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WETTABILITY AND SOLUBILITY BEHAVIOR OF Fe–B–C BINDER ON (Cr–Ti–C)-REINFORCED COMPOSITES

O.V. Sukhova

Oles Honchar Dnipro National University, Dnipro, Ukraine
e-mail: sukhovayas@ukr.net

Iron-base matrix composites containing Cr-20Ti-10C reinforcement fabricated by infiltrating at 1200°C to 1280°C for 30 to 60 mins are investigated in this work. Peculiarities of the formation of the interfaces between Cr-20Ti-10C hard alloy and Fe-3.1B-0.1C liquid alloy (wt. pct) are determined. It includes the study of the solubility between the iron-base binder and the reinforcement combined with the investigation of the contact angles of the liquid phase formed at infiltration temperature by sessile drop method. X-ray analysis as well as optical and scanning electron microscopy is employed to investigate the binder/particulate interfaces. The interfacial zones produced as a result of contact interaction consist of $(Cr,Ti)_7C_3$ and $(Ti,Cr)_3C$ phases embedded in α-$Fe_3(C,B)$ eutectic alloyed with Cr and Ti. The origin of the formation of the interfaces is probably related to the partial dissolution of the low-melting-temperature particulate phase identified as $(Cr,Ti)_7C_3$ in the molten Fe–B–C binder. When raising the infiltrating temperature and prolonging the infiltrating period, wetting properties of Cr-20Ti-10C improve. This fact opens the possibility to replace copper-base alloys as binder by a cheaper and stronger iron-base alloy.

Key words: composites, reinforcement particulate, molten binder, interface, wettability, contact angle, solubility.

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1. Introduction

To fabricate metal-matrix composites, the Cr–Ti–C alloys are used as reinforcement particulate due to their excellent combination of physical properties such as high melting point, hardness, wear resistance, and good chemical and thermal stability [1]. The binder is usually composed of copper-base alloy. In an attempt to replace the copper-base matrix with cheaper alloys, while increasing the performance characteristics, iron-base binder emerges as a competitive alternative. To evaluate the feasibility of a metal as an alternative binder, it must be considered that these composites are processed through infiltration. So, the binder is molten during infiltration and the particulate should be slightly soluble in the binder liquid phase. At this point, the dissolutive character of the liquid binder influence on the reinforcing particles is also a determining factor in the infiltration [2].

The wettability depends on the new phases formed at the interface or the changes in the composition of the liquid and solid caused by the dissolution of the solid and further reprecipitation. Therefore, the present work details a study to obtain a better knowledge of the interface formation mechanism in (Cr–Ti–C)-reinforced composites with iron-base binder with the aim to design new binder composition.

2. Experimental procedure

The metal matrix composites were fabricated by infiltrating of Cr–20Ti–10C particulate by eutectic Fe–3.1B–0.1C binder at 1200°C to 1280°C for 30 to 60 mins. The used particulate had irregular shape and was about 0.5 to 2.0 mm in size. Upon solidification the composites contain 50 to 60 vol pct of Cr–20Ti–10C particles embedded in the iron-base matrix.

The processes occurring at the particulate/matrix interfaces of the composite materials were studied using sessile drop method [3]. The experimental investigations proceeded by measuring and calculating a so-called wetting contact angle. Here a "drop" of the metal binder being investigated was placed on the Cr–20Ti–10C substrate. Then they both were heated simultaneously in a vertical tube furnace with a tungsten heater that was placed in the vacuum chamber. The working pressure did not exceed 6.65 Pa. A relative temperature resolution was better than 1°C, the absolute accuracy was about ±3°C.

After melting metal and reaching certain temperature, the liquid drop was held on the substrate during preset period of time (a holding time, τ) and cooled at the rate not exceeding 4 to 6 K/min. The shape of the drop was studied and the contact angle (θ) was measured and calculated. The value of the contact angle gave an indication of the strength of the surface bonding between the liquid metal and the substrate. After the wetting experiments, cross sections of the metal/substrate interface were prepared and investigated by metallographic, X-ray, and electron probe microanalyses.

