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The Breakdown of Carbide Network in a H23 Tool Steel by Hot Axisymmetric Compression

Meilinda Nurbanasari[1,a], Panos Tsakiropoulos[2,b], and Eric J. Palmiere[3,c]

[1]Department of Mechanical Engineering, Institut Teknologi Nasional, Bandung, Indonesia

Jl. PHH. Mustapha 23, Bandung, 40124, West Java, Indonesia

[2,3]Department of Materials Science and Engineering, The University of Sheffield,

Mappin street, S1 3JD, Sheffield, United Kingdom

[a]meilinda@itenas.ac.id, [b]p.tskiropoulos@sheffield.ac.uk, [c]e.j.palmiere@sheffield.ac.uk

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Abstract. The effects of hot axisymmetric compression to break down the primary carbide network of the H23 tool steels were studied. This current study only focused on one strain rate of 0.01 s^{-1}. The samples were deformed at 3 different temperatures (1000, 1050 and 1100 °C) with solutioning temperatures 1100 and 1250 °C, respectively. Afterwards, the samples were cooled by water quenching. The techniques used in this current study for investigation were the optical and electron microscopes and Vickers hardness test. The results show that hot axisymmetric compression had broken down the primary carbide network in the direction perpendicular to the compression axis and the carbides became finer. Although the highest hardness (274 HV) was achieved after solutioning at 1250 °C, followed by deformation at 1000 °C, however the microstructure analysis indicated that the optimum hot axisymmetric compression condition was solutioning at 1250 °C and deformation at 1000 °C.

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Introduction

The H23 tool steel contains high alloying elements, namely W and C (each at around 12 wt%), which are carbide forming elements. The carbides give a very significant contribution to determine mechanical properties of tool steels. The formation of carbide network in tool steels during solidification leads to detrimental their mechanical properties. The thermo mechanical processing (TMP) of tool steels is of great interest from both fundamental and industrial viewpoints due to the formation of carbides' network in the ingot that remain throughout processing. The TMP refers to high temperature deformation at $T > 0.6\ T_m$ where T_m is the melting temperature in degrees Kelvin [1]. At temperatures above 0.6 T_m, plastic deformation is strongly affected by thermally activated processes, thus the flow stress and structure changes are mainly functions of material, temperature and strain rate. The increase in peak stress of tool steel is more sensitive to the presence of carbides than alloying elements in solution in the austenite matrix. The hard carbide precipitates cause increase in flow stress and Q_{def}. According to Milovic, Manojlovic et al [2] and Imbert, Ryan et al [3] the Q_{def} suddenly increases when $M_{23}C_6$ carbides precipitate around 1000 °C. Another study by Imbert and McQueen [4] showed that the Q_{def} of a M2 tool steel was 14 % higher than that of a A2 tool steel due to greater alloy carbide content. The peak stress of tool steels is in general greater than that of carbon and HSLA steels due to greater amounts of alloying elements [5]. In this study, the effects of high axisymmetric compression parameters, namely solutioning and deformation temperatures on the microstructure and hardness of the H23 tool steels were studied. Special attention was paid to establish the deformation conditions that lead to break down of the carbide network occurred during solidification.

Experimental Method

The investigated H23 tool steel was melted using vacuum induction furnace with air cooling. The chemical composition (% wt) of the ingot was 0.3 %C, 0.4 %Mn, 0.5 %Si, 12.3 %Cr, 0.4 %Ni, 12.3

