Advanced Materials Research Vol. 1043 (2014) pp 154-158
Online available since 2014/Oct/20 at www.scientific.net
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doi:10.4028/www.scientific.net/AMR.1043.154

Submitted: 13.08.2014
Accepted: 13.08.2014

Cementite Precipitation of a H21 Tool Steel after Hot Compression and Double Temper

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Keywords: Tool steel, martensite, bainite, cementite, axisymmetric compression

Abstract. The cementite precipitation behavior in the martensite and banite of the H21 tool steel under high temperature axisymmetric compression test and double temper was investigated. The main purpose on this work is to develop a better understanding regarding the transformation mechanism of bainite and martensite in a H21 tool steel. The selected deformation temperatures were 1100 °C and 1000 °C and the double temper process was carried out at 650 °C for 1 hour respectively. The results showed that the cementite was sensitive to the stress. The applied stress has affected the Fe_3C precipitation behaviour by decreasing the number of variants carbides in tempered martensite and decreasing the number of a single variant carbides in tempered lower bainite. The results were in agreement with a displacive mechanism of martensite and bainite transformation. It was also found that hot deformation temperatures selected in this work have the same contribution in decreasing number of variant carbides in tempered martensite and decreasing number of single variant carbides occurred in tempered lower bainite.

Introduction

The H21 tool steel is one of the tungsten hot work tool steel group based on AISI standard. High concentration of carbide forming elements in this tool steel forms a brittle carbide network during solidification that gives negative effect to the mechanical properties. To remove the carbide network, heat treatment of tool steels, which consists of austenisation and tempering process, is carried out. However, it is difficult to remove completely the brittle carbide network during austenisation due to the thermodynamic stability of the carbides. Previous investigations reported that [1,2] controlled thermomechanical processing is a great way to improve the mechanical properties of the tool steels by breaking down the carbide network uniformly and controlling the microstructure. The applied stress during hot deformation not only affects the carbide network but also affect the cementite precipitation behaviour in bainite and martensite during tempering. Other investigations [3-6] concluded that the stress affected the cementite carbide variant and that their behaviour is consistent with displacive transformation. However most studies in the field of cementite precipitation only focussed on low alloy steel and never for tungsten hot work tool steel. The main purpose on this work is to develope better perception, which support the findings of a great deal of the previous work to confirm the transformation mechanism of bainite and martensite in a H21 tool steel.

Experimental Procedure

The material of the present study was a H21 tool steel, which has a nominal composition of 0.3C-0.3Si-0.3Mn-3.1Cr-7.5W-0.4V- Fe balance (wt%). This steel was made by casting using a vacuum induction unit. The high temperature axisymmetric compression was carried out on a SERVOTEST thermomechanical compression machine. The shape of samples for hot axisymmetric compression test was cylinders with the size 12 mm in diameter and 15 mm in height and had thermocouple holes of 1.1 mm in diameter in the middle and 5 mm in depth. The austenising temperature was 1250 °C and the samples were held at this temperature for 10 minutes. The samples were then continued to be cooled to the deformation temperature (1100 °C or 1000 °C) where they were deformed with strain rate 0.01 s^{-1} and then water quenched. The true strain for all tests was 0.5. The samples for double tempering process and scanning electron microscopy (SEM) were taken from deformed samples, which were cut along the longitudinal compression axis. The double tempering temperature was 650 °C and the samples were held for 1 hour respectively with air cooling in between the first and second tempering. For undeformed samples, the austenisation was carried out at 1250 °C and held for one hour, followed by water quenching. Afterwards the samples were double tempered using the same parameter as deformed samples. The microstructures were studied using a JEOL6400 SEM operated at 20 kV and a Philips 420 TEM operated at 120 kV. To reveal the microstructure, SEM samples were prepared using standard metallography procedures and the etching solution was picric acid plus 2 % HCl. Thin foils for TEM studies used the electrolytic jet polishing method with a solution of 5 % perchloric acid, 35 % butoxyethanol and 65 % methanol.

Results and Discussion

Electron microscope images of the as quenched microstructure after deformation at the different temperatures are shown in Fig. 1.

