

Proceedings of the XXIII Conference on Applied Crystallography, Krynica Zdrój, Poland, September 20–24, 2015

# Microstructural Characteristic of Hypereutectoid Iron Alloys Melted in ArcMelter Furnace

Ł. FROCISZ<sup>a,\*</sup>, J. KRAWCZYK<sup>a</sup>, T. KOZIEŁ<sup>a</sup>, M. GOŁY<sup>a</sup>, T. TOKARSKI<sup>b</sup> AND K. WIECZERZAK<sup>a</sup>

<sup>a</sup>AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science,  
al. A. Mickiewicza 30, 30-059 Krakow, Poland

<sup>b</sup>AGH University of Science and Technology, Academic Centre for Materials and Nanotechnology,  
al. A. Mickiewicza 30, 30-059 Krakow, Poland

ArcMelter furnace is commonly used as a method for synthesis of amorphous and nanocrystalline materials. Due to easy and precise chemical composition control, also short time of whole process, this method was used to synthesis of new model hypereutectoid iron alloys. Material for the investigation was 90CrV6 steel. The chemical composition of this steel was modified to obtain the increase of carbides volume fraction with preserving the same chemical composition and mechanical properties of the matrix. The melt was conducted at sub atmospheric pressure of argon. The obtained materials were chemically analyzed by the use of optical emission spectrometer. The metallographic analysis was performed by the use of microscope. Phase composition in cast state was analyzed by X-ray diffraction. Chemical composition of the ingots differed from the previously established compositions in the range of 0.08 mass percentage. The high cooling rate resulted in dendritic character of the obtained microstructures. The microstructure of modified tool materials was plate martensite with large amount of retained austenite. The stress induced martensitic transformation in the crack area was observed. Retained austenite destabilization was initiated by the stress relaxation related with material cracking.

DOI: [10.12693/APhysPolA.130.939](https://doi.org/10.12693/APhysPolA.130.939)

PACS/topics: 61.05.F–, 64.70.kd

## 1. Introduction

Hypereutectoid steels are commonly used as the tool materials, the relatively high carbon content determines the high volume fraction of carbides in these materials. The majority of the carbides are alloyed secondary cementite. The changes in the chemical composition of hypereutectoid steels influence on the material properties and material microstructure. It has been shown that addition of manganese and vanadium has increased the temperature of cementite ( $M_3C$ ,  $M = Fe, Cr, Mn$ ) formation in this types of materials [1–3]. Also the silicon and carbon content increase have influenced to the spheroidization of cementite precipitations. Chromium and manganese addition influence on the slowing down of the cementite dissolution. The chromium and manganese additions have effectively retarding the coarsening of cementite particles. The cementite particle size after the austenitization has been reduced by the addition of alloying elements [4]. Also the properties of the matrix have influenced on the material properties in these types of materials. Especially the changes in the interlamellar spacing and prior austenite grain size have influenced on the material fracture toughness, hardness, yield strength, and wear rate [5–9].

The quantity of the parameters influencing on the hypereutectoid steels microstructure has produced the problem with the interpretation of microstructural con-

stituents influence on the material properties. This problems led the authors to produce new model alloys having precisely controlled carbon, manganese and chromium content, with the constant range of the rest alloying elements. It is creating the opportunity to precise identification of microstructural constituents influence on material properties, especially the influence of the carbides morphology.

## 2. Material for the investigation

Material for the investigation were three high carbon cast iron alloys. The material were prepared by the re-melting in the ArcMelter furnace the commercially used 90CrV6 steel, with the additions of carbon, ferro-chromium and ferro-manganese. The changes in the chemical composition of 90CrV6 iron alloy allow to prepare the model alloys for the investigation of control carbon increase influence on the morphology of carbides in high-carbon iron alloys. The additives of chromium and manganese allow to prevent the decrease of carbon concentration in material matrix caused by the increase of carbides precipitate volume fraction. Materials for the investigation were five times remelted in the arc furnace, rotated 180 degrees along the material axis before subsequent remelting. The process was performed by the under argon atmosphere (80 kPa), with the presence of titanium getter in the chamber. Materials were melted on the copper water-cooled mould. The metallographic investigations allowed to define the as-cast microstructural state of investigated materials. The chemical composition of the ingots were analysed on the cross-sections with

\*corresponding author; e-mail: [lfrocisz@agh.edu.pl](mailto:lfrocisz@agh.edu.pl)

optical emission spectrometer Foundry-Master (WAS). The material characteristic was performed by the use of light microscopy and X-ray diffraction. The source was the cobalt lamp with the  $\lambda_{Co} = 1.79 \text{ \AA}$ . The established chemical compositions of model alloys are presented in Table I.

