EFFECT OF RAPID COOLING FROM THE SEMISOLID OR LIQUID RANGE ON STRUCTURE AND PROPERTIES OF M2 TOOL STEEL

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Abstract
M2 tool steel was used as a feedstock material for casting from the the semisolid range between 1310-1350^{o}C corresponding to 25 - 50 % of the liquid phase. The chemical composition of the investigated steel is following: 0.85%C, 3.9 %Cr, 6.7 %W, 4.7 %Mo and 1.7 % V. A specially constructed machine allowed thixoforming in a protective argon atmosphere and semisolid forming at a high piston velocity powered by a high air pressure. After heating of the feedstock using induction heating by the stamping of semi-liquid sample to a graphite mould pre-heated by resistance heating. The material after thixoforming from 1315^{o}C shows a globular microstructure with a relatively small globule's size between 30-50 µm. The crystal structure of globules contained, austenite and martensite, while that of the eutectic, ferrite and W_2C, Fe_3C, Mo_2C, $M_{23}C_6$ and VC carbides as determined by X-ray studies and confirmed using electron diffraction studies. The alloying elements like Mo, W and V are concentrated in the eutectic, while Cr only in thixoformed samples segregates to the carbides and indeed $M_{23}C_6$ was identified. The hardness significantly increases up to 780 HV after thixo-forming due to formation of martensite. The other part was cast from the liquid phase at 1450^{o} C using melt spinning method allowing high cooling rate. The microstructure of melt spun ribbon shows a cellular microstructure of austenitic and martensitic structure without the eutectic. The WC and $M_{23}C_6$ carbides were located at the cell's boundariers. The microhardness near 1300 HV of the ribbon was much higher than that of semisolid formed samples

Keywords: melt spinning, semisolid processing, analytical electron microscopy, tool steel

1 Introduction

The application of Semi Solid Metal (SSM) processing for steels is still at the development stage due to a high melting temperatures and the narrow liquidus-solidus range for a low carbon steels, which are of interest for a common use. SSM processing has been investigated for several steels compositions, starting with experimentally easier high carbon, mostly X210CrW12 tool steels with a broad semisolid range [1-3], through intermediate like M2 steels [3,4,5], up to a low carbon containing steels [6,7]. In order to obtain an easy flow of the semi-solid slurry, a microstructure of the alloy prior to forming should consist preferably of solid solution metal spheroids in a liquid matrix [2-7]. Such a microstructure can be obtained when the steel is initially cold or hot deformed prior to heating to a semisolid range [1-7]. Another important technological factor is fast die filling to prevent solidification in the die gate area. A reported piston rate of 0.5-1 m/s [4-7] was therefore applied. There are limited data concerning the microstructure of thixoformed steels [2-7]. In the X210CrW12 steel it was reported [2] that after

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thixoforming the structure of such steel mostly consists of austenite. Microstructure studies of the M2 steel [3,4] were concentrated on the change of a shape of grains and carbides after thixo-processing and phase analysis suggests the presence of austenite in the investigated semisolid range. In the present study, fine grain M2 steel was used as a starting material for thixoforming. Detailed structure and microstructure studies were performed to characterize phase shape and structure changes after the SSM processing. The steel was also subjected to melt spinning process. Earlier studies of rapid solidification using laser melting [8,9] have shown cellular/dendritic microstructure [9] the microstructure was identified as bcc iron. This statement is rather not likely in view of works from semisolid casting [3,4] of M2 steel where austenitic/martensitic structure was identified. There are similar cell size reported in laser melted 2-5 μm. In other rapidly solidified steels containing similar carbon content [10,11] similar size of cells was observed in case of melt spinning method applied to FeCrMn steel with 0.3% C [10] or rapid cooling in copper mould [11] of FeCrMoV steel with higher carbon content. In the latter case the size of cells was much higher pproaching 50 μm, however the austenitic/martensitic microstructue within cells was also observed allowing to obtain a high mechanical properties. In the present paper a comparison of microstructure and hardness of thixoformed and melt spun M2 steel was performed in view of microstructure and hardness in relation to process temperaturea and the cooling rate.

2 Experimental procedure

The chemical composition of the M2 steel was: 0.85 %C, 3.9 %Cr, 6.7 %W, 4.7 %Mo and 1.7 % V. The spray formed steel samples in of diameter of 40 mm were placed in the graphite cylinder covered with BN layer to avoid carbon transfer at higher temperatures. A scheme of the chamber using a piston rate of 1200 mm/s is given in [4]. The feedstock was heated to temperature of 1310°C what corresponds to 30-35 % of the liquid phase. The die temperature was 550°C and its dimensions were 20x50x15 mm. Melt spinning was performed in helium atmosphere using Artvac melt spinner. The linear copper wheel rate was 25 m/s and the pressure of melt ejection at 1450°C was 2.5 bars. The BN crucible contained a hole in bottom of size 0.7 mm and the sample was heated using high frequency generator.

The structure of the melt spun and SSM processed samples was studied using a Technai G2 transmission electron microscope (TEM) equipped EDS detector, scanning electron microscope FEI, Leica optical microscope equipped with QUIN quantitative image analysis and X-ray diffractometer Philips PW1840 using mono-chromatic Cu-Kα radiation.

