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Refractory Materials for Corrosive or High-Temperature Environments

CHAI REN,[1,4] RAVI ENNETI,[2] and GAOYUAN OUYANG[3]

1.—Xiamen Tungsten Co. Ltd, Chengdu, Sichuan, China. 2.—Global Tungsten and Powders, Towanda, PA, USA. 3.—Ames Laboratory, Ames, IA, USA. 4.—e-mail: chai.ren.cn@gmail.com

Recent developments in electronic, nuclear, and defense applications have resulted in new challenges and opportunities for refractory metals and ceramics with excellent corrosion resistance and high-temperature performance. There are also effective additives for alloy and composite systems to improve their functional and structural properties in corrosive or elevated temperature environments. However, common drawbacks like room temperature brittleness and low fracture toughness prevent the use of refractory materials in applications that need high mechanical reliability. Thus, new research is urgently required from academic and industrial research teams for both experimental and theoretical advancements in refractory materials.

The 2022 special topic of refractory metals and materials focuses on the advanced material design and innovative processes that can be used to improve their performance in extreme environments, and characterization studies to deepen fundamental understanding. The papers are mostly devoted to the challenges in overcoming refractory materials' major limitations: their brittleness and low fracture toughness. The collection presents six papers covering the research areas of carbides, metal-ceramic composites, refractory high-entropy alloys, and thermo-mechanical processes.

Tungsten is well known for its high-temperature performance. Combining tungsten with ceramic phases to form a metal-ceramic composite may reduce the material density, while maintaining the desired strength and thermal conductivity. This makes the material a promising candidate for high-temperature applications with strict weight requirements. In "Microstructure and Mechanical Properties of Continuous Tungsten Fiber-Reinforced Tungsten-Zirconium Carbide-Copper Composites by Reactive Infiltration," Wang et al. reported a novel continuous tungsten fiber-reinforced W-ZrC-Cu composite prepared using a pressureless infiltrating method. Addition of tungsten fibers, formation of submicron-sized ZrC particles, and the Cu-rich interfaces change the extrinsic energy dissipation mechanism. This new material shows a considerable improvement in both flexural strength and fracture toughness, which may be beneficial for heat exchangers or rocket nozzles.

TiCN-Ni based cermets have been proposed as a substitution for the conventional WC-Co cemented carbides in tool industries. However, the relatively low transverse rupture strength and toughness has limited their application. Approaches like grain refinement or improvement in interface wettability have been studied, and NiTi has been chosen as an effective binder for TiCN and Ni phases. In "Microstructure and Mechanical Properties of TiCN-Ni Based Cermets Strengthened by Fore-Solid Solubilizing Ti in Ni," Chen et al. discuss a method for improving the wettability through pre-alloying NiTi and forming solid-solution powders before sintering. This mechanically alloyed NiTi powder has a different microstructure and forms transition layers between the binder and ceramic phases, which modifies the fracture mode and improves toughness of the TiCN-Ni cermet material.

Single-phase concentrated solid-solution alloys are multi-principal-element metallic alloys with superior mechanical, corrosion resistant, and radiation resistant properties. Addition of refractory elements can further enhance these alloys' high-temperature strengths, but at the cost of low room-temperature ductility. In "The Impact Behavior of As-Cast TiVTa(Nb) Refractory Single-Phase Concentrated Solid-Solution Alloys," Yin et al.

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investigated the microstructure and ductility of as-cast TiVTa(Nb) alloys. These refractory single-phase concentrated solid-solution alloys exhibit single phase BCC crystal structure, with improved ductile behavior and better crack resistance. The ductile-to-brittle transition temperatures of TiV-Ta(Nb) were determined to be – 123 °C and 117 °C, with and without Nb addition.

Due to its excellent high-temperature stability, good thermal shock resistance, and low thermal expansion, Al_2O_3-SiO_2 mullite ceramic has been widely used in industrial refractories or thermal barrier coatings. It also has great potential as an electronic packaging material, with the desired low dielectric constant. However, the usefulness of mullite ceramic is greatly limited by its poor fracture toughness. In "Microwave Sintering of Mullite-Nd_2O_3 Composites: Investigation of Microstructure and Mechanical Properties," Ghasali et al. studied the effect of Nd_2O_3 on the density, microstructure, and mechanical properties of mullite ceramic composites. The advantages of microwave sintering and the effect of sintering temperature on densification and mullitization of the composites are also discussed.

Tantalum shows a novel combination of high melting temperature, excellent corrosion resistance, low thermal expansion, and relatively good ductility, which make it an ideal candidate for electronic, aero, and space applications in extreme environments. Among different manufacturing techniques, the majority of tantalum products are processed thermo-mechanically. Therefore, the microstructure and property developments of tantalum during rolling and other deformation methods are important. In "Effect of Rolling on Texture Evolution and Recrystallization of Polycrystalline Tantalum," Zhu et al. analyzed the texture evolution of deformed and recrystallized polycrystalline tantalum after room temperature rolling, accumulative pack-rolling, and cryogenic rolling. Compared with other techniques, recrystallization occurs more easily in the cryogenic rolled tantalum, which may relate to the high dislocation density and stored energy in these samples.

Refractory high-entropy alloys are important high-entropy alloys with superior strength, good oxidization resistance, and high stability at elevated temperature. Among them, the MoNbTa-based alloys are specifically used in high-temperature applications, and have excellent potential for uses in aerospace and petrochemical fields. In "Microstructures, Mechanical, and Electrochemical Properties of MoNbTa-Based Refractory Multi-Component Alloys," Gu et al. performed a systematic study on the phase composition and material properties of MoNbTa-based high-entropy alloys with addition of Cr, V, Zr, and Ti elements. In the as-cast condition, the six elements show different distribution tendencies in the microstructure of this BCC solid-solution alloy. Heat treatments at 900 to 1000 °C can significantly homogenize element distributions and improve both the mechanical properties and corrosion resistance.

All the articles published under the topic "Refractory Materials for Corrosive or High-Temperature Environments" in the November 2022 issue (vol. 74, no. 11) can be accessed at: http://link.springer.com/journal/11837/74/11/page/1.