Contribution to the study of the Fe-Nb-C ternary system

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Abstract: In the present paper, solidification sequences are proposed in relation to the observed microstructures for Fe-Nb-C iron based ternary alloys. These alloys are arc melted and characterised by means of differential thermal analysis, scanning electronic microscopy and by quantitative electron probe microanalysis. Thus, an invariant eutectic ternary reaction $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$ is proposed at 1140°C.

Résumé : Dans cet article, les séquences de solidification sont proposées en relation avec les microstructures observées pour une famille d'alliages ternaires base fer Fe-Nb-C. Ces alliages ont été élaborés dans un four à arc et caractérisés par Analyse Thermique Différentielle, Microscopie Electronique à Balayage et Microsonde Electronique. Ainsi, une réaction invariante ternaire $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$ est proposée à 1140 °C.

1 INTRODUCTION

The most important application for niobium is as an alloying element to strengthen high-strength-low-alloy steels used to build automobiles and high-pressure gas transmission pipelines. An important secondary role for niobium is to provide creep strength in superalloys operating in the hot section of aircraft gas turbine engines. Niobium is also used in stainless steel automobile exhaust systems and in the production of superconducting niobium-titanium alloys. Minor applications include electronic ceramics and camera lenses [1, 2].

The examination of the literature reveals that the Fe-Nb-C ternary phase diagram has rarely been experimentally investigated. However, this system was assessed on the basis of thermodynamic calculations [3, 4]. Isothermal sections have been presented by R.C. Das et al. [5] and by H. Ohtani et al. [3], for the Fe-Nb-C ternary system.

This work constitutes a part of a study that we carry out concerning the plot of the liquidus projection of the Fe-Nb-C system in the iron rich corner.

The major difficulty in this work is to explain the microstructures observed considering the recorded thermograms.

In the present paper, we give an example of solidification sequences in relation to the observed microstructures for Fe-Nb-C ternary alloys with a carbon content between 15 and 16.07 at.% and a niobium content between 1 and 2 at.%.

2 EXPERIMENTAL PROCEDURE

The studied alloys were arc melted in an argon gas atmosphere from pure metals and graphite. Their compositions are listed in table 1. The solid-liquid and the solid-solid transformation temperatures were followed by Netzsch 404S differential thermal analysis (cooling rate 10 K/min under argon atmosphere). Quantitative electron probe microanalysis (CAMECA SX50) was used to determine accurately the composition of the phases and particularly the carbon level in carbides. Atomic number, absorption and fluorescence effects were corrected with a computer program according to the PAP model [6]. Despite the weak signal of carbon, the total error on weight concentration was below 2 % [7].

3 RESULTS AND DISCUSSION

Table 1 shows the alloy compositions, the transformation temperatures and the solidification sequences in relation to the observed microstructures.

Table 1. Compositions, transformation temperatures and solidification sequences of the studied alloys (*: temperature not detected by our differential thermal analysis apparatus).

Alloys	Compositions (at.%)			Transformation Temperatures (°C)	Solidification sequences
	Nb	C	Fe		
NbI	1.78	16.07	82.15	*	$L \leftrightarrow NbC_{1-x}$
				1234	$L \leftrightarrow \gamma + NbC_{1-x}$
				1135	$L \leftrightarrow \gamma + NbC_{1-x} + Fe_3C$
				705	perlite
Nb5	1.78	15	83.22	1282	$L \leftrightarrow \gamma$
				1243	$L \leftrightarrow \gamma + NbC_{1-x}$
				1138	$L \leftrightarrow \gamma + NbC_{1-x} + Fe_3C$
				722	perlite
Nb7	2	16.07	81.93	1271	$L \leftrightarrow \gamma$
				1241	$L \leftrightarrow \gamma + NbC_{1-x}$
				1140	$L \leftrightarrow \gamma + NbC_{1-x} + Fe_3C$
				727	perlite
Nb8	1	16.07	82.93	1238	$L \leftrightarrow \gamma$
				1214	$L \leftrightarrow \gamma + NbC_{1-x}$
				1140	$L \leftrightarrow \gamma + NbC_{1-x} + Fe_3C$
				727	perlite

Table 2 summarises the quantitative electron probe microanalysis of the phases formed during solidification for NbI alloy.