TABLE I

Chemical composition of established model alloys [mass %].

Element	C	Mn	Cr	V	Fe
alloy 1	0.87	0.28	1.47	0.1	bal.
alloy 2	1.00	0.70	1.80	0.1	bal.
alloy 3	1.20	1.30	2.10	0.1	bal.

### 3. Results and discussion

The chemical composition of investigated materials are presented in Table II. Differences between the established and obtained chemical composition were observed. Decrease of manganese content in the alloy 1 was probably caused by the high vapor pressure of manganese and high reactivity of this element in the underpressure atmosphere used during the process. The gasses impurities from the input materials also could effect on the chemical composition changes during the melting. Also the decrease of manganese and chromium content was observed for the rest of investigated alloys. It was probably caused by the same reason as in alloy 1 and by the chemical segregation in the ingots, especially in the case of chromium.

TABLE II

Chemical composition of investigated alloys [mass %].

Sample	Fe	C	Si	Mn	S	P	Cr	Ni	V
alloy 1	Bal.	0.80	0.35	0.22	0.007	0.016	1.47	0.35	0.11
alloy 2	Bal.	0.99	0.35	0.70	0.003	0.021	1.72	0.30	0.09
alloy 3	Bal.	1.20	0.32	1.22	0.011	0.010	2.01	0.30	0.08

Metallographic investigations on the 2% nital etched cross-sections reveal three specific areas in investigated materials. The first area located on the top of the sample with the high porosity was observed, also probably chemical composition segregation on the material top was observed. Near the material axis the dendritic character of crystallization was observed. The dendrites have grown parallel and opposite to heat exchange direction. The high inhomogeneity of the microstructure observed in this region was probably correlated to the chemical composition segregations and cooling rate. On the material bottom the area of frozen crystals was observed. In this area the well visible grain boundaries was observed. It was related to the high cooling rate in this region (Fig. 1).

Observations with the greater magnification allow to observe the morphology of microstructure constituents in

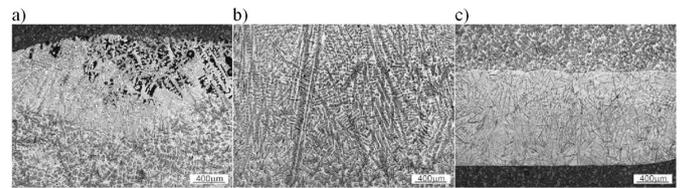


Fig. 1. The characterized microstructural zones in the investigated ingots on the basis of alloy 3: (a) top, (b) middle, (c) bottom of the sample.

each of the samples. The microstructure of each sample were supersaturated tetragonal iron solid solution (bct), called martensite, and residual after transformation, fcc iron solid solution called retained austenite. The supersaturation, and tetragonal change of the unit cell of bct phase unit cell was caused by the diffusionless transformation of high temperature fcc iron due to the high cooling rate during the casting process. The bct phase observed in the greater magnifications has aciform morphology. Interdendritic regions was characterized by the two different phases. First phase was also bct iron, but due to the chemical composition segregations, especially the chromium it was harder to etch. The second, brighter phase was the fcc iron. The carbon content increase has resulted in the changes of martensite morphology. Martensite plates weight has increased simultaneously with the carbon content. It was caused by the increase of the martensite unit cell tetragonality due to the increase of alloying elements content in this phase. Increase of the carbon content resulted in the increase of the retained austenite volume fraction. Higher volume fraction of the retained austenite content caused by the chromium and manganese content was caused by changes of the critical points positions on the Fe-Fe<sub>3</sub>C phase diagram, especially the eutectoid point, to the lower carbon content (Fig. 2a-c). Due to the high microstructural stresses, related with the martensite transformation in these material, the cracking in the area of the dendrite was observed (Fig. 2d). The stress relaxation during material cracking allow to form the martensite on the crack edges. Also the high structural stresses resulted in the microcracking in the area of martensite plates (Fig. 2a).

