Nanoindentation as a method for phase mapping auto-tempered martensite and lower bainite mixed microstructure steels

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Abstract

S960 is a grade of advanced high strength steel (AHSS) developed for the yellow goods market, for instance the production of blanks for crane booms. Currently, bendability is a limiting factor in progressing the product and enabling thicker grades to be produced, and factors limiting bendability and toughness must be evaluated. S960 can contain a mix of lower bainite and martensite which has autotempered during cooling. The currently methodology for identifying the phase fractions of these constituents is visual identification from scanning electron microscope (SEM) images, shown in Figure 1. A new method is proposed which utilizes instrumented indentation or "nanoindentation" to map local hardness variations across the surface, to determine the phase fractions of the steel.

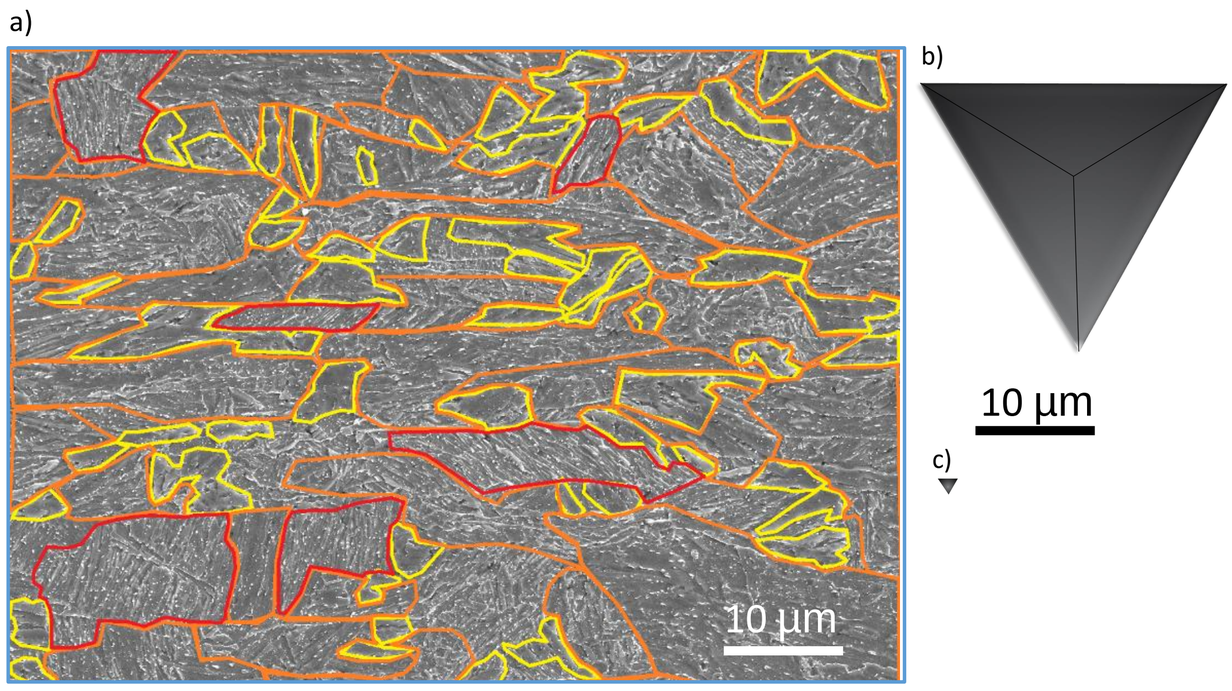


Figure 1: a) SEM micrograph of bainitic steel with an overlay of phase identification through visual identification (upper bainite in orange, lower bainite in red) [1] **b)** Microhardness indent scaled to the SEM image. **C)** Nanohardness indent scaled to the SEM image.

