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# Influence of the Microstructural Texture of Cast Superalloys on their High-Temperature Oxidation Behaviour

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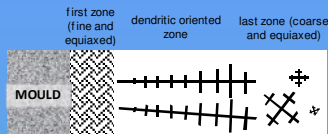
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## INTRODUCTION

The microstructure of alloys resulting from classical foundry practice depends on the solidification conditions. Local cooling rate and thermal gradient govern, respectively, grain size and dendritic orientation, then density and general orientation of grain boundaries.

Grain boundaries acting as special diffusion paths for Cr atoms or O<sup>2-</sup> anions, the kinetic of high-temperature oxidation of superalloys could depend on both microstructural fineness and orientation.



These points were studied for a Ni-base and three Co-base cast superalloys strengthened by carbides of different types (eutectic M<sub>23</sub>C<sub>6</sub> and/or MC), the oxidation kinetics of which were measured by thermogravimetry under industrial air and at different high temperatures.

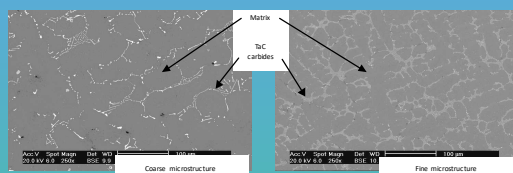
weight %	Co	Ni	Cr	C	W	Ta	Fe
Cobalt1	bal.	9	30	0,4	6	3	/
Cobalt2	bal.	9	30	0,4	/	6	/
Cobalt3	bal.	9	30	1,0	/	6	/
Nickel1	/	bal.	30	0,7	7,5	0	7,5

## fineness

## EXPERIMENTAL DETAILS

## orientation

The superalloys were synthesised using an induction furnace and solidified in sand moulds. First, a sample for oxidation tests, with a coarse microstructure (mean spacing between two secondary dendrite arms λ of about 50µm), was cut from the equiaxed zone. Second, a part of the casting was induction-remelted in a water-cooled copper crucible in which the alloy solidified with a higher cooling rate, then a finer microstructure (λ ≅ 25µm).



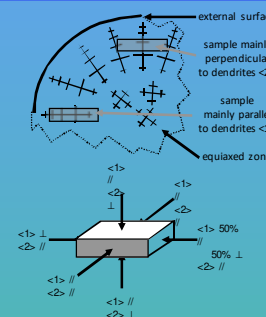
For the influence of dendritic orientation on oxidation behaviour (Cobalt1 and Nickel 1 alloys), two types of samples were prepared, with square faces parallel or perpendicular to dendrites.

Thus the external surface (S = S<sub>∥</sub> + S<sub>⊥</sub>) is either mainly parallel or mainly perpendicular to dendrites.

$$\frac{\Delta m_{\parallel}}{S_{\parallel}}(t) = \sqrt{2 \cdot K_{p\parallel}} \cdot t^{\frac{1}{2}} \quad \frac{\Delta m_{\perp}}{S_{\perp}}(t) = \sqrt{2 \cdot K_{p\perp}} \cdot t^{\frac{1}{2}}$$

$$\frac{\Delta m}{S}(t) = \frac{\Delta m_{\parallel}(t) + \Delta m_{\perp}(t)}{S_{\parallel} + S_{\perp}} = \frac{S_{\parallel}}{S_{\parallel} + S_{\perp}} \sqrt{2 \cdot K_{p\parallel}} \cdot \sqrt{t} + \frac{S_{\perp}}{S_{\parallel} + S_{\perp}} \sqrt{2 \cdot K_{p\perp}} \cdot \sqrt{t}$$

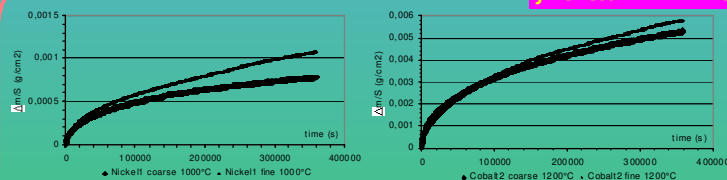
$$\frac{S_{\parallel}}{S} \sqrt{2 \cdot K_{p\parallel}} + \frac{S_{\perp}}{S} \sqrt{2 \cdot K_{p\perp}} = \sqrt{2 \cdot K_p}$$