3. Results and discussion

Cr–20Ti–10C hard alloy exhibits two-phase structure consisting of dark-colored primary crystals of $(Ti_{0.5}Cr_{0.5})_3C$ and light-colored crystals of $(Cr_{0.95}Ti_{0.05})_7C_3$ (Fig. 1). The results of the determination of structural, physical, and mechanical characteristics of the alloy are shown in Table 1.

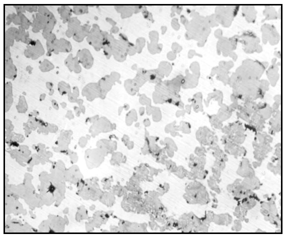


Fig. 1. Microstructure of Cr–20Ti–10C alloy, ×200

Table 1

The properties of Cr–20Ti–10C alloy

Characteristics	Phase		Cr–Ti–C
	$(Cr,Ti)_7C_3$	$(Ti,Cr)_3C$	
Microhardness, GPa	19.5±0.5	25.1±0.6	–
Microbrittleness, units	4.4±0.3	1.28±0.2	–
Brittle microstrength, GPa	1.95±0.3	5.94±0.1	–
Specific weight, g/cm^3	–	–	5.33±0.24
Apparent weight, g/cm^3	–	–	12.01±0.5

Fe–3.1B–0.1C liquid alloy composed of α-Fe dendrites and Fe–$Fe_2(B,C)$ eutectics [9] (Fig. 2) exhibits the wetting contact angles (θ) that decrease with increasing holding time (τ) and temperature (T). The results obtained are compiled in Fig. 3.

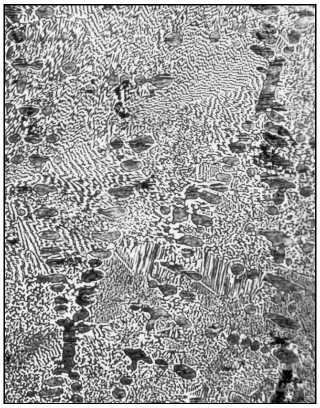


Fig. 2. Microstructure of wetting Fe–3.1B–0.1C alloy, ×400.

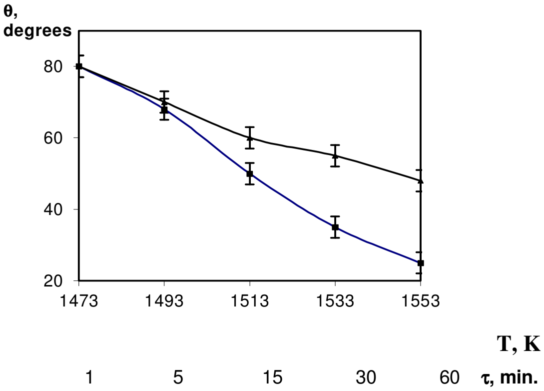
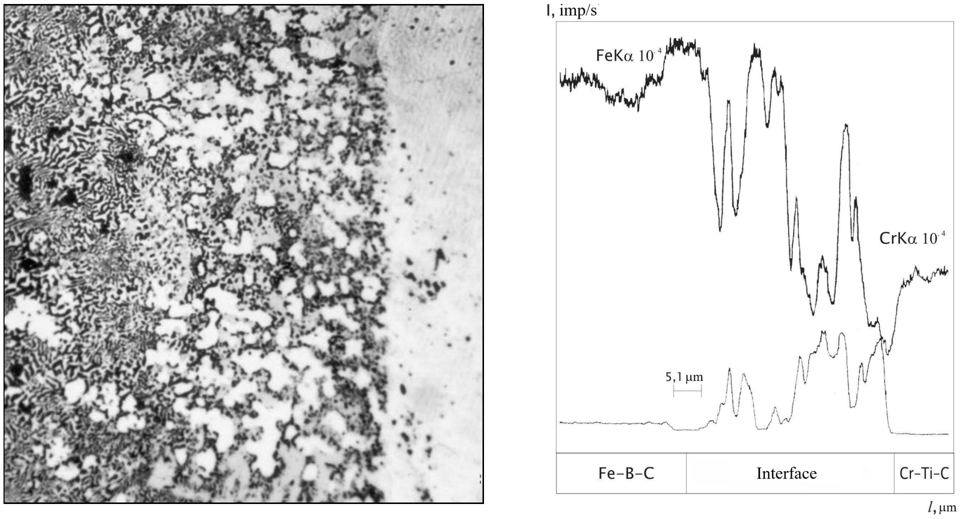


Fig. 3. Wetting angles of Cr–20Ti–10C alloy by Fe–3.1B–0.1C melt: 1 – as a function of temperature T; 2 – as a function of holding time τ.

