness by refining the pearlite below it.

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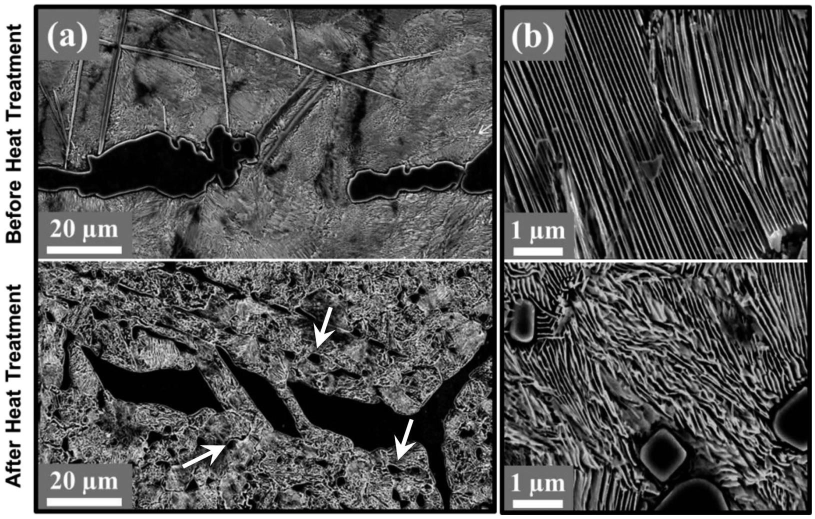

Figure 1. SEM images of AS-100 microstructure before and after heat treatment. (a) Idiomorphic carbides (a few are indicated by arrows) appear after heat treatment, and (b) pearlite is more disorganized

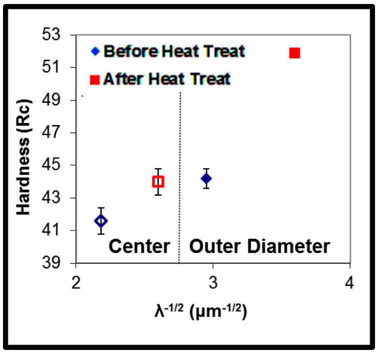

Figure 2. Hall-Petch plot of hardness versus pearlite lamellar spacing (λ) in as cast and heat treated AS-100 rolls. Samples from the outer diameter and center of the rolls were examined by SEM and tested in a Rockwell hardness tester.

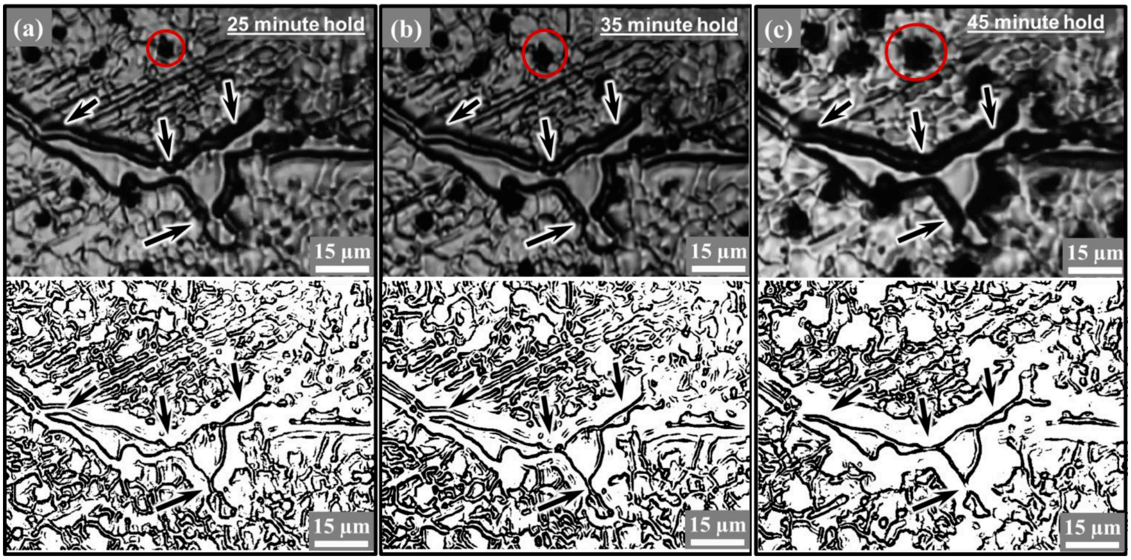

Figure 3. *In situ* CLSM images of microstructure results from holding at >1000°C for (a) 25 minutes, (b) 35 minutes and (c) 45 minutes show an increased idiomorph size (example of a growing idiomorph circled in the figure) and shrinkage of the network carbides (arrows denote shrinkage). ImageJ was used to detect edges in the CLSM images (bottom images) and then the edge-detected images were converted to binary contrast for better visual clarity.

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