Anisotropic in Situ Metal Matrix Composite Reinforced with VC Carbide Fibres

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Abstract

A eutectic reaction is a basic liquid-solid transformation, which can be used in the fabrication of high-strength in situ composites.
In this study an attempt was made to ensure directional solidification of Fe-C-V alloy with hypereutectic microstructure. In this alloy, the crystallisation of regular fibrous eutectic and primary carbides with the shape of non-faceted dendrites takes place. According to the data given in technical literature, this type of eutectic is suitable for the fabrication of in-situ composites, owing to the fact that a flat solidification front is formed accompanied by the presence of two phases, where one of the phases can crystallise in the form of elongated fibres.
In the present study an attempt was also made to produce directionally solidifying vanadium eutectic using an apparatus with a very high temperature gradient amounting to 380 W/cm at a rate of 3 mm/h. Alloy microstructure was examined in both the initial state and after directional solidification. It was demonstrated that the resulting microstructure is of a non-homogeneous character, and the process of directional solidification leads to an oriented arrangement of both the eutectic fibres and primary carbides.

Keywords: Cast composites, Directional solidification, Vanadium eutectic, Vanadium carbides, Microstructure

1. Introduction

A eutectic reaction is a basic liquid-solid transformation, which can be used in the fabrication of high-strength in situ composites. In the case of directional monovariant eutectic solidification, a flat solidification front is formed and two phases emerge, where one of them can crystallise in the form of elongated fibres. Among various factors limiting the ability to produce in situ composites, the most important factor is the type of eutectic formed in a given system. In the case of irregular eutectic, it is usually impossible to produce strictly oriented eutectic fibres or plates. For this reason, for the in-situ composites, regular types of eutectic are selected [1,2]. The vanadium eutectic crystallising in Fe-C-V alloys is known to be in the group of regular fibrous eutectics [1-6] – the fact that enables its crystallisation in the form of an oriented structure. An attempt to produce oriented structure in the eutectic Fe-C-V alloys has been taken in [1,2]. A sample of the eutectic composition (12.9%V, 2.94%C) was subjected to directional solidification at a temperature gradient of 150 K/cm and the following solidification front movement rates: 75.6, 50.4, 37.8, 25.2, 12.6, 6.3 mm/h. The rate of 6.3 mm/h produced a flat, stable eutectic solidification front, resulting in a structure of the in-situ composite. The fibres of VC_{1-x} carbides were uniformly distributed in a soft matrix of the γ phase and directed perpendicular to the solidification front [1,2]. In this study, an attempt was made to produce an oriented vanadium eutectic using an apparatus characterised by a substantially higher gradient of 380 K/cm at a rate of 3 mm/h.

2. Experimental

The test material containing 1.92% C and 13.19% V was melted in a vacuum furnace in a protective atmosphere of argon. The charge was composed of Armco iron, spectrally pure graphite and technically pure vanadium (99.7%V). The use of technically pure components was dictated by the need to eliminate other elements which might affect the stability of the solidification front. Ingots for further preparation of samples subjected to the directional solidification process were poured in a cast steel mould (Fig.1)
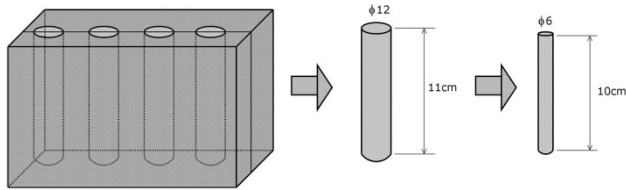

Fig. 1. Schematic diagram of the metal mould and the ingot from which a sample for the directional solidification was made by turning

From the cylindrical 12 mm diameter ingot cast in metal mould, a rod with a diameter of 6mm and a length of about 100mm was prepared by turning. Thus prepared sample was placed in an alundum crucible with an inner diameter of approximately 6mm and 120mm length. The crucible was connected with the sliding mechanism to make the sample move in the furnace ceramic reactor preheated to a temperature of 1550°C. The specimen was moving in a zone with the temperature gradient of 380 K/cm at a rate of 3 mm/h.

Because vanadium at high temperatures shows very strong chemical activity and readily combines with oxygen, the furnace reactor was filled with pure argon and constant flow of argon during the entire process of directional solidification was ensured.

