



Effect of small addition of Cr on stability of retained austenite in high carbon steel



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ABSTRACT

High carbon steels with dual phase structures of martensite and austenite have considerable potential for industrial application in high abrasion environments due to their hardness, strength and relatively low cost. To design cost effective high carbon steels with superior properties, it is crucial to identify the effect of Chromium (Cr) on the stability of retained austenite (RA) and to fully understand its effect on solid-state phase transition. This study addresses this important knowledge gap. Using standard compression tests on bulk material, quantitative X-ray diffraction analysis, nano-indentation on individual austenitic grains, transmission electron microscopy and electron backscatter diffraction-based orientation microscopy techniques, the authors investigated the effect of Cr on the microstructure, transformation behaviour and mechanical stability of retained austenite in high carbon steel, with varying Cr contents. The results revealed that increasing the Cr %, altered the morphology of the RA and increased its stability, consequently, increasing the critical pressure for martensitic transformation. This study has critically addressed the elastoplastic behaviour of retained austenite – and provides a deep understanding of the effect of small additions of Cr on the metastable austenite of high carbon steel from the macro- to nano-level. Consequently, it paves the way for new applications for high carbon low alloy steels.

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1. Introduction

High carbon steels with dual phase structures of martensite and metastable austenite are hard, strong and cost effective, making them potentially ideal for industrial applications in high abrasion environment. However, the ductility of high carbon steel can be very low due to the brittleness of their martensitic structure which is same structure as martensite in low carbon steel [1,2]. It is possible to have a good balance of strength and high-energy absorption properties in high carbon steels by selective alloying and well-controlled microstructures, achieved by thermal treatments. Dual phase steel contains certain amounts of retained austenite after quenching at controlled temperatures [3–7]. Previous research has demonstrated that retained austenite (RA) enhances wear resistance and can prevent sudden breakage by absorbing the energy from impacts and attenuation [8,9]. In the process, these strains induce the solid transformation of much of the RA to martensite contributing to the steel's plasticity, increasing its hardness and reducing its wear rate [10]. Therefore, to optimize mechanical properties for wear resistance in industrial operations is essential to control the percentage and stability of RA.

Metastable RA will transform to the more stable martensite structure when the chemical free energy required for this transformation reaches the critical threshold; as measured by stress, strain and/or temperature values [11–14]. This deformation induced solid-state phase transformation affects the strength and ductility of the steel due to the strain hardening effect [15,16].

Cr is usually added to steel to enhance its resistance to corrosion and oxidation and to improve its high temperature strength [17]. Although it can be assumed the resulting enhanced mechanical properties may be a consequence of the effect of Cr on the stability of RA but this supposition needs further investigation. In order to be able to design/customise cost-effective high carbon steels for industrial applications, it is crucial to understand the critical Cr % and its effect on the structure of high carbon steel.

This study aims to address this knowledge gap by investigating the effect of small additions of Cr on the stability and solid-state transition of RA in high carbon steel. High carbon steel with three different Cr percentages from 0.10% to 2.5% was investigated under compression stress from the macro- to the nano-level. Using standardized compression tests, the effect of pressure on the transition of RA to HCP (hexagonal close-packed) martensite and BCT (body-centred tetragonal) martensite at the macro-level was investigated. Nano-indentation experiments were also conducted to investigate this solid-state transition at the nano-level. At both the macro- and nano-level, phase transitions were

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Table 1
Retained austenite percentage in high carbon steels.

Sample	Cr (wt%)	RA %
A	1.80–2.50 Cr	57–59
B	0.60–0.80 Cr	48–53
C	0.10–0.18 Cr	47–50

investigated using electron backscattering microscopy and quantitative X-ray diffraction analysis. The effect of austenite grain boundaries and the properties of the surrounding matrix and morphology were also considered and are explained below. In addition, the results are discussed in terms of the nature and scale of the various steels' microstructures to provide new experimental evidence to explain the mechanical behaviour and stability of RA in high carbon steels with different Cr percentages.

2. Experimental Procedure

Industrial grade 1.0%C steels with three different Cr contents in chemical composition were investigated in this study. The samples were carefully selected to have similar RA as per the starting percentages of RA listed in Table 1, to determine the effect of Cr on solid-state transformation of RA. As the increase in the Cr content of the steel from 0.10% to 2.5% causes both a corresponding increase in the eutectoid temperature and a decrease in the eutectoid carbon content, the additional Cr increases the potential for carbide formation. To offset this effect, the Manganese (Mn) content of the samples were adjusted accordingly, in a range from 1.00% to 0.50%, depending on the Cr content.

