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# Influence of tantalum on the rates of high temperature oxidation and chromia volatilization for cast (Fe and/or Ni)-30Cr-0.4C alloys

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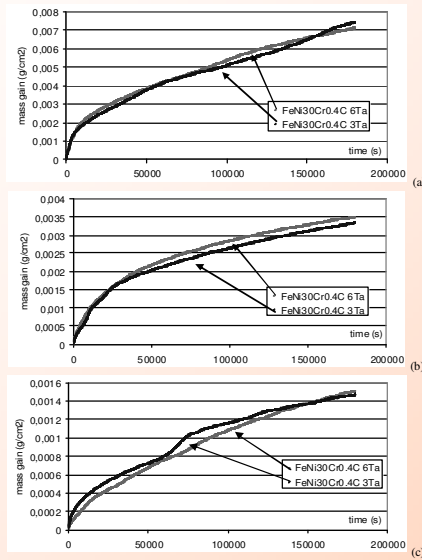
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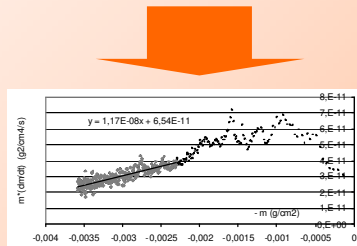


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The equiaxed superalloys obtained by classical foundry process are often reinforced by interdendritic carbides appeared during solidification. It is notably the case of cobalt-base alloys, but this principle of strengthening can also be used for nickel and iron-base alloys. Thus, in addition to chromium, the (well known) role of which is to bring a good resistance against high temperature oxidation to the conventionally cast superalloys, tantalum, which is a very oxidable element too, can also play a role in the high temperature oxidation of (Fe and/or Ni) - base alloys. In this work the high temperature oxidation behaviours of two iron-base alloys and two iron-nickel base alloys, containing 0.4 wt.%C and two amounts of tantalum 3 wt.%Ta and 6 wt.%Ta, are studied, with comparison with results obtained previously for ternary M30Cr0.4C alloys and two nickel-base alloys with 0.4%C and 3% to 6%Ta .



Mass gain curves of the FeNi30Cr0.4C(y = 3 and 6) alloys at 1,200 (a), 1,100 (b), 1,000°C (c)



$[m \times (dm/dt) = K_p - K_v \times m]$ -type treatment of the curve for FeNi30Cr0.4C6Ta at 1,100°C

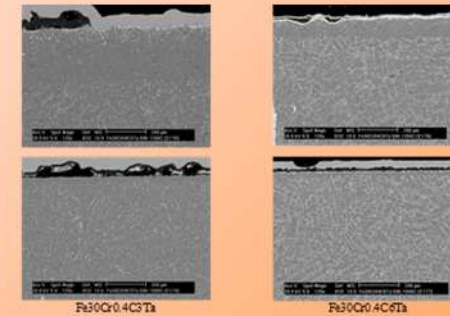
Tantalum diffuses from the carbides towards the oxidation front to be oxidized in internal oxides. This promotes the development of a carbide-free zone, the depth of which is higher for a higher temperature of oxidation, but also higher for a lower Ta-content in the alloy. Oxidation involves almost the same quantity of tantalum, then promotes, in the Fe-base alloy with 3%Ta, the disappearance of tantalum carbides over a double depth compared to the Fe-base alloy with 6%Ta.

The ratio of carbide-free depths between the (Fe,Ni)-base alloys with 3%Ta and 6%Ta, or between the Ni-base alloys with 3%Ta and 6%Ta, are not the same. A significant part of Ta is also contained in the matrix of these alloys while Ta is almost only present in the form of carbides in Fe-base alloys. The location of tantalum in the alloy seems to have consequences on the importance of internal oxidation, more precisely on the oxidation of tantalum. When this element is in grain boundaries as tantalum carbides (Fe-base alloys: higher equivalent thickness of tantalum oxide and deeper carbide-free zones) its diffusion towards the oxidation front seems easier than when a part of tantalum is in solid solution in the matrix ((Fe,Ni)-base and Ni-base alloys).

Oxidation of tantalum leads to higher mass gains at 1,200 and 1,100°C, and to difficulties for the (Kp+Kv) determinations and validations. The fast oxidation of the Fe-base alloys, compared to the (Fe,Ni)-base and Ni-base alloys, can be related both to the distribution of Ta in the alloy (more present in interdendritic carbides and less in matrix) and to the crystallographic structure of the matrix at the test temperatures, i.e. BCC (ferritic) for the Fe-base alloys and FCC (austenitic) for the others. The nature of the major element itself probably plays a role since oxidation is also slightly faster for a (Fe,Ni)-base alloy than for its corresponding Ni-base alloy. The decrease of the parabolic constant of a Fe-base alloy when the Ta content is changed from 3 to 6%, is also different to what it is encountered for the austenitic alloys. There is probably an effect of the BCC-FCC difference and/or of the base element difference here too. The obtained Kv values are in accordance with data from literature.

