



MC complex carbide in AISI M2 high-speed steel

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ABSTRACT

MC complex carbide was observed in spray formed AISI M2 high-speed steel. This carbide was extracted from samples after austenitizing and tempering. The carbide was characterized by X-ray diffraction, X-ray fluorescence and scanning electron microscopy. The extracted MC is a type of carbide not yet reported in the open literature. It is a face centered cubic carbide with lattice parameter $a=0.417028(4)$ nm, very close to the VC carbide but with a totally different chemical composition. The M represents the metallic elements (at.%): 36.70 V, 19.72 Cr, 2.67 Fe, 32.31 Mo and 8.60 W.

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1. Introduction

According to literature the AISI M2 steel is constituted by a ferritic or martensitic matrix, which are embedded the MC and M_6C carbides [1–4]. These carbides have a face centered cubic structure (fcc). The M_6C is a mixed iron, molybdenum and tungsten carbide; present yet vanadium in low concentration. The MC carbide is basically non-stoichiometric vanadium carbide with molybdenum and tungsten dissolved. The chromium, molybdenum and tungsten do not present the fcc structure at the room temperature. Hence, the solubility of these elements in the MC has been related to be depending of the stoichiometry, because the substitutional elements can stabilize others crystalline phases [19–22]. The microstructure of this high-speed steel is strongly influenced by the obtainment process [1,5]. Ideally, depending on the application, some best mechanical properties are expected when the microstructure showed a homogeny distribution of the carbides in the matrix, but the achievement of this microstructure is very difficult because the carbide formation occurs in several stages of the obtainment process. Table 1 shows an overview of the characteristic of the carbides MC and M_6C and the chemical composition is a mean value collected from literature [6–12].

The M_6C correspond at isomorphs complex carbide structure Fe_4Mo_2C or Fe_3W_3C , pertaining at the $Fd3-mS$ space group. Composts where M represents vanadium, chromium, molybdenum or tungsten do not have structure with this stoichiometry. The lattice parameter of the Fe_2Mo_4C is 1.1260 nm and Fe_3W_3C is 1.1087 nm. Hence, composition with intermediary stoichiometry showed variation in the lattice parameter [13].

The MC carbide corresponds to the VC structure pertaining at the $Fm3-m$ [7]. In the midst of the atoms considered, only the vanadium presents this structure in the ordinary conditions with a lattice parameter 0.4172 nm. The cell parameter of the MoC , in the high pressure, carbide not stable at room temperature and at atmospheric pressure, is 0.4273 nm. Häglund et al. [14] define monocarbide of the transition metals as a centered cubic structure of the metal atoms where the carbon is lodged in the octahedral interstitials; carry on the increase in the cell volume. The theoretical values calculated by Häglund for the fcc structure is: vanadium $a=0.379$ nm, chromium $a=0.360$ nm, iron $a=0.343$ nm, molybdenum $a=0.403$ nm and tungsten $a=0.406$ nm. Consequently, these carbides VC and MoC , will present an increase in the lattice parameter when compared to face centered cubic metals.

In this paper it is reported a carbide, with no related chemical composition, detected in the spray formed AISI M2 type high-speed steel after the heat treatment – austenitization and quenching.

2. Experimental

The alloy used in this study was an AISI M2 spray-formed high-speed steel [15]. The chemical composition measured by inert gas fusion, atomic absorption spectroscopy and titulometry was (mass%): 1.03 C, 3.29 Cr, 4.98 Mo, 6.19 W, 1.87 V, 0.22 Si, 0.18 Mn and 0.30 Ni

Table 1
Mean characteristics of the carbides in AISI M2 high-speed steel [6–12]

Carbide	Hardness (HV)	Crystalline structure	Chemical composition (% at.)				
			V	Cr	Fe	Mo	W
M_6C	1500	fcc	6	7	50	21	16
MC	2800–3000	fcc	72	6	4	10	8

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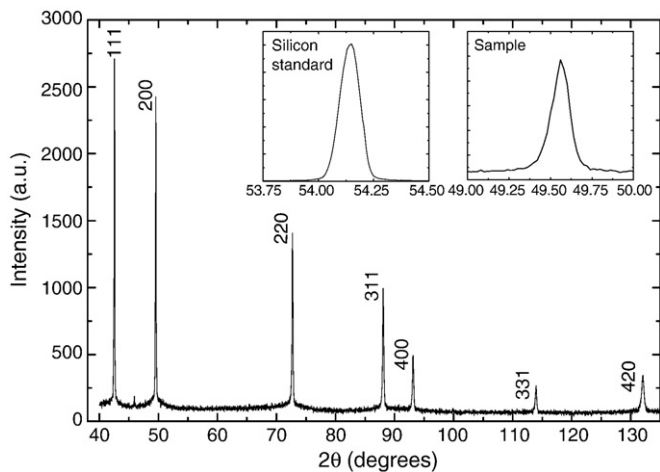


Fig. 1. X-ray powder diffraction profile of the extracted MC carbide.

($N \leq 0.04$). This material was soft annealed at 880 °C for 9 min and austenitized at 1210 °C for 3 min in a salt bath, then the material was cooled at 520 °C and it was triple tempered at 560 °C for 1 h.