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%W, 1.2%V, 0.01%P, 0.03 % S and Fe-balance. The samples for hot axisymmetric compression were machined with a diameter of 12 mm, a height of 15 mm, and the thermocouple holes, which has a diameter of 1.1 mm in the middle and a depth of 5 mm for monitoring the temperature during deformation. The hot compressions tests were performed on a SERVOTEST thermomechanical compression (TMC) machine. The samples were heated up to the solutioning temperature (T_S) with rate 15 $^oC/s$ and then held at that temperature for 10 minutes. Two solutioning temperatures was chosen, namely, 1100 ^oC and 1250 ^oC. Afterwards, the samples were cooled to the respective deformation temperature (T_D) at a rate 2 $^oC/s$ with a holding for 10 minutes. The samples were then deformed to a true equivalent strain of 0.5 at a constant true strain rate of 0.01 s^{-1} and continued by water quenching. Three deformation temperatures were selected, namely 1000, 1050 and 1100 ^oC with solutioning temperatures 1100 and 1250 ^oC, respectively. The validity of deformation test was decided based on aspect ratio, barrelling coefficient and height coefficient. The techniques used to study the microstructure were scanning electron microscopy (SEM) that was carried out on a JEOL 6400 (operated at 20 kV and equipped with EDS and INCA software for chemical analysis) and transmission electron microscopy (TEM), which was performed on a Philips 420 microscope operated at 120 kV. The etchant used for the H23 tool steel was Groesbeck's with etching time 5 – 10 seconds. The area of the sample for microstructure analysis and hardness test was taken from the center of perpendicular direction to the compression axis. Thin foil samples for TEM investigation were produced by twin-jet electro polishing. The hardness test was done with 10 kg load and 15 s dwell time using a CV Instrument Vickers Hardness tester.

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Results and Discussion

Microstructure analysis. All deformation tests were valid because the aspect ratio (D_R) was in the range 1 to 2, the barrelling coefficient (B) was not larger than 1.1 and the height coefficient (H) was below 0.04 [6]. Fig 1 shows the SEM images of the deformed H23 tool steel.

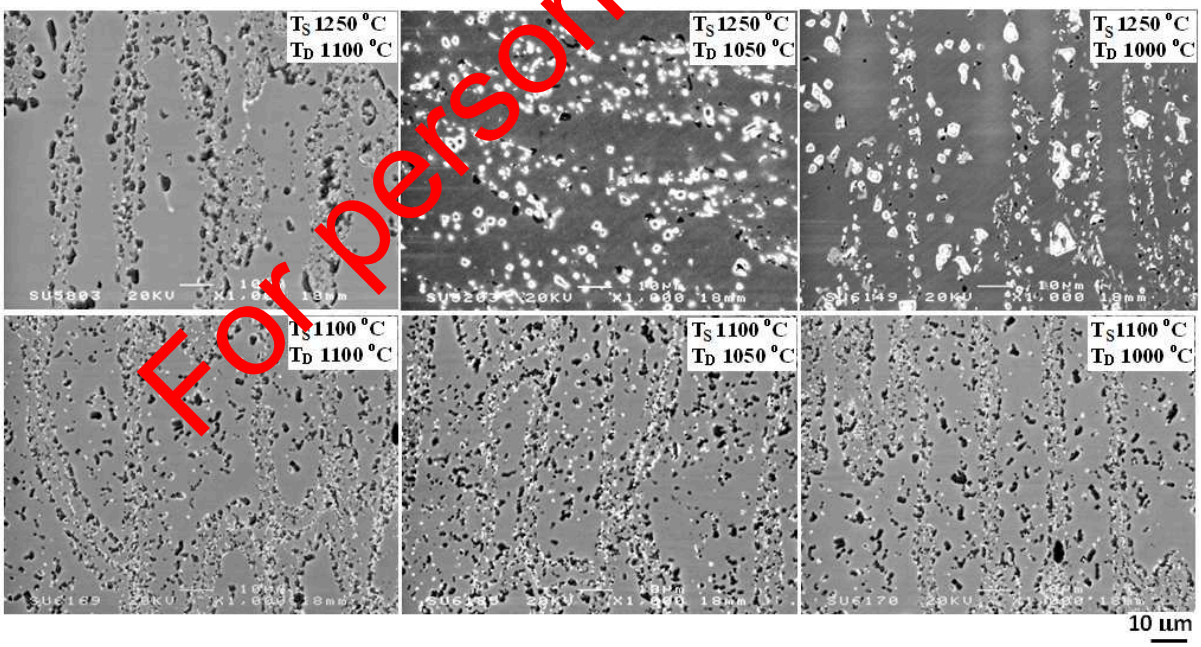

Fig. 1 SEM back scatter electron images of the H23 tool steel after hot axisymmetric compression and water quenching.