3 Results and discussion

Fig.1a shows optical micrographs taken from the sample used as an feedstock of the M2 tool steel prepared using powder metallurgy method, containing mainly ferrite and M_6C or MC carbides surrounding elongated grains, however a smaller ones can also be seen within grains. **Fig1b** shows an optical micrograph from the thixoformed sample. It shows globular microstructure consisting of austenitic and martensitic structure similarly as reported in [4,5] for thixocast M2 steel. It shows a typical globular microstructure surrounded by the eutectic observed also in thixocast steels [1-5]. As results from the X-ray diffraction taken from the thixocast steel presented in **Fig.2** the globules consists of austenite and ferrite (or martensite). The carbides surrounding globules were identified as M_6C, M_2C and MC. Transmission electron micrograph shown in **Fig.3** shows the area near the eutectic. One can see carbide particles of size of a few micrometres being components of the eutectic. The electron diffraction pattern allows to identify the carbides as Fe_3C of zone axis [1-11]. It was not identified using X-rays

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since its reflections coincide with other reflections and also electron diffraction is taken only of a small area which may not be representative for a whole sample. Next micrograph shows SEM micrograph from the melt spun ribbon from M2 steel taken using back scattered electron detector with contrast depending on the atomic number. One can see cells which are of columnar shape at the bottom of the ribbon and length of several μm and thickness of a few μm and in the upper part become of regular shape due to changing nucleation and growth conditions. The size of cells is of a few micrometres is similar like in laser melted M2 steel [8,9] or in melt spun ribbon of CrMn steel [10], in spite of columnar cells which length is od several micrometres.

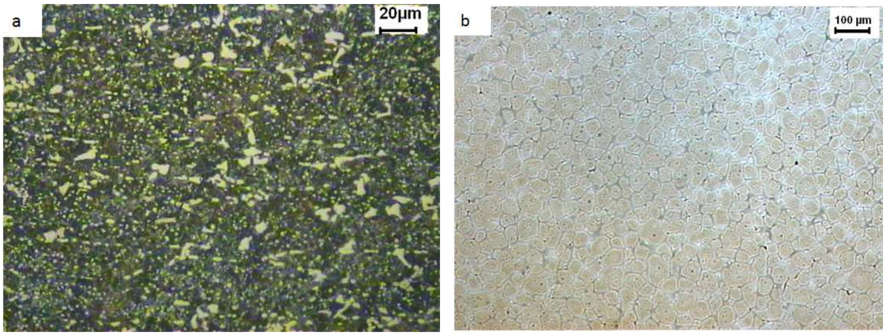

Fig. 1 Optical microstructure (a) of the M2 steel in the as delivered state and (b) after thixo-forming process

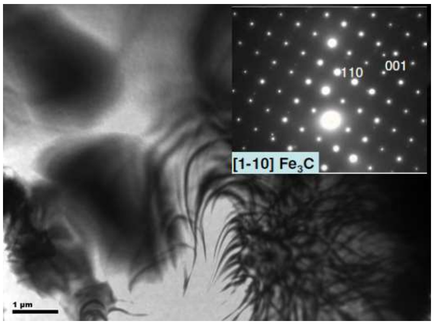

Fig. 2 X-ray diffraction taken from the thixoformed sample

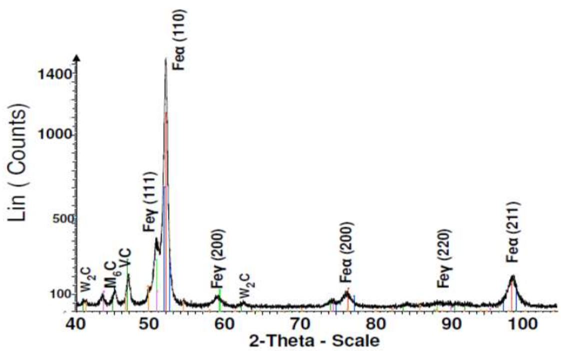

Fig. 3 TEM micrograph and the electron diffraction pattern from the visible area shown as an insert

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The central part of cell form iron solid solution with carbides surrounding them. The average microhardness of the ribbon measured on the transverse side, based on 10 measurements was 1270 HV, which is much higher than that of the thixoformed samples which was at the level of 760 HV. The carbides are visible in a bright contrast when using back scattered electrondetector due to a high tungsten and molybdenum content. X-ray diffraction data from the melt spun ribbon M2 steel are shown in **Fig.5**. One can see a significant difference when compared to the X-ray diffraction from thixocast sample. There is much higher content of austenite due to a higher cooling rate from the melt. It is also less carbides and only a low intensity peak from MC carbide was identified. This is due to the higher solubility of carbon in austenite.