The X-ray diffraction analysis allows to observe two phases in the each alloys: the bct martensite —  $\alpha$  and fcc retained austenite —  $\gamma$ . The X-ray diffraction analysis allows to confirmed the increases of the retained austenite content with the increase of carbon content. The alloy 3 was characterized by the high intensity from the (200), (220) and (311) crystallographic planes for the alloy 3 was observed. High intensity of these crystallographic planes for this alloy was related with the high chemical composition segregation between the dendrite ( $\alpha$ -phase) and interdendritic regions ( $\gamma$ -phase) and high cooling rate during the process (Fig. 3). Investigation of martensite tetragonality allows to observe that tetragonality of martensite has increased simultaneously with

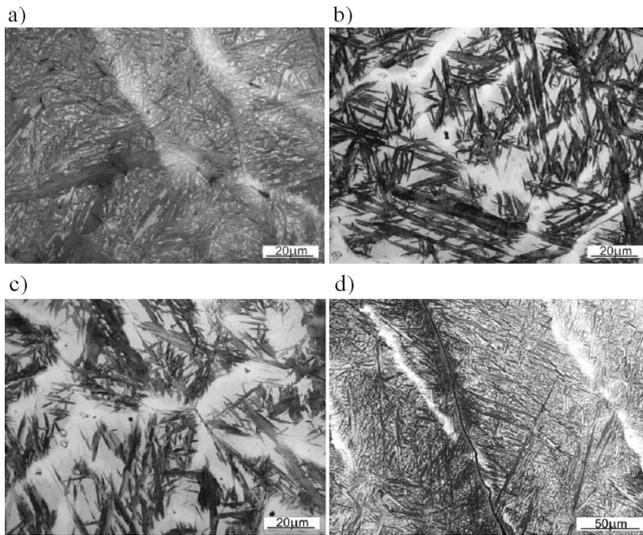


Fig. 2. The microstructure of investigated materials: (a) alloy 1, (b) alloy 2, (c) alloy 3, (d) the hardening cracking in the area of the dendrite.

the carbon content. Deformation of the unit cell in the  $\alpha$ -phase was caused by the high supersaturation by carbon and other alloying elements (Fig. 3b). There were no carbides precipitations in the alloys microstructure despite the high carbon content in these materials. The high cooling rate during the casting process does not allow to carbide formation during the crystallization of these alloys.

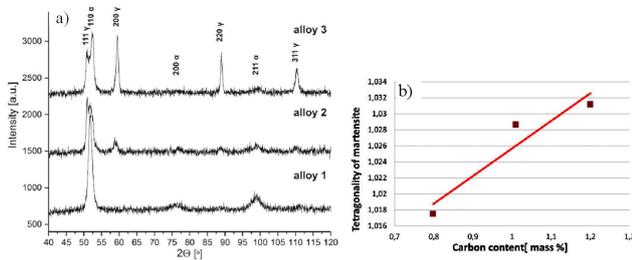


Fig. 3. The X-ray diffraction analysis results: (a) the X-ray diffractograms of the investigated alloys, (b) the tetragonality of martensite changes with the carbon content increase.

#### 4. Conclusions

The performed investigations allowed to form the following conclusions:

- The arc melting method allows to perform the cast iron alloys with the control of carbon content changes, this method allows to control the chemical composition of obtained materials with about 0.08% of accuracy.
- Microstructure of obtained ingots was characterized by the dendritic character of crystallization. The phase composition of these materials were supersaturated tetragonal  $\alpha$ -Fe solid solution in the dendrite regions and  $\gamma$ -Fe solid solution in the area of interdendritic regions.
- The increase of carbon content resulted in the increase of martensite plates weight, and volume fraction of retained austenite. The increase of alloying elements content (Mn and Cr) affects on increase of retained austenite volume fraction.
- High intensity of structural stresses related with the martensitic transformation in investigated alloys resulted in the present of material cracking. The stress relaxation during the cracking could cause the martensite formation on the cracks edges.

#### References

- [1] A.M. Elwazri, P. Wanjara, S. Yue, *ISIJ Int.* **46**, 1354 (2006).
- [2] K.H. Kim, J.S. Lee, D.L. Lee, *Met. Mater. Int.* **16**, 871 (2010).
- [3] J.Y. Chae, J.H. Jang, G. Zhang, K.H. Kim, J.S. Lee, H.K.D.H. Bhadeshia, D.W. Suh, *Scr. Mater.* **65**, 245 (2011).
- [4] S.D.W. Zhang Guo Hong, Chae Jae Yong, Kim Kwan Ho, *Mater. Charact.* **81**, 56 (2013).
- [5] E.M. Taleff, J.J. Lewandowski, B. Poursadian, *JOM* **54**, 25 (2002).
- [6] A.M. Elwazri, P. Wanjara, S. Yue, *Mater. Sci. Eng. A* **404**, 91 (2005).
- [7] Z. Guo, T. Furuhashi, T. Maki, *Scr. Mater.* **45**, 525 (2001).
- [8] M.-X. Zhang, P.M. Kelly, *Scr. Mater.* **37**, 2009 (1997).
- [9] O.P. Modi, D.P. Mondal, B.K. Prasad, M. Singh, H.K. Khaira, *Mater. Sci. Eng. A* **343**, 235 (2003).