Journal of Manufacturing Processes 22 (2016) 115–119

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Influence of prior cold deformation on microstructure evolution of AISI D2 tool steel after hardening heat treatment

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ARTICLE INFO

Article history:
Received 26 October 2015
Received in revised form 6 February 2016
Accepted 12 February 2016
Available online 31 March 2016

Keywords:
Electron microscopy
Hardness measurements
Steel
Bulk deformation
Grain refinement
Phase transformation

ABSTRACT

4 mm thick plates of AISI D2 steel were subjected to two different percentage of cold rolling prior to quench hardening. Prior austenite grain size and volume fraction of carbides were reduced after hardening heat treatment for both 10% and 20% cold-rolled samples in comparison with non-deformed one. Hardness measurements revealed that pre-deformation resulted in a 3 to 4 HRC decrease. Scanning electron microscopy images revealed more uniform mean plate size of martensite for the cold rolled samples. The obtained results are analyzed in the framework of the existing theories on martensitic transformation and the influence of strain on second phase dissolution kinetics. The drop in hardness is related to the effect of pre-deformation on the dissolution rate of carbides. The volume fraction of martensite compared to non-deformed condition didn't show dominant reduction.

1. Introduction

AISI D2 tool steel is widely used in die making industry and different type of cutting tools [1,2]. High hardness and ultimate strength combined with good wear resistance are characteristics of this steel. The superior mechanical properties are due to its chemical composition (high carbon and alloying elements) and specific processing conditions that allow the formation of various types of strong phases (e.g. martensite and bainite) and hard second phase particles. The processing of the alloy consists of ingot casting followed by forging and/or hot rolling [3]. The as-deformed material is then subjected to quench and temper operations [3]. Austenitization temperatures between 1233 K and 1353 K are used to allow for higher dissolution of alloying elements in austenite and partial carbide dissolution before quenching [1–4]. The higher dissolution of alloying elements increases the propensity for solid solution hardening upon quenching and the undissolved carbides halt extreme austenite grain growth [5].

Phase transformation during conventional quenching of this steel has received much interest because of the high hardness (close to 63 HRC) and hence brittleness of the material after quenching. Most reports are focused on the application of a cryogenic treatment (below 200 K) and subsequent tempering process in the temperature range of 423–773 K to reduce brittleness by transforming more austenite to martensite, relieving internal stresses, and precipitating temper carbides [6–9].

Cold deformation is widely used in metallic materials for grain refining and strengthening of the initial microstructure [5]. The influence of cold deformation of martensite on recrystallization behavior of low carbon steels was studied by Tokizane et al. [10]. Chojnowski and Tegart [11], and Joo et al. [12] reported that prior cold deformation accelerated the spherodiziation process in hypereutectoid steels. In addition, it is well established that reduction in prior austenite grain size (PAGS) affects the start temperature of martensitic transformation (M_s) as discerned by Guimarães [13,14], Lee and Lee [15], and Yang and Bhadeshia [16]. The smaller mean PAGS pushes down the M_s temperature and increases the stability of retained austenite instead of martensite [13–15]. However, examination of the literature indicated that no work has been reported on the influence of prior cold deformation on the initial microstructure of AISI D2 steel and its impact on microstructure evolution during quenching and subsequently the final mechanical properties. The present work has therefore objective to investigate the effect of pre-deformation on microstructure evolution, carbide dissolution behavior, mean PAGS reduction, hardness changes, and the kinetics of martensitic transformation after hardening cycle in the investigated AISI D2 alloy. Adding cold deformation route before hardening heat treatment of tool steels is expected to improve the strength and wear properties of these alloys and therefore result in higher quality products and longer service life for cutting tools made of these alloys.

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http://dx.doi.org/10.1016/j.jmapro.2016.02.002

