Temperature and concentration dependences of viscosity of $Fe_{85-x}Cr_{15}C_x$ (x=10-17) melts

I V Sterkhova, L V Kamaeva, V I Lad`yanov and A Yu Korepanov

Physical-Technical Institute of Ural Branch of Russian Academy of Sciences, 132 Kirov Street, Izhevsk, Russia

E-mail: irina.sterkhova@mail.ru

Abstract. The investigations of temperature and concentration dependences of viscosity of $Fe_{85-x}Cr_{15}C_x$ (x=10-17) melts have been performed. It has been shown that the viscosity polytherms of the studied melts do not have any peculiarities in the entire studied temperature range and are well described by Arrhenius-type monotonic dependences. It has also been shown that there is no strong dependence between the viscosity of $Fe_{85-x}Cr_{15}C_x$ melts at x=10-17 at.%C and carbon concentration, and only close to eutectic concentration a sharp viscosity increase is observed.

1. Introduction

Among many physicochemical characteristics of metal melts viscosity is especially important, since being highly sensitive to the structural changes in a system. It attracts much attention as a basic technological parameter of a metallurgical process.

A Fe-C system is a basic system for the majority of steels and alloys that are widely applied as functional and structural materials. The addition of Cr into the system results in carbide phase formation, which increases strength and wear properties of these materials. Owing to these improved mechanical characteristics, including high resistance to various types of wear (abrasion, erosion, corrosion, etc.) the alloys Fe-Cr-C are widely used in modern industry as hardfacing materials [1, 2]. Depending on a practical purpose composition of these alloys can be considerably different. Of special importance in estimating abrasive wear at low stress is carbon content [1, 2]. In alloys with high content of carbon a carbide M_7C_3 is formed surrounded by softer austenitic matrix. This results in cracking at the interfaces and hinders the application of such materials without additional treatment. The optimum relationship of components in a ternary Cr-Fe-C system depends on the region of existence of $M_{23}C_6$ and eutectic [1, 2]. Apart from the choice of the chemical composition of an alloy its structure and properties depend on the liquid phase state prior to hardening as well as cooling conditions [3]. Direct structural research devoted to high-temperature melts is hindered by the complexity of experiment and data interpretation, and hence, is not practically performed. Abrupt changes of atomic short-range order in a melt with temperature or concentration change are manifested on temperature and concentration dependences of structural-sensitive properties of a liquid phase. Therefore, the basic information about structural changes in liquid alloys is derived from the data about temperature and concentration dependences of their structural-sensitive properties. In this connection in this paper the investigation of kinematic viscosity of $Fe_{85-x}Cr_{15}C_x$ (x=10-17 at.%) melts has been performed. The concentration area studied in the Fe-Cr-C system includes near-eutectic compositions with carbide phases $(Fe,Cr)_{23}C_6$ or $(Fe,Cr)_7C_3$.

2. Experimental procedure

The alloys were prepared by alloying the corresponding proportions of $Fe_{75}Cr_{15}C_{10}$ and $Fe_{68}Cr_{15}C_{17}$ ligatures in a furnace of the viscometer at 1680°C for 30 min. The synthesis of ligatures was carried out according to the traditional metallurgical technology by alloying carbonyl iron powder (Ultra High Purity 13-2), chromium and graphite (HP) powders in a vacuum furnace at 1700°C for 30 min.

Kinematic viscosity, (ν), was measured by the method of damping torsional vibrations of the crucible filled with the melt. The detailed measurement and calculation techniques are described in [4]. The experiments were carried out in a crucible made of Al_2O_3 in a purified helium atmosphere. To prevent the uncontrolled effect of the oxide film a Al_2O_3 cover was placed into a crucible on top of the sample as a second face surface [5]. The viscosity polytherms were obtained in heating conditions starting from the liquidus temperature to 1680°C with subsequent cooling. The temperature is changed gradually with the step equal to 10°C. The specimens were held under isothermal conditions for 20 min at every temperature before measurement. Then the samples were cooled up to room temperature. Replicates of the experiments on the viscosity measurements (during heating and cooling) were made using the method described above. Maximum error of the viscosity measurement does not exceed 4%.

According to the results of a previous investigation on the viscosity of carbon-containing systems including a certain fraction of a carbide phase [6], thermodynamic equilibrium of the system after melting took place for a long time. For this reason prior to viscosity measurements the ingots were remelted in vacuum at 1600°C for 30 min.

Differential thermal analysis (DTA) carried out in a high-temperature thermal analyzer [7] was used to plot the phase diagram of the Fe-Cr-C system in a concentration area of interest. DTA of alloys was performed under heating in the range from 300°C to 1680°C at a heating rate of 20°C/min. The measurements were performed in Al_2O_3 crucibles in helium atmosphere. The resultant thermograms were used to determine the temperatures of phase transitions in the alloys in the temperature range under study, and these temperatures were afterwards used to plot the phase diagram.