## fineness

## RESULTS

## orientation

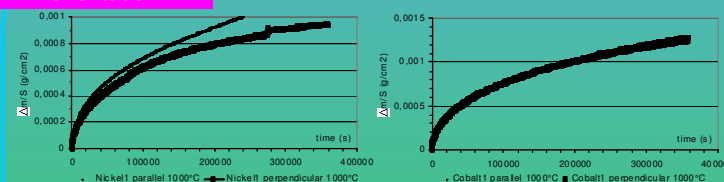


The oxidation kinetic varies with grain size but not always in the same way. The alloys showing a higher oxidation rate for a fine structure than for a coarser one all contained tungsten, while the opposite was found for the other.

A fine Cobalt1 oxidized faster at low temperature and slower at high temperature than a coarse one. Oxidation and/or diffusion phenomena seem to be different (different activation energies). Microscope examinations showed that, with increasing temperature, oxidation rate and the carbide-free band growth rate increased and were higher for a fine microstructure than for a coarse one, while the internal oxidation depth also increased but with an inverted order between coarse and fine.

10 <sup>12</sup> · K <sub>p</sub> g <sup>2</sup> ·cm <sup>-4</sup> ·s <sup>-1</sup>	microstructure		K <sub>p</sub> <sub>fine</sub> K <sub>p</sub> <sub>coarse</sub> ratio	Activation energy (kJ·mol <sup>-1</sup> )	
	coarse K <sub>p</sub> <sub>coarse</sub>	fine K <sub>p</sub> <sub>fine</sub>		for the 3 temperatures	for the 2 lowest temperatures
Nickel1* (1000°C)	0.57	1.55	2.72		
Cobalt1* (1000°C)	1.15	1.44	1.25		
Cobalt2 (1000°C)	2.69	1.52	0.53		
Cobalt2 (1100°C)	18.7	15.3	0.82	185	253
Cobalt2 (1200°C)	28.0	37.8	1.35		
Cobalt3 (1000°C)	3.46	1.39	0.41		

\* contains tungsten



The parabolic constants were more or less dependant on the dendritic orientation (amplified after uncoupling of the two contributions). The oxidation rate of Nickel1 was higher for samples mainly parallel to dendrites than for perpendicular ones, with a ratio of 10 at 1000°C and of 4 at 1100°C on the parabolic constants. For Cobalt1, oxidation rate was slightly higher for the sample mainly perpendicular to dendrites than for the parallel one at 1000°C, and the difference increased with temperature.

For Nickel1 the internal oxidation depth did not depend on the dendritic orientation. On the contrary, for Cobalt1, this depth was greater for the perpendicular orientation than for the parallel one. The differences in oxidation rate observed for the two orientations appeared to be directly associated to the chromia growth rate in the case of Nickel1, while it was more related to the internal oxidation for Cobalt1.

values of 10 <sup>12</sup> ·K <sub>p</sub> in g <sup>2</sup> ·cm <sup>-4</sup> ·s <sup>-1</sup>					
1000°C	K <sub>p</sub> <sub>parallel</sub>		1100°C	K <sub>p</sub> <sub>parallel</sub>	
	K <sub>p</sub> <sub>parallel</sub>	K <sub>p</sub> <sub>perp</sub>		K <sub>p</sub> <sub>parallel</sub>	K <sub>p</sub> <sub>perp</sub>
Nickel1	1,71	2,30	Nickel1	5,57	6,28
	0,63	0,19		2,67	1,51
Cobalt1	1,32	1,22	Cobalt1	7,14	5,76
	1,69	1,90		10,38	14,32

## CONCLUSIONS

The chemical composition is not the only alloy parameter having some influence of the high-temperature oxidation behaviour of carbide-strengthened cast superalloys. Indeed, it appeared here that both grain size and dendritic orientation must be taken into account, for example, when comparative oxidation tests are made in order to optimise the chemical composition of an alloy for improving its oxidation behaviour. But this influence, which seems also to depend on other chemical or microstructural parameters, is difficult to define

and more work remains to be done for better understanding of the involved phenomena. First, tests at other temperatures are needed on all alloys in order to define the activation energies. Second, microprobe contents profiles and texture analysis of the chromia layer are required to understand the diffusion phenomena and their differences when grain size or dendritic orientation vary.