Kp	Values of Kp ( $\times 10^{12} \cdot \text{g}^2 \cdot \text{cm}^{-4} \cdot \text{s}^{-1}$ ) and Kv ( $\times 10^{10} \cdot \text{g} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ ) constants			
	temperature	0% Ta	3% Ta	6% Ta
Fe30Cr0.4C	1200°C	499	844	696
	1100°C	59	131	119
	1000°C	6.3	87	13
FeNi30Cr0.4C	1200°C	/	213	204
	1100°C	/	43	65
	1000°C	/	8.5	10
Ni30Cr0.4C	1200°C	70	218	248
	1100°C	18	39	42
	1000°C	7.1	5.8	3.2
Kv	temperature	0% Ta	3% Ta	6% Ta
	1200°C	514	436	770
Fe30Cr0.4C	1100°C	73	98	137
	1000°C	27	348	-3.6
	1200°C	/	217	200
FeNi30Cr0.4C	1100°C	/	53	117
	1000°C	/	57	23
	1200°C	82	156	235
Ni30Cr0.4C	1100°C	58	26	70
	1000°C	32	16	24

**Bold characters:** excellent fit between the experimental mass gain curve and the mathematical one  
Normal characters: good fit between the experimental mass gain curve and the mathematical one  
*italic characters:* not good fit between the experimental mass gain curve and the mathematical one



Cross section metallographs of the two Fe-base alloys containing Ta after oxidation for 50 hours at the two extreme temperatures 1,200°C (top) and 1,000°C (bottom)

Values of the average thicknesses of external chromia and of the equivalent (Cr,Ta) oxide assessed by image analysis (in each case average of 3 measures +/- 1 std deviation)

Av. thick. of Cr oxide Equ. thick. of Ta oxide	T (°C)	0%Ta			3%Ta		6%Ta	
		Cr <sub>2</sub> O <sub>3</sub> (µm)	Cr <sub>2</sub> O <sub>3</sub> (µm)	(Cr,Ta) ox. (µm)	Cr <sub>2</sub> O <sub>3</sub> (µm)	(Cr,Ta) ox. (µm)		
Fe30Cr0.4C	1200	18 ± 3	32 ± 6	7.4 ± 0.4	16 ± 4	8.0 ± 2.0		
	1100	18 ± 3	22 ± 2	5.3 ± 1.0	19 ± 3	7.3 ± 0.8		
	1000	6.6 ± 0.7	11 ± 1	0.7 ± 0.2	8.3 ± 1	2.2 ± 0.3		
FeNi30Cr0.4C	1200	/	30 ± 2	4.8 ± 0.3	31 ± 2	9.2 ± 1.1		
	1100	/	13 ± 2	1.8 ± 0.3	12 ± 2	4.4 ± 0.9		
	1000	/	10 ± 1	0.7 ± 0.3	6.2 ± 2	1.1 ± 0.4		
Ni30Cr0.4C	1200	21 ± 3	<i>n. o. r.</i>	5.9 ± 0.7 (42*)	<i>n. o. r.</i>	4.8 ± 2.3 (34*)		
	1100	11 ± 1	13 ± 1 (9.2*)	2.9 ± 0.7 (21*)	8.6 ± 1.0 (6.1*)	6.0 ± 0.6 (4.2*)		
	1000	4.6 ± 0.7	13 ± 1 (9.2*)	1.9 ± 0.2 (13*)	6.0 ± 1.0 (4.2*)	2.1 ± 0.2 (1.5*)		

(\*: values deduced from the former multiplied by  $\sqrt{50h/100h}$ , i.e. divided by  $\sqrt{2}$ )  
*(italic characters: the oxidation time for Ni30Cr0.4C3or6Ta was of 100h [3] and not 50 hours)*  
(n. o. r. : no external oxide remained on the sample after cooling)

Values of the average depths of the carbide-free zones (average of 3 measures +/- 1 std deviation)

Average depth of the carbide-free zone	Temperature	0%Ta		3%Ta		6%Ta	
		d <sub>cf</sub> (µm)	d <sub>cf</sub> (µm)	d <sub>cf</sub> (µm)	d <sub>cf</sub> (µm)		
Fe30Cr0.4C	1200°C	333 ± 33	272 ± 11	91 ± 9			
	1100°C	144 ± 17	98 ± 2	65 ± 4			
	1000°C	41 ± 2	36 ± 6	20 ± 2			
FeNi30Cr0.4C	1200°C	/	103 ± 10	107 ± 6			
	1100°C	/	49 ± 7	40 ± 4			
	1000°C	/	19 ± 5	11 ± 1			
Ni30Cr0.4C	1200°C	143 ± 2	21 ± 3 (100*)	190 ± 8 (134*)			
	1100°C	66 ± 5	79 ± 8 (56*)	76 ± 4 (54*)			
	1000°C	26 ± 3	30 ± 2 (21*)	21 ± 4 (15*)			

(\*: values deduced from the former multiplied by  $\sqrt{50h/100h}$ , i.e. divided by  $\sqrt{2}$ )  
*(italic characters: the oxidation time for Ni30Cr0.4C3or6Ta was of 100h [3] and not 50 hours)*  
(n. o. r. : no external oxide remained on the sample after cooling)

When present in Fe-base and (Fe,Ni)-base carbon-containing alloys, tantalum leads to a TaC carbides network which seems to influence the high temperature oxidation behaviour. Their mass gains are higher than for Ta-free alloys, especially for the highest temperatures. Moreover the oxidation of Ta leads to difficulties for determining the parabolic and chromia volatilization constants by using the  $[m \times dm/dt = K_p - K_v \times m]$ - treatment. This is particularly true in the case of iron-base alloys in which the diffusion of Ta towards the oxidation front is the easiest because of its availability in grain boundaries. Thus, an efficient reinforcement by tantalum carbides is probably easier to obtain in Fe-base and (Fe,Ni)-base alloys than in Ni-base alloys, but unfortunately with a significant decrease of the resistance against high temperature oxidation of alloys.