Refractory Metals—An Exploration of High-temperature Materials

S.K. Varma

The U.S. government is spending a significant amount of human and financial resources to develop high-temperature materials that can be used for turbine engines to elevate their service temperature capabilities as well as improve efficiency. A promising class of materials with potential to address such issues is refractory metals. By definition, these metals have high melting points. Such research could have a positive impact on the U.S. economy and lead to the development of more operationally efficient and economical turbine engines.

Historically, the role of high-temperature metallic materials has been dependent on nickel-based superalloys. However, these superalloys have limited service temperature because of the relatively low melting point of nickel, at 1,453°C. On the other hand, niobium and molybdenum, candidates for nickel-based superalloys replacement, have melting points of 2,468 and 2,610°C, respectively. Thus, weight may play a crucial role in the selection of materials for high-temperature applications.

The Refractory Metals 2010 symposium held in Seattle, Washington, was sponsored by the TMS Refractory Metals Committee. Energy issues related to high-temperature materials, thermal stability, and their mechanical and oxidation properties were among the subjects of presentations made by various authors. The vast experience and the noted expertise of these authors allowed the dissemination of state-of-the-art technology. Their continued research promises a quick delivery of the actual material to be used in practices involving high temperatures.

In this issue, J.H. Perepezko and R. Sakidja's paper examines the effect of surface coating of molybdenum-based alloys for ultra-high-temperature applications. In particular, the Mo-Si-B system was studied; typical borosilica oxidation scale was expected to provide a passive surface layer for enhanced oxidation resistance. The surface coating could reduce the thickness loss per unit area per unit time but thermodynamic compatibility between the substrate and the coating needs to be addressed. The authors stipulate that B/Si ratio can control the diffusion through the coating. The authors present their work on Mo-14.2Si-9.6B (at.%) ternary alloy and discuss the layered structure formation consisting of $MoSi_2$ and T_1 phase (Mo_5Si_3) with dispersoids of MoB.

Next, Michael R. Middlemas and Joe K. Cochran deal with alloys from the Mo-Si-B system containing molybdenum solid solution phase and two Mo_3Si and Mo_5SiB_2 (T_2) silicides. Powders of molybdenum, Si_3N, and BN, were used to synthesize an alloy through powder processing. The approach is to control the morphology of the three phases to tailor-make the properties. The processing has allowed the minimization of the clustering of the T_2 phase through the control of BN addition. Oxidation resistance is derived from the molybdenum solid solution phase while other phases can provide the mechanical properties through the control of their morphologies.

The possibility of developing an alloy from the Mo-Ni-Al system up to 1,200 –1,300°C is explored by P.K. Ray et al. However, oxidation resistance is expected from the intermetallic NiAl through the formation of Al_2O_3 passivating scale. The compositional variation in molybdenum ranged from 15–35 at.% while maintaining the atomic ratios of nickel and aluminum to be the same. The authors conclude that better oxidation resistance for up to 20 hours can be obtained by keeping the molybdenum concentration to less than 20 at.%.

Finally, Simon Hollad and Andreas Bührig-Polaczek used vacuum investment casting to produce 25×90×160 mm turbine blades by using 45 equiatomic percent of nickel and aluminum, 7.5%Cr, and 2.5%Ta. A shell mold free of SiO_2 was produced for the investment casting of NiAl. There are two reasons for using an SiO_2-free mold: silicon reacts with the NiAl melt and lowers the temperature capability of the mold and cannot be used for this alloy since it melts at 1,600°C. The production of castings free of cracks uses a precise cooling rate control during the equiaxed process. A continuous production of turbine blades may be prepared following their experimental process subject to adaptation.

S.K. Varma, professor, is with the Department of Metallurgical and Materials Engineering, University of Texas at El Paso and is the advisor to *JOM* from the Refractory Metals Committee of the Structural Materials Division of TMS.