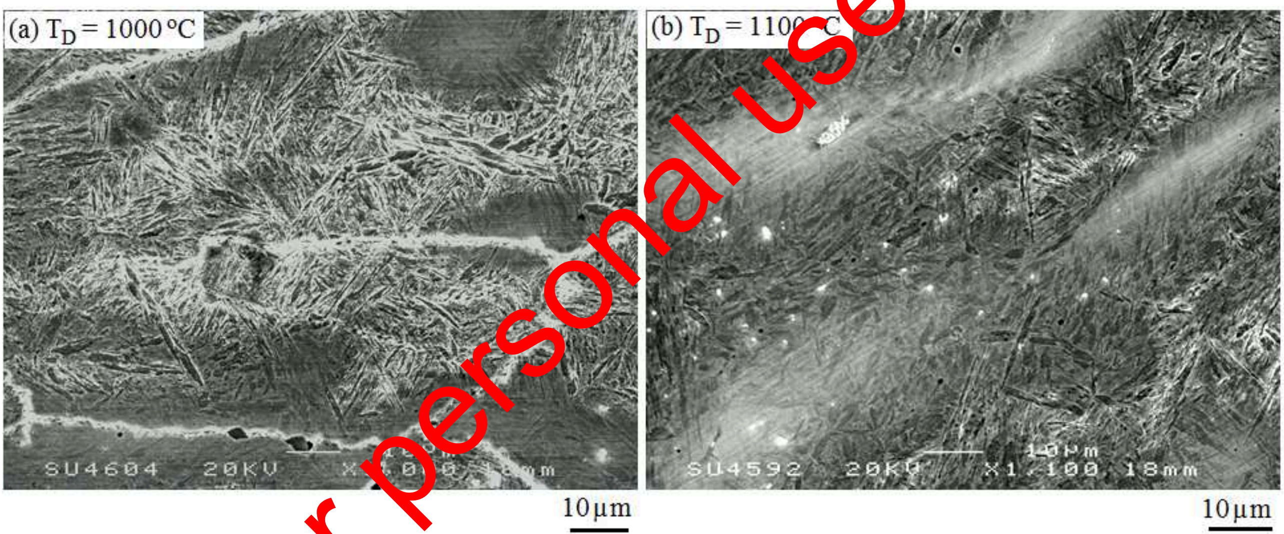

Fig.1 Secondary electron SEM images of teh H21 tool steel after hot deformation and water quenching (a) Deformation temperature (T_d) = 1000 °C, (b) T_d = 1100 °C [7]

The secondary electron SEM images show that the microstructures consisted of colonies of layers of thick lath martensite and undissolved carbides. The bright field of TEM images (Fig. 2) gave strong evidence for the presence of lath martensite and high dislocation density and in addition the formation of lower bainite. It has been reported that the microtwins was also observed in the lath martensite in the same condition treatment of the steel [7].

The tempering process in steels changes the martensite microstructures including carbide formation [8]. Investigation of the double tempered specimens with and without deformation using TEM revealed that carbide precipitation had occurred inside the lath. Fig. 3 (a) is bright field of TEM image showing the microstructure after austenising at 1250 °C without deformation and double temper at 650 °C.

It can be seen that the tempered lath martensite contained more than one crystallographic variant of cementite carbides and produced the formation of widmanstätten array carbides, which was occurred when carbon supersaturated martensite was tempered [7]. Hence, it can be noted that "without stress, each grain of austenite transforms into many different orientation and the carbides precipitated in several crystallographic variants in any given plate in lath martensite" [9]. Fig. 3 (b) shows the tempered lower bainite with single variant of cementite carbides in large number and forming tightly. Fe_3C carbides grew from the lath of tempered lower bainite and made an axis approximately 60° to the lath of tempered lower bainite. The precipitation of single variant carbide in lower bainite without deformation is known "to be affected by the self-stress of the bainite plate, which hinder multi variants of cementite carbides precipitation" [8-10]. The lower bainite plates prefer to contain only a single variant of cementite carbide compared with martensite that has been described by Stewart et.al [3, 9] who concluded that the chemical driving force for carbide precipitation in lower bainite is lower than for lath martensite due to the B_s (bainite start) temperature being higher than M_s (martensite start) temperature in the same steel. Moreover, chemical driving force tended to decrease further due to partitioning of carbon into austenite. Therefore, there is a decrease of driving force for carbide precipitation and only the carbide variant satisfying with the self-stress of the ferrite plate is precipitated [1].