Methodology

Nanoindentation is a depth sensing indentation using the load-displacement data obtained during an indent to determine the local hardness. Using a force of less than 10 mN, indents of less than 1 µm can be placed within a single packet of the microstructure, with a plastic zone of ~ 4 µm. If an array of indents is placed on the surface of a multiphase steel, as seen in Figure 2, the hardness distribution can indicate the phase fraction present. Comparing to a visual based approach, this new methodology eradicates human bias, saves time and can be automated, but requires tightly controlled surface preparation and the use of small loads which affects the precision of the indents.

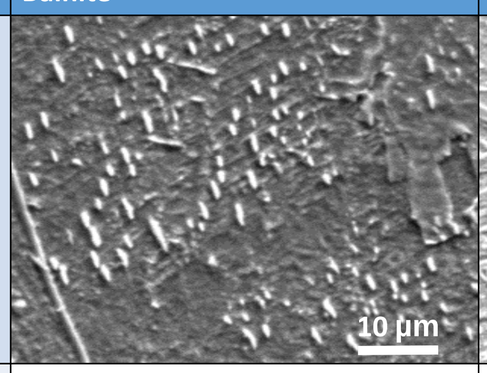
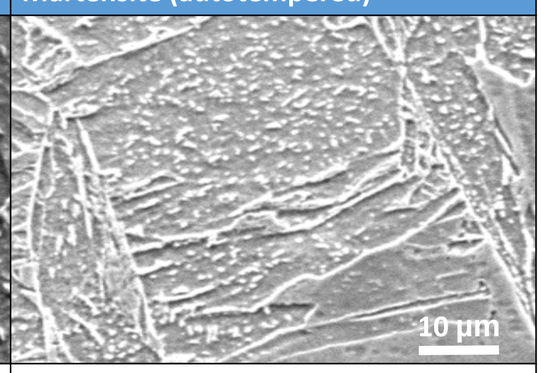
	Bainite	Martensite (autotempered)
SEM Image of microstructure		
Identifying features	Carbides along a single orientation within lathes	Carbides along 3 orientations (X,Y,Z)
Hardness ($HV_{0.2}$)	385	415

Table 1: Comparison of differentiating features in lower bainite and autotempered martensite.

Results

Nanoindentation mapping has successfully identified phase fractions in multiphase steel. Figure 3 shows a cumulative distribution plot of 20x20 arrays of indents with varying loads, showing a clear transition between the soft (< 1.75 GPa) ferrite and the harder (> 2 GPa) pearlite phase with an intermediate where indents, or their plastic zone, spanned both phases. A volume fraction of 60-80% was identified through all loads, close to the true value of 80%. Figure 4 shows the varying hardness distributions for different phase balances of mixed microstructure steels, with 100% lower bainite (LB) showing the lowest hardness (4.25-5.25 GPa) up to the 100% martensite (M), (5.25-6.25 GPa). In the future, nanoindentation mapping will also be used to identify chemical variations within a steel through similar methods.

