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High temperature properties of ZrC-strengthened Co-based and Fe-based cast superalloys

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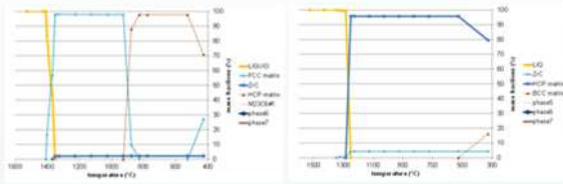
Usually introduced in superalloys and other alloys for trapping impurities such as sulfur, zirconium can be used as carbide-former element to promote strengthening by MC carbides. This type of carbides, more usually issued from tantalum (TaC carbides), is known as being both very imbricated with matrix and very stable at high temperature, and consequently especially efficient for the reinforcement of alloys for high resistance to creep deformation at high temperature. ZrC are not or rarely used in this field and the purpose of this work is to test them in refractory cobalt-based and iron-based alloys.

Several Co-based and Fe-based alloys of the {M-25Cr-xC-yZr}-type (x=0.25 with y=1.9, and x=0.50 with y=3.8, in wt.%) were elaborated by classical foundry in inert atmosphere. The obtained ingots were cut to obtain parts for the metallographic characterization of the as-cast microstructures, for Differential Thermal Analysis for specifying their melting range, for {1200°C, 20MPa}-flexural creep tests and for oxidation tests in synthetic air at 1200°C.

Preliminary thermodynamic calculations

As-cast microstructures and DTA results

Mushy zone temperature range

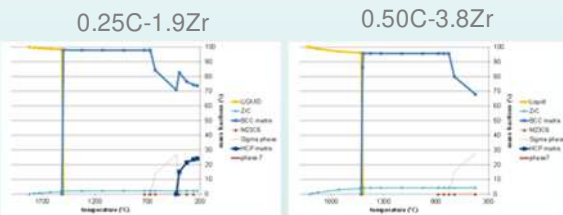


0.25C-1.9Zr

0.50C-3.8Zr

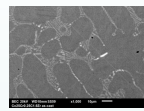
Co-based alloys

Fe-based alloys

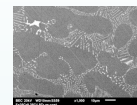


0.25C-1.9Zr

0.50C-3.8Zr

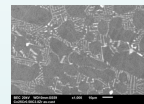


0.25C
-
1.9Zr
(as-cast)

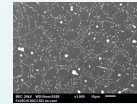


Fe-based alloys

Co-based alloys



0.50C
-
3.8 Zr
(as-cast)



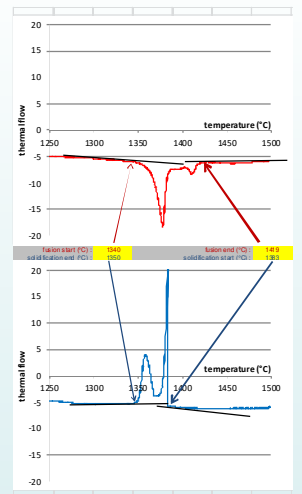
Fe-based alloys

Co-based alloys
0.25C-1.9Zr
Fusion over: 1330 → 1445°C
Solidification over: 1350 ← 1400°C

Fusion over: 1445 → 1500°C
Solidification over: 1450 ← 1500°C

0.50C-3.8Zr
Fusion over: 1340 → 1420°C
Solidification over: 1350 ← 1385°C

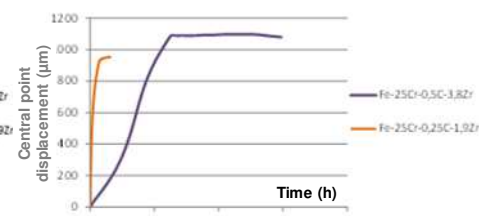
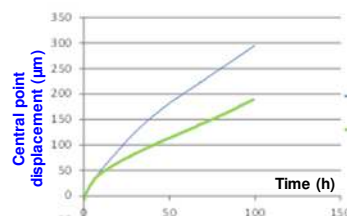
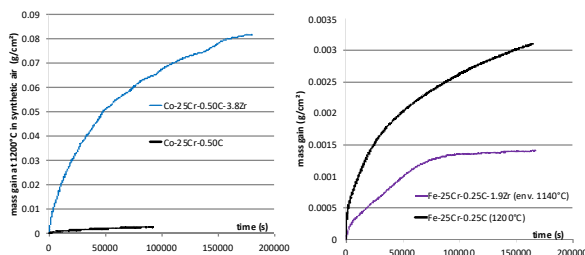
0.50C-3.8Zr
Fusion over: 1445 → 1500°C
Solidification over: 1445 ← 1500°C



Co-25Cr-0.50C-3.8Zr
(example)

Thermogravimetry tests at 1200°C in dry synthetic air (parallelepiped samples: about 10 mm length × 8 mm width × 3 mm thickness)

Centered 3-points flexural creep at 1200°C, for 20 MPa just below the central point (parallelepiped samples: 12 mm length × 2mm width × 1 mm thickness)



Thanks to well chosen contents in carbon and zirconium (rather high mass contents, and equal molar content between C and Zr) the four obtained alloys contain all almost only zirconium carbides. Indeed, as predicted by the preliminary thermodynamic calculations, ZrC have precipitated instead chromium carbides despite the much higher contents in the second carbide-former element, chromium. However, as predicted again with Thermo-Calc, some of the obtained ZrC are of a pre-eutectic nature (compact white particles seen in SEM/BSE images), notably in the two Fe-based alloys. The other part of the ZrC phase is a eutectic one, present as script-like carbides in the interdendritic spaces. All alloys are very refractory (fusion start temperatures higher than 1330°C), especially the Fe-based ones (> 1450°C) which were not wholly melted by the DTA apparatus (operating temperature limited to 1500°C). Despite their remarkably high refractoriness the two Fe-based alloys were very weak in flexural creep test, consequently to the not compact BCC ferritic structure of their matrices. The two Co-based were much resistant in this field, with rather low deformation rates for 1200°C and 20 MPa which are both particularly high for equi-axed conventionally cast superalloys. Unfortunately these were the mechanically weak Fe-based alloys which displayed the best oxidation behaviour in air at 1200°C. The two Co-based alloys, which were almost wholly destroyed by oxidation during the thermogravimetry tests, necessitate to be isolated by protective coatings from the oxidative working hot atmosphere to hope benefiting of their superior strength at high temperature.