The structure of the deformed H23 tool steel consisted of ferrite and carbides (Fig.1). The martensite was absent due to the M_s temperature of the H23 tool steel being far below room temperature (- 46 ^oC) [7]. It can be seen form Fig. 1 that the consequence of hot deformation was banding of the primary carbide colonies. The banding of carbides consisted of disintegrated undissolved carbides formed by mechanical fragmentation during hot deformation, and these bands

were more pronounced at the lower solutioning temperature. Banding occurred primarily because of the segregation of solutes in the last regions of the liquid to solidify during the cooling of steel from the molten state. Hot deformation caused these regions to spread out as bands [8]. The former carbides' network was also observed at the lower solutioning temperature. Qualitative assessment of Fig. 1 also indicated that the higher deformation temperature, the lower volume fraction of carbides and as the deformation temperature increased the more carbides dissolved into the matrix [9]. At the lower solutioning and deformation temperatures, the carbides are more dispersed. The average fine carbides size in all deformed condition was less than 1 μm. Back scatter electron imaging in the SEM can be used to identify the types of carbide using the different contrast of carbides.

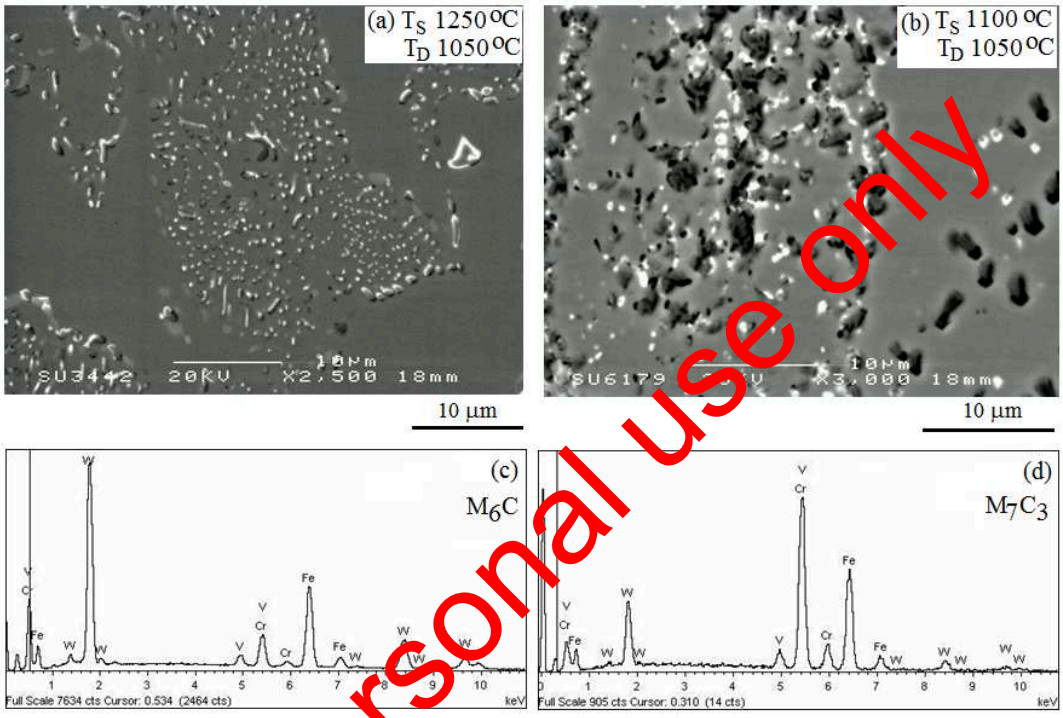

Fig. 2 SEM back scatter electron images and typical EDS spectra of carbides in the H23 tool steel after hot compression with different solutioning temperatures.