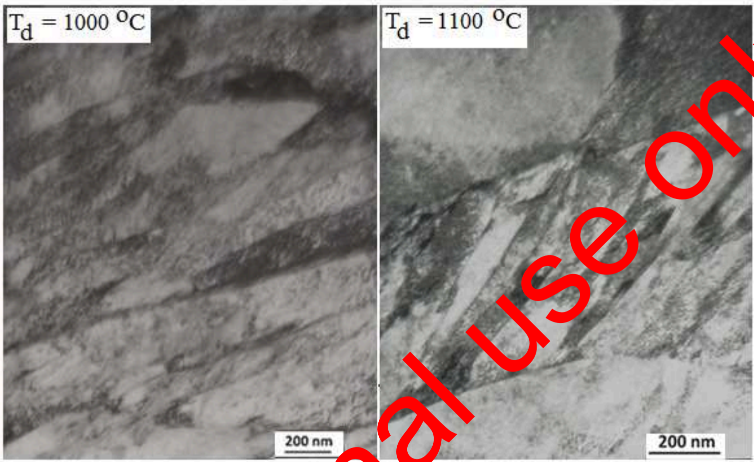

Fig. 2 Bright field TEM images of microstructures deformed at T_d = 1000 and T_d = 1100 °C and water quenched.

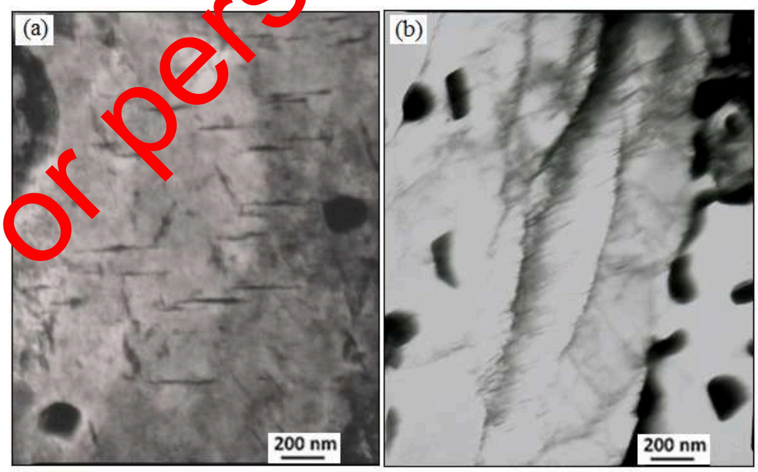

Fig. 3 Bright field TEM images after austenising at 1250 °C and double tempered at 650 °C (without deformation) showing (a) tempered lath martensite and (b) tempered lower bainite

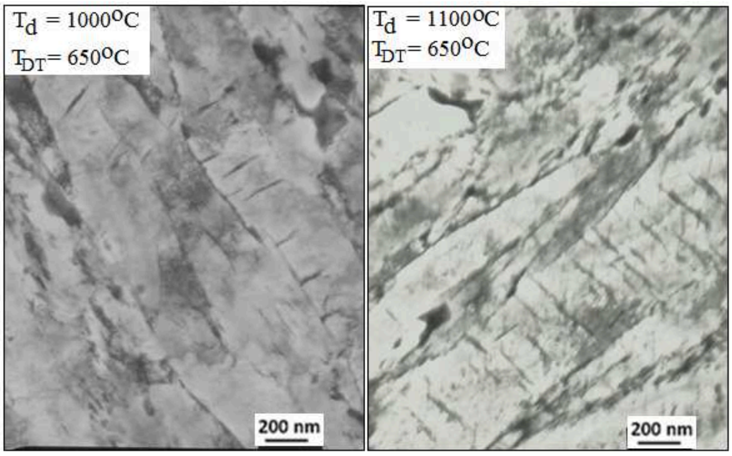

Fig. 4 Bright field TEM images with different deformation temperatures (T_d) and double tempered at 650 °C showing tempered lath martensite.