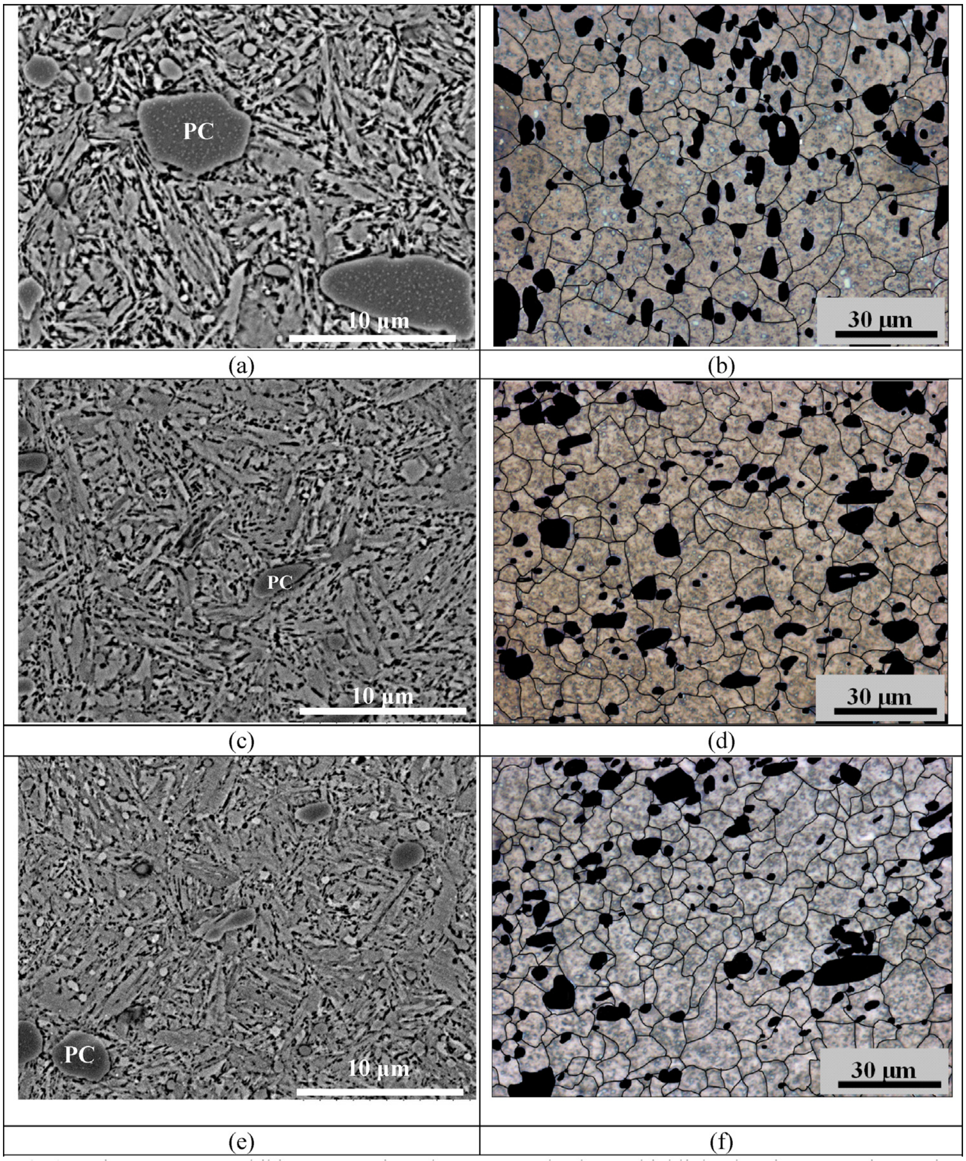

Fig. 1. Microstructure exhibits martensite plates, second phase, highlighted prior austenite grain boundaries, and primary carbide (PC) with other finer carbides either M_7C_3 or $M_{23}C_6$: (a) and (b): non-deformed, (c) and (d):10% cold-rolled, (e) and (f): 20% cold-rolled and hardened samples, highlighted prior austenite grain boundaries are shown in part (b), (d), and (f) in a consecutive order corresponding to conditions (a), (c), and (e), respectively; smaller mean martensite plate size in (c) and (e) compared to (a). Black highlighted particles in parts (b), (d), and (f) correspond to intergranular carbides which were eliminated during grain size measurements.

2. Experimental material and procedures

AISI D2 tool steel plates with nominal composition of C 1.54–Si 0.33–Mn 0.32–Cr 11.88–Mo 0.76–V 0.75–P 0.008–S 0.008 (wt%) and 4 mm initial thickness were given 10% or 20% reductions in thickness by cold rolling. The rolling machine was a 2-high laboratory milling mills fabricated by Fenn Model: 4-046 with anvil diameters of 100 mm and maximum rolling pressure of 136 kN. In order to avoid internal cracking because of high work-hardening susceptibility of the alloy, a rolling speed of 1 m min^{-1} was used. Samples were cut from the cold rolled bars and then heated to 1303 K for austenitizing and maintained for 1200 s followed by water quenching (hardening cycle). For microstructural investigations and hardness measurements, cold rolled samples were sliced in half along the width and their central faces parallel to top surface were polished and etched.

Samples from the as-received bar were also given similar treatment for comparison purposes. An etchant with the following composition 40 g NaOH + 60 g H_2O + 15 g $NaNO_3$ initially proposed by Gouné et al. [17] was modified and successfully used to reveal martensite as well as prior austenite grain boundaries. HITACHI TM3030 scanning electron microscope (SEM), PANalytical X-ray diffraction machine model X'Pert Pro, MIP image analysis software [18], and Rockwell C (150 kg, 10 s) macrohardness were employed to evaluate microstructure evolution after cold rolling and hardening cycle. In order to measure the volume fraction of carbides, back scattered electron (BSE) images showing phase contrast (carbides as black regions and matrix bright) were taken from 3 different areas in each sample and then were analyzed by MIP software. The limitation for the size of carbides is considered to be 0.2 µm to eliminate the noise effect from BSE images [19,20]. In order to measure the volume fraction of retained austenite, ASTM E975-13 standard was used. It is worth mentioning that the constant values in this standard are just for Cr and Mo targets. For this reason, the constants for Cu-target were calculated by the present authors. For metallographic studies, after conventional surface preparation