Figs. 2a and b show that there were two different contrasts of carbides, namely the white carbides that were M_6C carbides and the light grey carbides that were the M_7C_3 carbides. SEM-EDS analysis also supported the presence of M_6C carbide that has a spectrum with a high peak of W and a high peak of Fe (Fig. 2c) and the presence of M_7C_3 by a spectrum with Cr peak higher than Fe peak or vice versa (Fig. 2d) [10,11]. Qualitative assessment of the Figs 2a and b indicated that the total volume fraction of carbides was higher at the lower solutioning temperature. At the higher solutioning temperature (Fig. 2a), the M_6C carbides were finer and dominant and a smaller volume fraction of the M_7C_3 carbides was found in some areas. At the lower solutioning temperature (Fig. 2b), the volume fraction of the M_6C carbides was lower than the M_7C_3 carbides and the latter clearly were coarser and had coalesced with the M_6C carbides. It is well known that the stability of carbides depends on time, temperature and their chemical composition. Increasing the solutioning temperature caused the more carbides dissolved into the matrix [9] and as a result decreased the volume fraction of carbides. As the M_7C_3 carbides were rich in Cr and the M_6C carbides rich in W, and the diffusivity of Cr is higher than W, the M_7C_3 carbides grew and dissolved faster than the M_6C carbides. The M_7C_3 carbides were more stable at the solutioning temperature of 1100 °C compared with T_S = 1250 °C as they were coarser at the former temperature. With increasing the solutioning temperature, the M_7C_3 carbides lost their stability and dissolved into the matrix and as a result the M_6C carbides became the dominant ones (see also Fig. 1). TEM investigation was carried out on one deformation condition.

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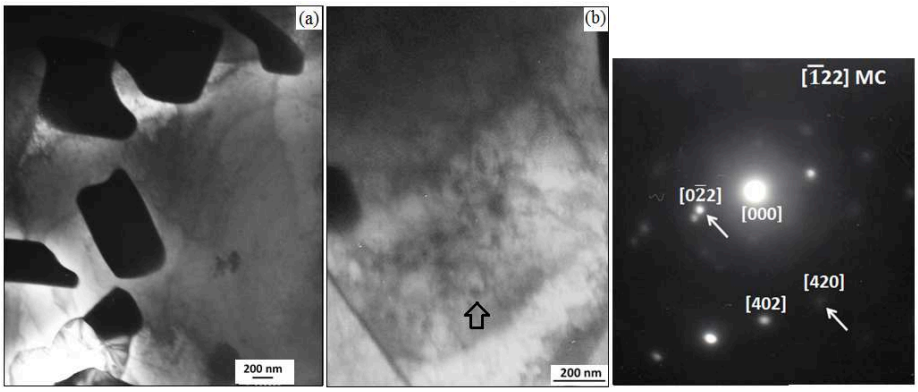

Fig. 3 Bright field TEM images of the H23 tool steel after solutioning at 1250 °C and deformation at 1000 °C showing (a) coarse M_6C carbides, and (b) the presence of dispersed fine MC carbides (indicated by arrow) and diffraction pattern of MC carbide.

Fig.3 shows bright field TEM images of the H23 tool steel after hot compression and water quenching. The grain structure (Fig. 3a) was not clear enough but elongated grains, which are typical of dynamic recovery, were seen and there was no indication that recrystallization occurred. Fig. 3b shows the presence of fine MC carbides and the diffraction pattern of a MC carbide. The morphology of MC carbides was in the range 20-50 nm.

The Effect of Hot Deformation on Hardness. The hardness of the tool steels was affected by solutioning and deformation temperatures and the results is shown in Table 2.

Table 2. The hardness value (HV) on deformed samples.

Ts (°C)	T_D = 1000	T_D = 1050	T_D = 1100
1250	274 ± 2	236 ± 2	220 ± 1
1100	264 ± 3	235 ± 1	210 ± 2

From Table 1, it can be seen that the higher solutioning temperature resulted to a higher hardness due to the more carbides being dissolved into the matrix [9]. The lower deformation temperature gave the higher the hardness value, which may be attributed to the higher volume fraction of dispersed M_6C carbides at the lower deformation temperature. However, the absence of martensite in the H23 tool steel was the main reason for the lower hardness values compared with the hardness of the as cast condition. Although the highest hardness (274 HV) was achieved after solutioning at 1250 °C and deformation at 1000 °C, however the solutioning temperature at 1250 °C and deformation at 1100 °C were the chosen parameter for the optimum hot deformation condition. This is because at the later parameter shows the carbides network had broken down and the carbides were finer than other deformation condition.

Conclusions

From the aforementioned results, the following concluding remarks can be made:

1 The hot axisymmetric compression had broken down the primary carbide network effectively in the center of perpendicular direction to the compression axis and as a consequence the carbides were finer

2 The solutioning temperature at 1250 °C and deformation temperature at 1100 °C were the optimum hot deformation condition for the best hotworkability of the H23 tool steel with the parameter used in this study.

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