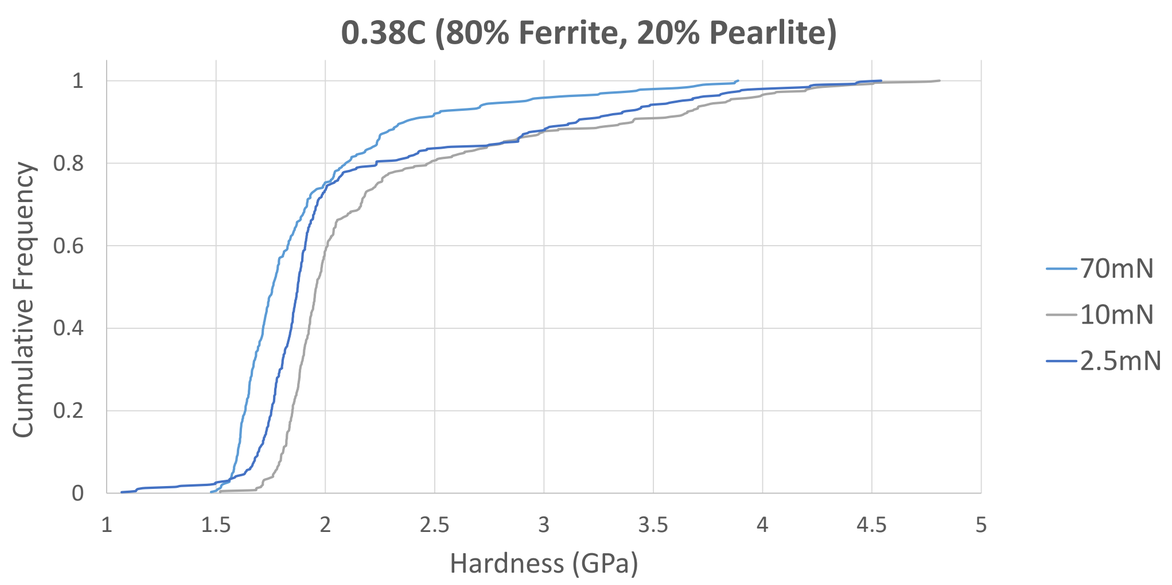


Figure 2: Cumulative distribution plot of 20x20 arrays of Berkovich indents at varying loads in a ferrite pearlite steel.

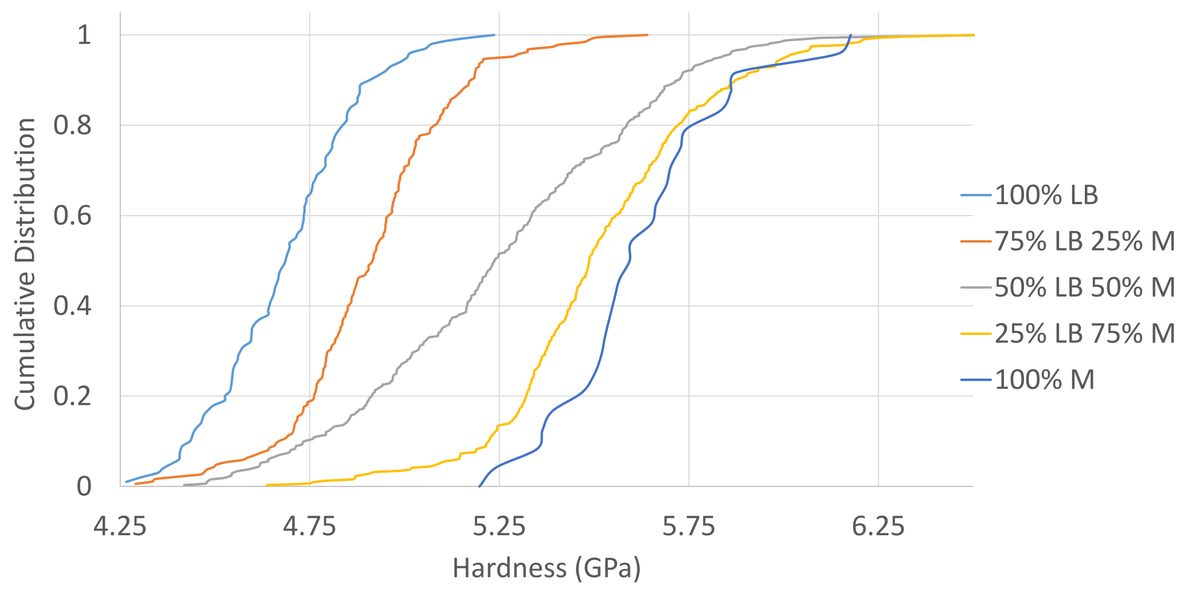


Figure 3: Cumulative distribution plot of 20x20 arrays of Berkovich indents in mixed microstructure steels of varying phase fractions.

References: [1] Development of high strength hot rolled strip steel products with bainitic microstructures. Du, Jinlong (2017). University of Birmingham.