The adhesion of iron-base alloy to the carbide substrate occurs upon metal melting, interfacial zones forming (Fig. 4). The origin of the formation of these interfaces is probably related to the partial dissolution of the low-melting-temperature phase identified as Cr_7C_3 alloyed with titanium from the particulate into molten Fe–B–C alloy. Due to a loss of carbon, Cr_7C_3 carbide decomposes to the lower $Cr_{23}C_6$ carbide, which contributes to the rapid dissolution of the phase. The high-melting-temperature ternary $(Ti,Cr)_3C$

phase retains unchanged during all the processes of contact interaction, and, therefore, it is present in the form of dark inclusions in the eutectic structure of Fe–B–C alloy. The dissolution of the ternary phase is hampered not only by relatively high melting temperature of the phase, but also by an increase in the melting temperature of the surrounding eutectic alloyed with diffusing titanium. The stability of the $(Ti,Cr)_3C$ phase during the contact interaction processes is confirmed by the results of determination of microhardness, microbrittleness, and brittle microstrength of the ternary phase present in the eutectic structure of interfacial zone and the ternary phase of the initial cast Cr–20Ti–10C alloy.



a b

Fig. 4. Microstructure, ×400 (a) and distribution of components at (Fe–3.1B–0.1C)/(Cr–20Ti–10C) interface (b).

The above observations are in good agreement with the results of the structure determination of iron-base matrix composites that displays the formation of interfacial zones which vary in thickness from 50 μm to 250 μm. The interfacial zones produced as a result of contact interaction consist of $(Cr,Ti)_7C_3$ and $(Ti,Cr)_3C$ phases embedded in α-$Fe_3(C,B)$ eutectic alloyed with Cr and Ti. The microhardness of the eutectics is 8.5 GPa. At higher infiltrating temperatures and longer holding times the formation of $(Cr,Ti)_7C_3$ can be accelerated.

The diffusion of carbon from the Cr–20Ti–10C particulate into the iron-base matrix gives rise to forming regions of the particulate depleted with carbon that are relatively remote from the interface. And, that is why, it leads to lowering the melting temperature of the Cr_7C_3 carbide alloyed with titanium and compound transforming to the lower $Cr_{23}C_6$ carbide, on the one hand, and to lowering the melting temperature of the Fe–B eutectic enriched in carbon, on the other hand. There is enough time for the heat needed to melt the Cr_7C_3 carbide alloyed with titanium to transfer deep into the particulate, which creates additional preconditions for developing contact interaction processes and widening interfacial zones. This assumption evidences that the said mechanism of contact interaction retains at the stage when the interaction proceeds through the liquid phase and there is a continuous contact of liquid (and solid) iron matrix with the particles [10-12].

4. Conclusions

In summary, it can be concluded that the wetting of the Cr–20Ti–10C alloy with iron-base melts is accompanied by the processes of chemical interaction over the whole range of investigated temperatures. The Cr–20Ti–10C alloy reacts with Fe–3.1B–0.1C molten alloy, forming mixtures of $(Cr,Ti)_7C_3$ and $(Ti,Cr)_3C$ phases embedded in α-$Fe_3(C,B)$ eutectic alloyed with Cr and Ti.

Eutectic Fe–3.1B–0.1C alloy can be successfully used as a metal matrix of the composite material reinforced with the Cr–20Ti–10C particulate. This material exhibits strong adhesion at the particulate/matrix interfaces. The iron-base matrix and the reinforcement are soluble at the infiltrating temperature but are reasonably nonreactive below the melting temperature of the matrix.

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