Directional solidification was carried out in a specially designed apparatus shown in Figure 2. The apparatus comprises: 1 - top cover, 2 - bottom cover, 3 - ceramic shell, 4 - heater housing, 5 - heating element 6 – high-temperature fibrous insulation, 7 - control thermocouple, 8 - measuring thermocouple, 9 - cooler, 10 – base, 11 - pull rod, 12 - power supply-control cabinet, 13 - main circuit breaker, 14 - temperature control unit, 15 – heater switch on, 16 - switch over for the charge loading direction, 17 - ingot transfer unit.

To increase the rate of heat removal from the sample, or to increase temperature gradient, the clearance between the inner copper pipe and the steel rod was filled with low-melting gallium-indium - tin alloy (68.5% Ga, 21.5% In, 10.0% Sn), characterised by a very low melting point (about 19°C) and high boiling point (above 1300°C). By immersing the sample directly in the Ga - In - Sn alloy, a high temperature gradient was obtained.

Microscopic examinations were performed with a LEICA MEF4M optical microscope at a magnification of 35x, 100x and 250x. The average diameter of the eutectic carbide fibres in alloy after the directional solidification and the average spacing between them were determined with a LEICA QWin automatic image analyser.

a)
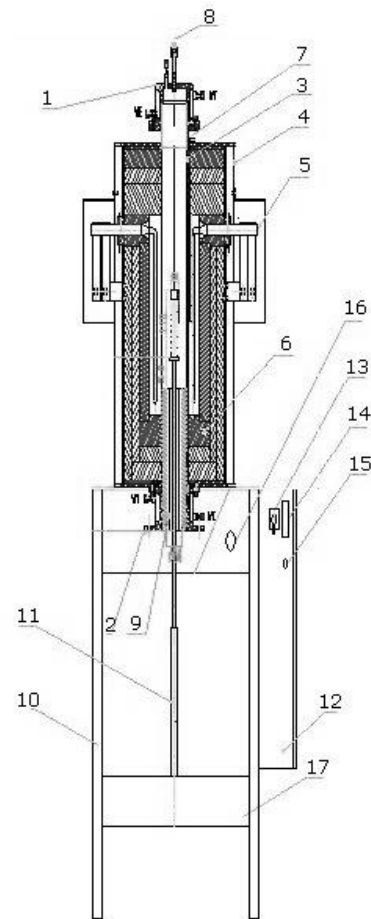
b)

Fig. 2. Schematic representation and true appearance of the furnace for directional solidification

3. Experimental Results and Analysis

Figure 3 shows microstructure of the examined alloy before the directional solidification process. The degree of eutectic saturation of the alloy is 1.24, which indicates that it is a hypereutectic alloy. This is also confirmed by the analysis of microstructure. The eutectic crystallising in this alloy is a regular fibrous eutectic, while primary carbides take the shape of non-faceted dendrites.
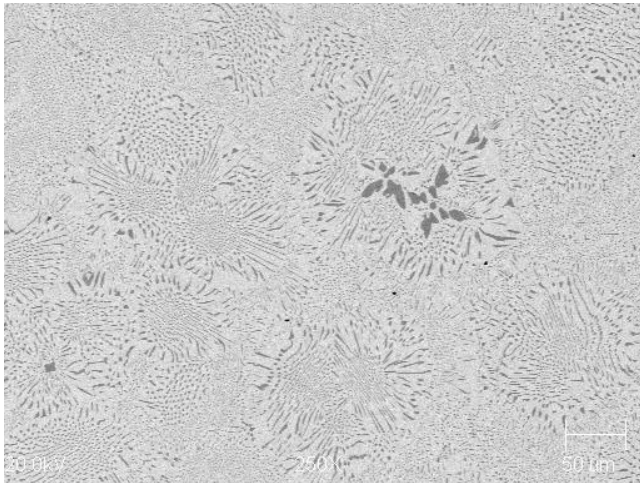

