学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Microstructure and phase stability of multi-phase alloys in refractory-metal base systems
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The AB_2-type intermetallic Laves phases with topologically close-packed (TCP) structures have been considered for high-temperature structural materials, because of their high melting points and attractive mechanical properties at elevated temperature. Although the concept of ductile phase toughening has been applied to improve their room temperature toughness of some alloys including Nb/$NbCr_2$ and Cr/$TaCr_2$, the large volume fraction of ductile phases resulted in lower strength of the alloys. However, the strength of the ductile phase, mainly BCC structure for refractory ductile phase, is not adequate at high temperature. To overcome this trade-off relationship, a new BCC_1/BCC_2/Laves three-phase alloy is proposed. It is intended to introduce a second BCC phase with a fine structure to bring the BCC_1/BCC_2interfaces into the conventional single ductile phase and AB_2 Laves phases disperse in the BCC_1/BCC_2 two-phase microstructure.

The isothermal sections of the Cr-Mo-Nb ternary phase diagram have been studied. The C15 $NbCr_2$ Laves precipitation behavior in three different alloys has been investigated in the Cr-Mo-Nb ternary system. The orientation relationship (OR) of $NbCr_2$ in BCC matrix among BCC/Laves two-phase alloys and Cr-rich BCC_1/Mo-rich BCC_2/Laves three-phase alloy is different at 1473 K; OR 1: (011)BCC // (11-1)C15, [0-11]BCC // [-110]C15 and OR 2: (-411)BCC // (111)C15, [0-11]BCC // [-110]C15 with low lattice mismatch are both observed in Cr-rich alloys #3 (74Cr-16Mo-10Nb) and #2 (50Cr-30Mo-20Nb). OR 3: (011)BCC // (111)C15, [-11-1]BCC // [01-1]C15 with a lattice mismatch relatively larger than that of OR 1 and OR 2 is only observed in alloy #2, which may be due to the presence of BCC_1 and BCC_2 interphases formed after BCC decomposition. Only discontinuous precipitation is observed at grain boundaries in Cr-lean alloy #1 (42Cr-31Mo-27Nb) without obvious OR between the BCC matrix and Laves phase.

The supersaturated BCC single-phase solid solution alloy obtained by homogenization at 1973 K for 1 h shows a microstructure evolution during heat-treatment at 1473 K: the intragranular nucleation of Cr-rich BCC_1, which leads to the formation of an alternating BCC_1/BCC_2 two-phase microstructure through a discontinuous precipitation process, followed by nucleation of the Laves phase at the BCC_1/BCC_2 interphase boundaries. At a relatively higher temperature of 1523 K, a similar microstructure is obtained with higher BCC decomposition and Laves precipitation rates, while the alloy consists of BCC and Laves phase at 1773 K. The mechanical properties of the alloys heat-treated at 1473 K for various periods after the solid solution treatment are also investigated. The highest fracture compressive strength of 1493 MPa and minimum hardness of 773±7 HV are obtained for the alloy aged for 24 h, where the BCC_1/BCC_2two-phase microstructure dominates. The Vickers hardness of the alloy aged for 72 h with a fine structure including the Laves phase is 839±8 HV under a load of 0.5 kgf, and no

obvious microcracks are observed.

Besides, silicon has been chosen to add to the Cr-Mo-Nb system to study the stability of $NbCr_2$ Laves phase. It is found that the amount of Laves phase in as-cast increases with the increase of the Si addition. In 1973 K heat-treated alloys with 0.5Si and 1Si, Laves phase still exists. It is also found that Si is enriched in $NbCr_2$ phase and Mo is also tend to be distributed into the Laves phase. It indicates that $NbCr_2$ is relatively stabilized with Si addition and the solvus line of BCC moves towards Mo-rich direction.