Table 2. Quantitative electron probe microanalysis of the formed phases.

Alloys	Compositions (at.%)			Identified phases	Phase's compositions (at.%)		
	Nb	C	Fe		Fe	Nb	C
NbI	1.78	16.07	82.15	Matrix	93.1	0.0	6.9
				Primary NbC_{1-x}	1.4	55.5	43.1
				Eutectic NbC_{1-x}	3.6	52.3	44.1

The NbI alloy thermogram, given in figure 1a, shows three peaks at 1234, 1135 and at 705 °C. These temperatures are attributed respectively to the formation of the γ -NbC_{1-x} binary eutectic, γ -NbC_{1-x}-Fe₃C ternary eutectic and the perlite. The NbI microstructures are presented in figures 1b and 1c. These microstructures show the NbC_{1-x} primary carbides (figure 1b) and the Chinese script γ -NbC_{1-x} binary eutectic (figure 1c).

The four peaks at 1282, 1243, 1138 and at 722 °C appearing on the Nb5 alloy thermogram of figure 2a are attributed respectively to the formation of the γ dendrites, the γ -NbC_{1-x} binary eutectic, the γ -NbC_{1-x}-Fe₃C ternary eutectic and the perlite. The γ dendrites, γ -NbC_{1-x} binary eutectic (Chinese script) and can be observed in the figures 2b.

Figure 3 presents the micrograph of the Nb8 alloy showing the γ -NbC-Fe₃C ternary eutectic structure. The thermograms interpretation in relation to the observed microstructures allows the determination of solidification sequences of our alloys (table 1). Therefore, the main important result in this work is the determination of an invariant eutectic ternary reaction: $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$. This latter occurs at 1140°C.

A hypothetical liquidus projection was proposed by Hannerz et al. [8] with the same ternary eutectic reaction $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$ but without indicating the invariant temperature. Note that Huang [4] has also proposed, by calculation, a liquidus projection and gave the same invariant reaction at 1147°C.

Figure 1. a) NbI thermogram showing three peaks at 1234, 1135 and 705 °C relative to the reactions: $L \leftrightarrow \gamma + \text{NbC}_{1-x}$, $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$ and the perlite. b) Electron micrograph of NbI alloy showing primary NbC_{1-x} carbide (1) (300X, in Absorbed electron (ABS)). c) Electron micrograph of NbI alloy showing NbC_{1-x} eutectic carbide (2) (Chinese script) (300 X, in ABS).

Figure 2. a) Nb5 thermogram showing four peaks at 1282, 1243, 1138 and 722 °C relative to the reactions: $L \leftrightarrow \gamma$, $L \leftrightarrow \gamma + \text{NbC}_{1-x}$, $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$ and the perlitic. b) Electron micrograph of Nb5 alloy showing γ dendrite (1) and γ -NbC_{1-x} binary eutectic (2) (Chinese script) and the γ -NbC_{1-x}-Fe₃C ternary eutectic (3) (in Back Scattering Electron (BSE)).

Figure 3. Electron micrograph of Nb8 alloy showing γ -NbC_{1-x}-Fe₃C ternary eutectic (in BSE).

4 CONCLUSION

The solidification sequences in relation to the observed microstructures are proposed for some Fe-Nb-C ternary alloys. NbC_{1-x} primary carbides, the γ phase and NbC_{1-x} eutectic carbides have been analysed. Note that, a low solubility of niobium in the γ phase and a light solubility of iron in eutectic and primary niobium carbides are observed. The monovariant eutectic reaction $L \leftrightarrow \gamma + \text{NbC}_{1-x}$ and the invariant eutectic reaction $L \leftrightarrow \gamma + \text{NbC}_{1-x} + \text{Fe}_3\text{C}$ are proposed. The invariant reaction occurs at 1140°C.

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