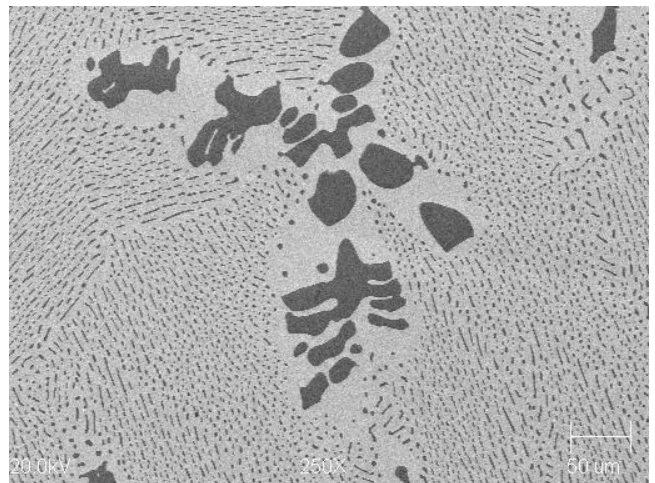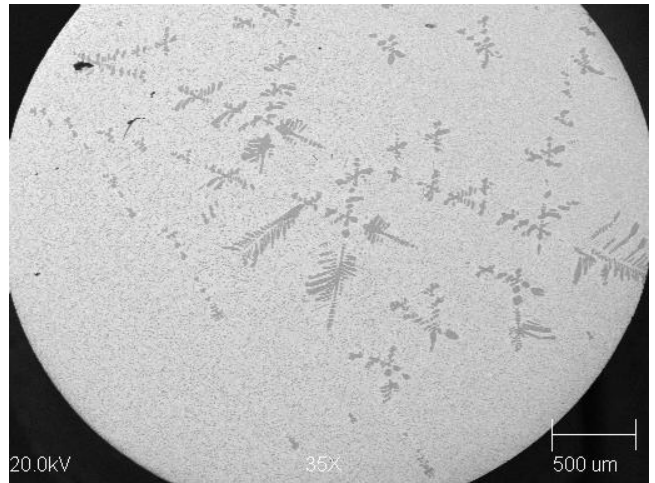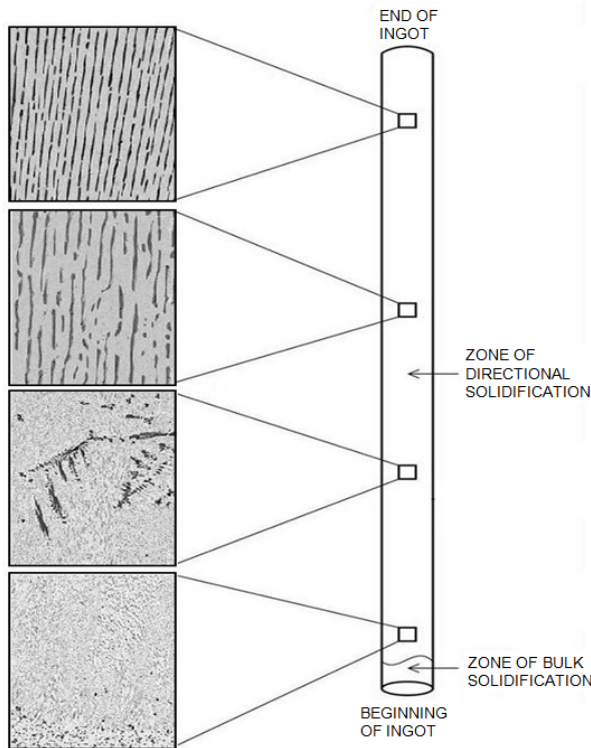Fig. 3. Microstructure of alloy before directional solidification

Fig. 4. Diagram of changes in microstructure on the longitudinal section of sample subjected to directional solidification

Fig. 5. Microstructure on the cross-section of sample after directional solidification

Figure 4 shows changes in microstructure on the longitudinal section of the examined sample after directional solidification.

It is clear that the microstructure is very heterogeneous, and the process of directional solidification leads to an orientation of both eutectic fibres and primary carbides.

The heterogeneity of the resulting microstructure is confirmed by further examinations carried out on the cross-section of an oriented sample. An example of the observed microstructure is shown in Figure 5.

The average diameter of the fibres of eutectic carbides in the examined alloy after directional solidification is 1.94 μm, and the average spacing between them is 6.76 μm.

4. Conclusions

The conducted studies allow drawing the following conclusions:
- the applied method of directional solidification produces an oriented fibrous structure in the examined alloy,

- after directional solidification, the alloy with hypereutectic composition acquires microstructure composed of the oriented fibres and primary carbides in a dendritic form,
- the average diameter of the fibres of eutectic carbides in the examined alloy after directional solidification is 1.94 μm, and the average spacing between them is 6.76 μm.

Acknowledgments

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