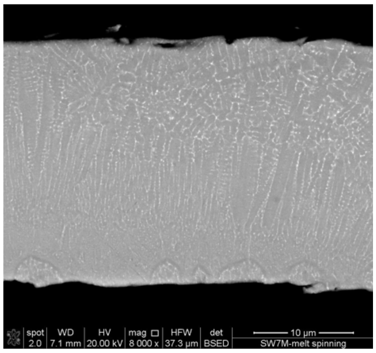

Fig. 4 SEM micrograph of the melt spun ribbon from the M2 steel

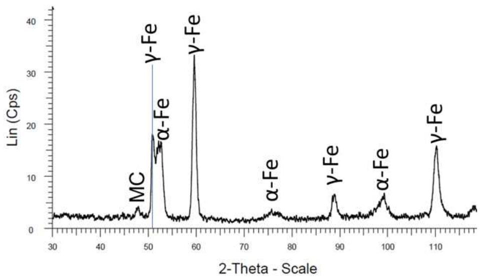

Fig. 5 X-ray diffraction taken from the ribbons after melt spinning

The cellular microctructure is better visible at higher magnification in the next micrograph taken using scanning transmission electron microscope (STEM) presented in **Fig.6**. The carbides surrounding cells are much better seen due to a bright contrast of carbides containing heavy elements as results from Energy Dispersive X-Ray spectra (EDS) from the area marked 1 representing carbides. The X-ray spectra presented in **Fig.7** show much higher content of W, Mo, Cr and V in carbides, however a small amount of alloying elements is present also in the iron solid solution. The transmission electron microstructure from the central part of the cell is presented in **Fig.8**. One can see there a high density of dislocations and several narrow needles within the microstructure indicating presence of martensite what was confirmed by X-ray diffraction and is in accord with earlier works on rapidly solidified M2 steel using laser melting [8,9] where presence of a large amount of martensite [8] or ferrite [9] was reported. Other micrographs allowed also to identify residual austenite within globular grains. The diffraction pattern from the area visible in Fig.8a presented in Fig.8b allows to identify martensite of zone axis [113] and M_6C carbide of zone axis [113]. A high density of dislocations observed also in

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CrMn steel melt spun ribbon [10] confirms presence of martensite. The high fraction of martensite accompanied by alloyed carbides are responsible for a high hardness of the sample.

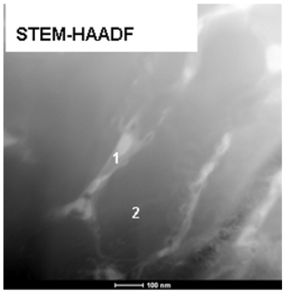

Fig. 6 STEM micrograph of the melt spun ribbon with marked points 1 and 2 where microanalysis was performed

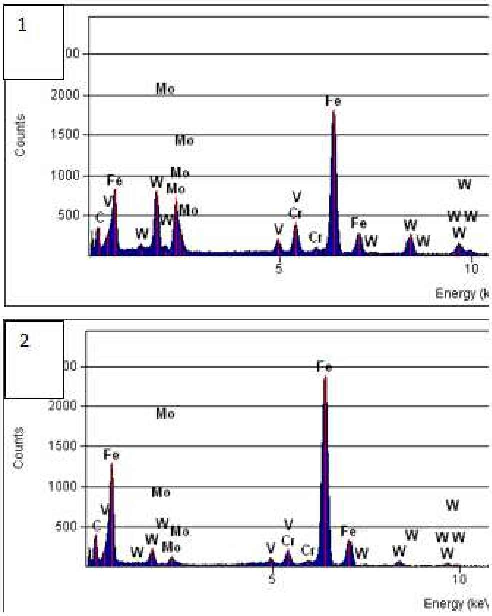

Fig. 7 EDS spectra taken in STEM mode from places marked 1 and 2 in Fig.6

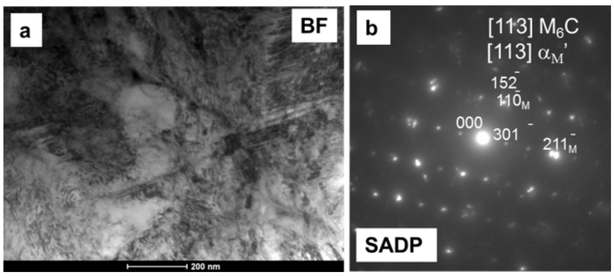

Fig. 8 a) TEM micrograph from the cell showing martensitic plate structure, b) Selected area diffraction pattern from the area visible in Fig.8a showing zone axis of martensite [113] and of M_6C carbide [113]

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4 Conclusions

1. Thixoforming process was applied to M2 tool steel using fine grain powder metallurgy prepared feedstock. After heating to a temperature corresponding to 30% of the melt a globular structure in thixoformed materials was obtained. The structure of thixoformed sample consists of martensite and residual austenite surrounded by the eutectic where carbides were identified as Fe_3C. The hardness of thixocast sample is comparable to a conventionally prepared steel.
2. Melt spun ribbon from M2 steel shows a typical cellular microstructure of the cell size of a few micrometres. Majority of cells contain martensite accompanied by a residual austenite. The cells are surrounded by carbides rich in Fe, Cr, W and Mo. Their structure was identified as M_6C, MC and Fe_3C. The microhardness of the melt spun ribbon was near 1270 HV far exceeding that of thixocast sample.

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