The selective carbide extraction was used; firstly the M_6C and MC carbides were extracted by electrolytic dissolution of the matrix in a hydrochloric acid cell as proposed by Blickwede and Cohen [16]. The MC carbide was extracted by dissolving the M_6C carbide with a Berzelius solution [17] at room temperature for 3 h followed by vacuum filtration with a membrane of polytetrafluorethylene PTFE filter with mean porous size 0.22 μm . The chemical composition of this carbide was analyzed by X-ray fluorescence and the crystalline structure was identified by X-ray diffraction. X-ray diffraction was performed with a synchrotron light source, with energy of 7.1054 keV. The microstructure of the extracted carbides was analyzed using scanning electron microscopy (MEV) fitted with energy dispersion spectrometer – EDS.

3. Results and discussion

Fig. 1 shows the X-ray diffraction profile for the MC extracted and measured at room temperature. All peaks in the profile can be indexed with the NaCl-type structure, i.e., the fcc structure. The lattice parameter measured is $a = 0.417028(4)$ nm. The structure and the lattice parameter of the carbide extracted are very close to the MC-type described in the literature. In the insert detail of Fig. 1 is possible to observe that FWHM (full width at half maximum) of the sample is very narrow, near the FWHM of the silicon standard also showed in the insert; it is an indication that the peaks pertain to one crystalline phase.

The chemical composition of the MC extracted is showed in Table 2. In the literature, the MC carbide is reported to be carbide rich in vanadium but the results from Table 2 show that the substitution of the vanadium in this carbide by chromium and molybdenum atoms is high. This fact is corroborated by the SEM micrograph obtained with backscattered electrons, which show a homogeneous grey scale, see Fig. 2 (a). Furthermore, this residue has not showed magnetism, a circumstantial evidence of the steel matrix dissolution as non-magnetic particles were not picked up. Fig. 2(b) showed the M_6C and the MC rich in vanadium, which present a high contrast between them.

The microstructure showed in Fig. 3 is from a spray formed billet centre region, which comprises a ferritic matrix, a cell net of carbides rich in heavy atoms (Mo and W) and a disperse carbides formed by heavy and lighter atoms. The chemical analysis and carbides arrangement suggests that a mixture of the MC and M_6C carbides forms the net

Table 2

Chemical composition of metallic elements in the extracted MC carbide

	Chemical composition (at.%)				
	V	Cr	Fe	Mo	W
MC	36.7	19.7	2.7	32.3	8.6

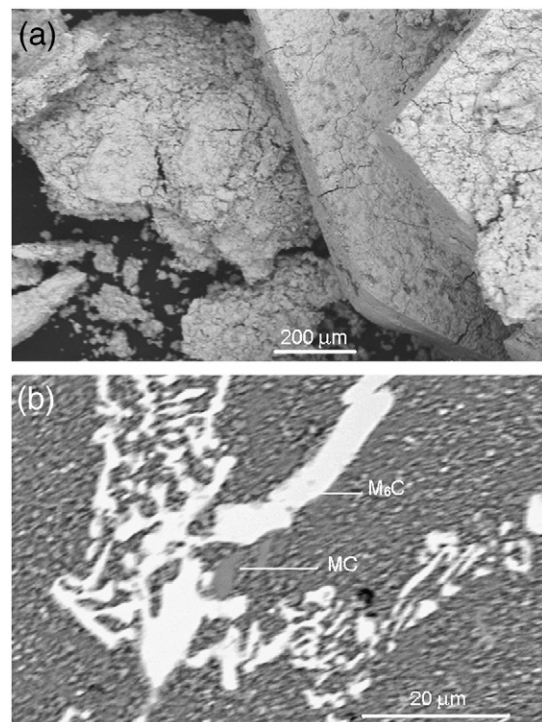


Fig. 2. Backscattered electrons SEM micrographs of (a) MC and M_6C carbides after electrolytic dissolution and (b) AISI M2 high-speed steel polished surface after chemical etch with Berzelius solution.

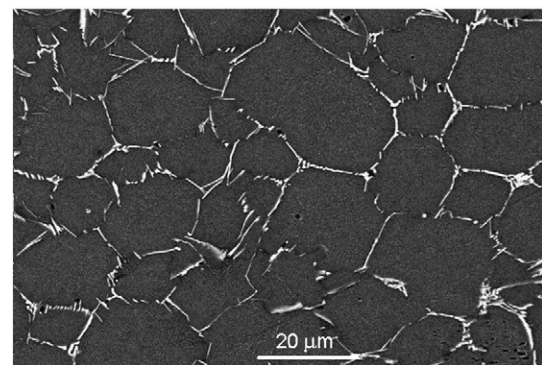


Fig. 3. Secondary electrons SEM micrograph of the spray formed AISI M2 high-speed steel, after soft annealing, showing the carbides cells and the intra-cell carbide precipitation.

of carbides. The EDS analysis of the particles in the cell showed that this carbide is predominately of the type M_6C . Besides, it was observed some carbide, type MC, rich in vanadium.

Mass percentage of the total carbides extracted was 20.61 wt.%, in this fraction the MC carbide is 58.20%; hence the fraction of the MC carbide in the alloy is 11.9%. This fraction is very large when compared to the published literature [12,16,18]. This fact can be partially explained by the substitution of the vanadium by chromium and molybdenum mainly, which are heavier than the vanadium. These results also indicate that the applied heat treatments induce the MC carbide formation at the expenses of the M_6C carbide. This fact may result in technological improvement once a higher MC carbide fraction may imply in better mechanical properties.

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