3. Results and discussion

Figure 1 shows equilibrium temperature dependences of viscosity obtained at heating and further cooling of $Fe_{85-x}Cr_{15}C_x$ melts, where x=10-17 at.%. It is seen that with allowance for the measurement error, the heating and cooling polytherms coincide. They do not have any peculiarities (Figure 1a) and are well described by the Arrhenius equation (Figure 1b):
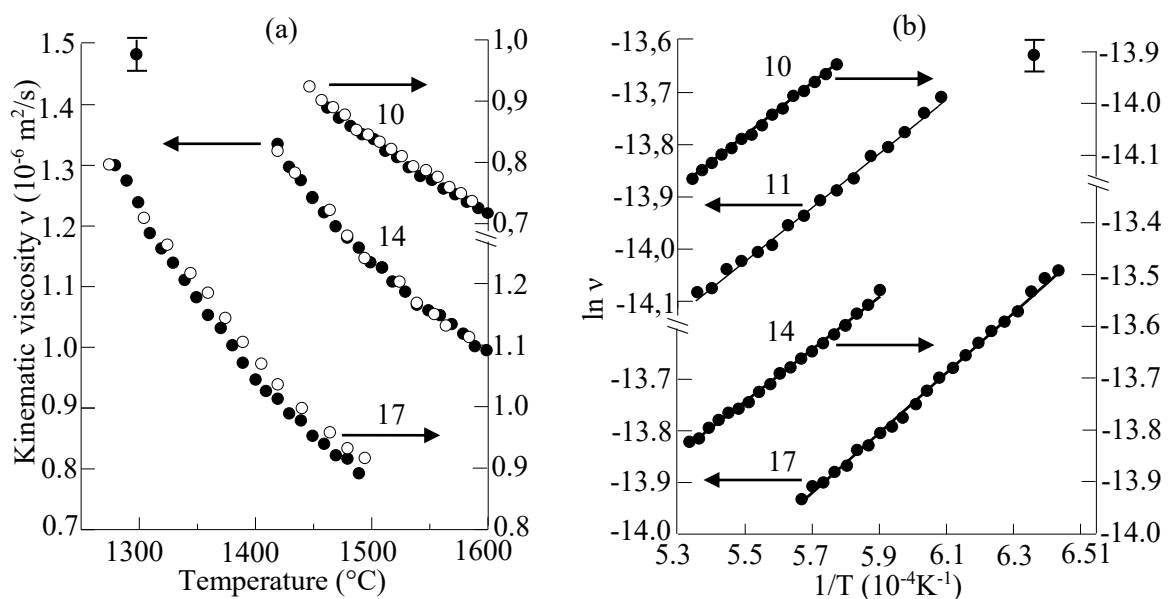

Figure 1. The temperature dependences of viscosity of $Fe_{85-x}Cr_{15}C_x$ melts (x=10-17 at.%C - the numeral near dependence), ● – in heating regime, ○ – in cooling regime.

$$\nu = A_\nu \exp\left\{\frac{E_\nu}{RT}\right\}, \tag{1}$$

where Aν - constant, Eν - activation energy of viscous flow, R – universal gas constant, T - absolute temperature. The repeated heating and cooling polytherms are highly reproducible, with allowance for an error.

The calculation of the concentration dependences of viscosity was based on two series of measurements of temperature dependences of ν (at the first heating – cooling regime and the repeated heating – cooling regime after the melt crystallization). The viscosity isotherms obtained are shown in Figure 2. Also, Figure 2 presents a pseudobinary section of the equilibrium phase diagram of the Fe-Cr-C system at 15 at.%Cr built using the DTA data. According to the results obtained, the viscosity values of the majority of the melts under study close to the melting point make up 9.5·10^{-7}m^2/s, which is in good agreement with the literature data. However, a sharp increase of ν values is observed close to 14 at.%C, which is appeared as the maximum on concentration dependences of viscosity in this concentration area. According to the phase diagram built, 14 at.%C corresponds to the eutectic point. A maximum on the viscosity isotherms close to eutectic is not typical of viscosity behavior for the systems metal – metalloid, where eutectic components in solid state are a metal-based solid solution and a chemical compound. The concentration dependence of viscosity in the eutectic area for such systems is usually characterized by a minimum [8, 9]. For better understanding of the concentration-related behavior of viscosity of Fe-Cr-C melts it is possible to use the analysis of the
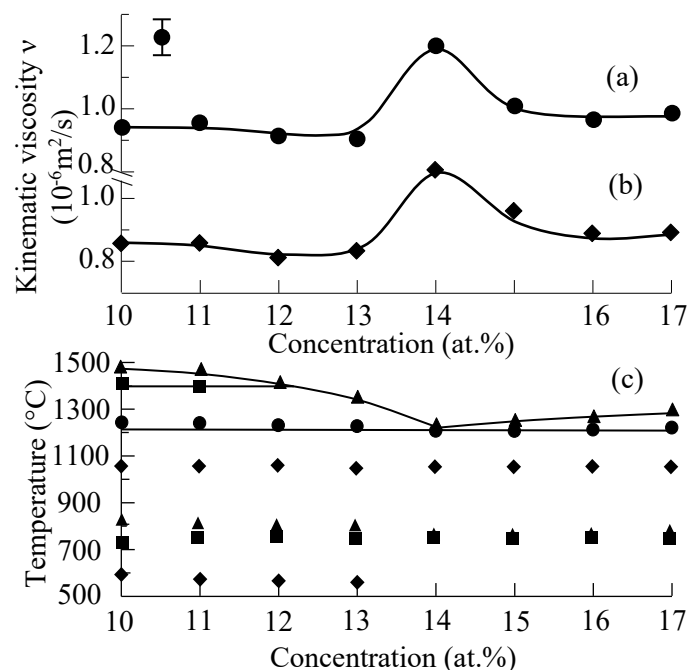

