Foreword

Materials for High Temperature Applications: Next Generation Superalloys and Beyond

Nickel-based superalloys possess an excellent combination of mechanical properties and environmental resistance at elevated temperatures, and have been widely used in challenging environments prevalent in aircraft engines and land-based power generation gas turbines, as well as in nuclear power systems and chemical plants. The ever-increasing demand for higher operating temperatures to achieve better fuel efficiency has been driving the development of the next generation of superalloys, in which the higher temperature capability has been achieved by increasing additions of refractory elements, optimizing processing conditions, and through the application of coatings. However, there is a strong need for materials that can make a disruptive change in temperature capability beyond that provided by current materials.

The symposium ‘‘Materials for High Temperature Applications: Next Generation Superalloys and Beyond’’ was held during the 2017 TMS annual Meeting from February 27 to March 2, 2017 in San Diego, California, with the sponsorship from the TMS High Temperature Alloys Committee and TMS Refractory Metals Committee. The goal of this symposium was to discuss (i) challenges that current Ni-based superalloys are facing and (ii) the recent progress in the development of next generation of superalloys and high temperature material systems beyond Ni-based superalloys. The symposium was composed of a total of seven sessions covering current and next generation Ni-based superalloys, refractory metal-based materials, intermetallic-based materials, coatings, Ir-based alloys, and ceramics composites and emerging materials. The organizers would like to thank all the presenters and the participants for their excellent contribution to the success of this symposium. There were in total 60 oral presentations, including 2 keynote presentations and 18 invited presentations, and 6 poster presentations. This special issue presents selections of 10 high quality research papers submitted to this symposium. We would like to express our appreciation to Prof. Tresa Pollock, Principal Editor; Prof. Jonathan Cormier, Editor; and Ms. Karen Doyle, of Metallurgical and Materials Transactions A for their support in the publication of these papers in a single issue.

The first paper by Mignanelli *et al.*[1] investigated the precipitation behavior in a new class of Ni-based superalloys strengthened by two superlattice intermetallic phases, γ' ($L1_2$) and γ'' ($D0_{22}$), as a candidate next generation alloy system having temperature capability beyond IN718. A T-T-T diagram was constructed, and the stability of the γ'' phase against δ phase was discussed. The formation of the γ'' precipitates were shown to contribute to age hardening of the alloy.

Detor *et al.*[2] presented their Ni-based superalloy design approach to solve a unique issue associated with physically large components, such as land-based power generation gas turbine disks, in which the inability to achieve fast cooling rates makes it difficult to suppress coarsening of the γ' precipitates. Two successful approaches to reduce the coarsening kinetics of the γ' precipitates were presented: (1) changing the chemistry of the γ' precipitates, and (2) using co-precipitation of the γ' phase with the γ'' phase that acts as a diffusion barrier.

The microstructural stabilities of Ni-based superalloys are critical for prolonged service of these materials at elevated temperatures. The evolution of the γ' precipitates during thermal exposure at 760 °C was studied in detail using a model alloy by Goodfellow *et al.*[3]. The secondary γ' precipitates exhibited morphological instability associated with precipitate splitting, while the tertiary γ' precipitates coarsened in line with LSW theory. The changes in phase compositions were measured and discussed in comparison with CALPHAD predictions.

Boron is one of the important minor elements commonly added to superalloys for improving grain boundary properties. Antonov *et al.*[4] investigated distribution of B in high Nb-containing powder-processed polycrystalline Ni-based superalloys. The analyses showed that a relatively high solubility of B in the γ phase leading to a lower concentration of B along grain boundaries affects formation of borides and σ phase. Challenges in applying thermodynamic predictions to boride formation were also discussed.

Lattice misfit between the γ matrix and the γ' precipitate phases has been known to be one of the critical parameters that influence thermal stability and mechanical behavior of Ni-based superalloys. Huang *et al.*[5] performed high temperature *in situ* misfit measurements in various single-crystal superalloys using neutron diffraction. Several factors that affect the misfit values, including phase chemistry, interface coherency, and internal stress, were discussed.

Stein *et al.*[6] investigated the Nb-rich corner of the Nb-Al-Fe ternary phase equilibria as a part of the effort to develop structural Nb-based alloys for very high temperature applications that possess multi-phase microstructure consisting of a Nb solid-solution phase and high-melting, strengthening intermetallic phase(s). Effect of Fe on the stability and the solubility limits in the Nb solid-solution phase, Nb_2Al, and Nb_3Al intermetallic phases was examined.

Nb-Si-based alloy system possesses superior temperature capability compared with Ni-based superalloys. Gang *et al.*[7] determined the ternary eutectic composition in the Nb-Si-Cr system, and evaluated the stability of the eutectic structure consisting of Nb_{ss}, Cr_2Nb, and $Nb_9(Si,Cr)_5$ phases during static thermal exposure and creep deformation. It was shown that the presence of the load-bearing $Nb_9(Si,Cr)_5$ matrix phase significantly improves the creep strength of the eutectic alloy.

Refractory metal-based high entropy alloys are of great interest for high temperature applications. Chen *et al.*[8] investigated the impact of lattice distortion on the solid-solution strengthening of a NbMoCrTiAl alloy and its derivatives. The correlation between the microhardness at room temperature and the atomic size difference was successfully demonstrated and affirmed by assessment of the athermal component of the strength of the alloys.

MAX phases possess many attractive attributes for high temperature applications. Smialek[9] studied oxidation of the alumina-forming MAX phases, Ti_2AlC and Cr_2AlC, under turbine engine environment and coating configurations. The oxidation behavior of the Ti_2AlC in combustion gas environment containing water vapor was examined using a high pressure burner rig and compared with that in the air. Compatibility of the MAX phases with a thermal barrier coating as well as with Ni-based superalloys was evaluated.

Ir-based alloys are extensively used for space applications where high-melting point, high temperature impact ductility, and oxidation resistance are required. In these alloys, it′s been known that one of the impurity elements, Si, has detrimental effects on embrittlement during high temperature impact testing. Pierce *et al.*[10] performed a detailed investigation on the segregation of Si to grain boundaries, and evaluated its temperature dependence and kinetics in a Ir-based alloy containing trace levels of Si.

Lastly, we would like to dedicate this special issue to Dr. Martin Palm (MPI for Iron Research, Düsseldorf, Germany) who has made seminal contributions to the field of intermetallic materials, both with respect to establishing fundamental relations in relevant phase diagrams as well as in bringing together the scientific community in this field by organizing workshops and conferences to promote industrial application.

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