Small samples of 4 mm × 4 mm × 4 mm were prepared for X-ray diffraction measurements, compression testing and nano-indentation using a diamond cutter (Struers Acutom50) at a low speed (0.05 mm/s) and with medium force. This very low cutting speed was used to prevent shear stress or thermal effects triggering any transformation in the samples' microstructure during preparation. Sample preparation consisted of standard grinding steps, followed by polishing using 3 μm and 1 μm diamond paste and several cycles of interval etching, using 2% nitric acid in ethanol, and polishing to remove the deformed layer. Samples were finally polished using a colloidal silica

suspension. To eliminate the effects of sample preparation on Electron backscatter diffraction (EBSD) results, the mechanically damaged layer induced by grinding was removed using deep electro-polishing before EBSD was conducted. Quantitative XRD analyses were used to determine the volume fraction of martensite and retained austenite in all samples. A PANalytical Empyrean XRD instrument was used with unfiltered Co-K α radiation at 45 kV and 40 mA current for quantitative XRD analysis, to measure the volume fraction of phases from a 2 θ spectrum that was acquired at a step size of 0.026 over an angular range of 47° to 120°. Unfiltered Co-K α radiation was used to avoid strong fluorescence from copper radiation and to achieve high resolution spectrums.

The compression deformation experiments on the bulk samples were performed at room temperature with an Instron 8510 instrument operating at 0.10 mm/min cross-head speed at loading pressures ranging from 200 MPa to 3500 MPa.

Nano-indentation tests were performed in load control mode using a TI 900 Hysitron Tribolab system with a Berkovich three-sided pyramidal diamond tip indenter (Berkovich, 142.3°, 100 nm tip radius). This investigation was conducted at a load of 8000 μN so that the phase transformation phenomena could be studied in a single austenite grain. An optical microscope was available in the system, which made it possible to evaluate grain morphologies and identify precisely those areas that had been previously analysed by EBSD using an Oxford system attached to a Carl Zeiss AURIGA® CrossBeam® field emission gun scanning electron microscopy (FEG SEM) workstation. Guided by the EBSD images, single austenite grains were selected for nano-indentation.

After indentation, the indented areas were analysed again by EBSD to determine any changes in their structure. Martensitic transformation within single grain of RA was studied using TEM. The focused ion beam (FIB, XT Nova Nanolab 200, at 30 kV) technique was performed to mill the cross-sectional TEM thin foils beneath the nano-indentation. A protective layer of platinum was deposited over the surface of the indents with a built-in gas injection source system. In the initial thinning, the Ga + beam was accelerated to 30 kV with a current of 5 nA, which was used to mill a staircase on both sides of the plate area. Then, the plate was further thinned to a foil of less than 100 nm with a lower Ga + current of 0.1 nA. The damaged layers formed during the initial high energy milling were removed by applying smaller beam currents

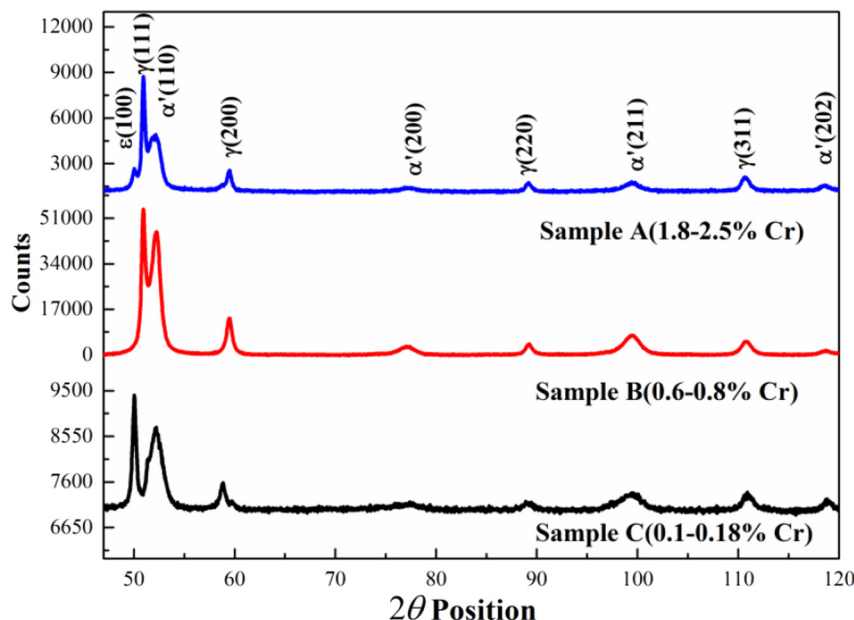


Fig. 1. XRD spectrums of three steel samples before compression deformation.

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