Figure 2. (a) and (b) The concentration dependences of viscosity of Fe$_{85-x}$Cr$_{15}$C$_x$ (x=10-17 at.%C) melts at different temperatures ((a) - at 1450°C, (b) - 1500°C). (c) The phase diagram of Fe-Cr-C system in investigated area.

concentration dependences of viscosity of binary Fe-Cr [10], Fe-C [11], and Cr-C [12] systems.

Although concentration dependences of viscosity of Fe-Cr melts are non-monotonic, the viscosity changes observed are far less than in systems Fe-C and Cr-C, and hence, can be neglected. Concentration dependences of viscosity of Fe-C melts at low content of C are also non-monotonic. However, at carbon content more than 10 at.% a sharp decrease of ν and no peculiarities in the

viscosity polytherms are observed. For Cr-C melts the increase of carbon content from 10 to 17 at.% results in a sharp increase of viscosity, with viscosity maximum at 14 at.%C (which corresponds to an eutectic point (L→Cr(C)+$Cr_{23}C_6$) for a binary system Cr-C) [12].

It thus follows that the observed concentration dependence of viscosity of ternary liquid Fe-Cr-C alloys is a result of the combined influence of the concentration-related behavior of viscosity of its binary subsystems Fe-C and Cr-C.

4. Conclusion

The investigations of temperature and concentration dependences of viscosity of $Fe_{85-x}Cr_{15}C_x$ (x=10-17) melts have been performed by the method of damping torsional vibrations. It has been shown that the viscosity polytherms of the studied melts do not have any peculiarities in the entire studied temperature range and are well described by Arrhenius-type monotonic dependences. It has also been shown that there is no strong dependence between the viscosity of $Fe_{85-x}Cr_{15}C_x$ melts at x=10-17 at. %C and carbon content, and only close to eutectic concentration a sharp viscosity increase is observed. The concentration dependences of viscosity obtained for the ternary Fe-Cr-C system in the concentration area studied have been stated to be the result of concentration-related changes of viscosity in the binary systems Fe-C and Cr-C.

5. References

[1]   Fan C, Chen M C and Wu W 2006 *Surface and Coating Technology* **201** 908
[2]   Lin C M, Chang C M, Chen J H, Hsieh C C and Wu W 2009 *Metall. Mater. Trans. A* **40** 1031
[3]   Lad`yanov V I, Sterkhova I V, Kamaeva L V, Chueva T R and Molokanov V V 2010 *J. Non-Cryst. Sol.* **356** 65
[4]   Bel`tyukov A L and Lad`yanov V I 2008 *Instrum. Exp. Tech.* **2** 304
[5]   Olyanina N V, Bel'tyukov A L and Lad'yanov V I 2015 *AIP Conference Proceedings* **1673** 020015
[6]   Sterkhova I V, Kamaeva L V and Lad`yanov V I 2013 *Rasplavy* **3** 3
[7]   Sterkhova I V and Kamaeva L V 2014 *J. Non-Cryst. Sol.* **401** 250
[8]   Lad'yanov V I, Volkov V A, Kamaeva L V and Bel'tyukov A L 2003 *Russ. Metall.* **6** 38
[9]   Lad'yanov V I, Kamaeva L V and Volkov V A 2006 *Russ. Metall.* **1** 8
[10]   Kamaeva L V, Sterkhova I V and Lad`yanov V I 2012 *Inorganic Materials* **48** 318
[11]   Elanskii G N and Kudrin V A 2015 *Bulletin of the South Ural State University. Serias Metallurgy* **15(3)** 11
[12]   Sterkhova I V and Kamaeva L V 2014 *J. Non-Cryst. Sol.* **401** 241