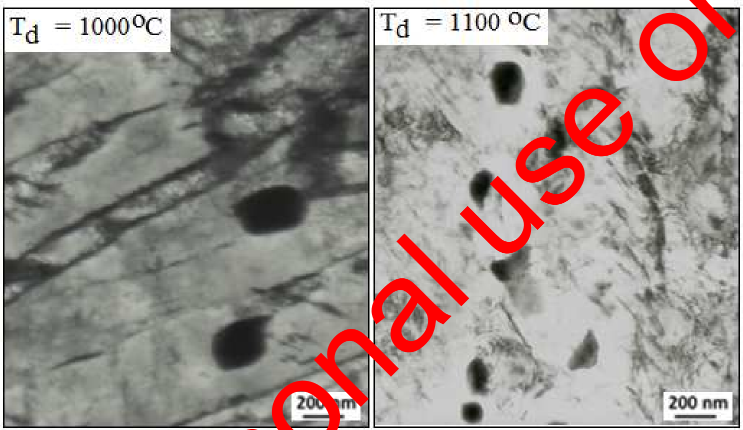

Fig. 5 Bright field TEM images with different deformation temperature (T_d) and double tempered at 650 °C showing tempered lower bainite

Bright field TEM images of the double tempered sample after experiencing hot deformation showed that the stress applied during hot axisymmetric had reduced the number of variants of cementite carbides in lath tempered martensite as can be seen in Fig. 4 and decreased the number of single variant cementite carbides formed in tempered lower bainite, as shown in Fig. 5 [7]. This is in good agreement with the displacive transformation mechanism and also consistent with previous work on different alloys [3, 10]. Olson et.al [11] explained that the cementite carbides grow in the form of thin plates by a displacive mechanism, in which the carbide lattice is produced by a deformation of the supersaturated ferrite lattice and the change in shape can be described as an invariant plane strain with a larger shear component. As a result, precipitation becomes sensitive to stress, which favours the formation of those variants complying with the stress. Other researchers [12, 13] also concluded that the stress produced a high degree of alignment of bainite platelets. There are a contribution to a mechanical driving force of mechanical interaction between the stress and the crystallographic variant change. When the stress is large enough, only a dominant crystallographic variant of carbide will precipitate [9, 14]. Bhadeshia [10] concluded that the response of bainite and martensite to stress is similar.

The cementite precipitation in martensitic and bainite at the deformation temperatures 1000 and 1100 °C did not differ significantly, as can be seen in Figs. 4 and 5. Although the effect of hot deformation increased the M_s and B_s temperatures, which gave contribution to the chemical driving force [15, 16], but it suggested that the cementite precipitation behaviour is strongly affected by large stress applied to the steel. The applied stress in both deformation temperatures is the same, as a consequence producing the same contribution to the mechanical driving force. Stewart et.al [5] in their research compared the effect of chemical and mechanical driving force to carbide precipitation behaviour and the result showed the applied stress had a great effect on carbide precipitation behaviour.

Conclusions

It has been shown that the high axisymmetric compression test carried out after austenising and before tempering, affected the cementite precipitation behaviour during tempering by decreasing the number of variants carbides in tempered martensite and decreasing the number of a single variant carbides in tempered lower bainite. This result is consistent with displacive transformation. In addition, there was no different on cementite precipitates variant at deformation temperatures 1000 and 1100 °C. It is considered that both hot deformation temperatures have the same contribution to the mechanical driving force in decreasing number of variant carbides in tempered martensite and decreasing number of single variant carbides occurred in tempered lower bainite condition.

Acknowledgement

One of the author (MN) is very grateful to the Directorate General of Higher Education, Indonesian Government and the Institut Teknologi Nasional, Bandung for their financial support.

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10.4028/www.scientific.net/AMR.1043

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10.4028/www.scientific.net/AMR.1043.154

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http://dx.doi.org/10.1007/BF02670444