Nuclear Applications of Oxide Dispersion Strengthened and Nano-Featured Alloys: An Introduction

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The Nuclear Materials Committee of TMS is sponsoring the current topic in *JOM*, which is dedicated to a newer generation of materials called oxide dispersion strengthened (ODS) alloys and nano-featured alloys (NFA). These newer materials are fabricated by using powder stock materials and processing them through high energy attrition followed by either extrusion or forging. The presence of nano-sized oxides throughout the matrix makes the recrystallized alloy have grains that are smaller than 1 μm diameter. The nano-features in the matrix of ODS or NFA materials make them highly resistant to degradation by irradiation such as void swelling. There are four papers dedicated to ODS and NFA materials, including fabrication, joining and testing.

INTRODUCTION

Worldwide, the generation of electric power has several sources of energy that can be grouped as: (1) fossil fuels (coal, petroleum and natural gas), (2) nuclear and (3) renewable (wind, solar, hydroelectric, geothermal, biomass, etc.) sources.¹ The world energy consumption is still dominated (>85%) by the burning of fossil fuels.^{2,3} Currently, there are approximately 30 countries that produce electricity using the energy released during nuclear fission. The percentage of electricity generated from nuclear energy varies from country to country. In some countries like France nuclear electricity represents approximately 75% of the national consumption, in the United States, it is approximately 20%, and in other countries like China it is only 2%.^{2,3} The United States has the largest number of reactors (100) in capacity of operation, followed by France with 58 reactors, while China currently has 18 nuclear reactors in operation. In the mid-1980s, more than 20 reactors per year were connected globally to the grid; however, for the last 10 years, on average only 3–4 reactors were connected.³

Due to concerns about climate change, in the early 2000s there was a renewed interest in nuclear

energy, since it does not contribute to climate change. However, the natural disaster in northeast Japan in March 2011 further relegated the construction of newer nuclear power plants.³ The events in Fukushima have propelled the U.S. Department of Energy to fund cost-shared research in the field of accident tolerant fuel (ATF), that is, a fuel that will be able to sustain a longer lack of active coolant before the release of radioactive material to the environment.^{4,5}

Most of the under-construction plants are located in Asia, where the mandates for new sources of electrical power are mostly controlled by the central governments. The currently operating nuclear power plants and the new plants under construction use technology that can be ascribed as up to Generation III. In this technology, the most common materials used are carbon steels, stainless steels and nickel alloys manufactured by traditional methods of melting, casting and forging.

This *JOM* topic is dedicated to a newer generation of materials called oxide dispersion strengthened (ODS) alloys and nano-featured alloys (NFA). These newer materials are fabricated by using powder stock materials and processing them through high energy attrition followed by either extrusion or forging. The presence of nano-sized oxides throughout the matrix makes the recrystallized alloy have grains that are smaller than 1 μm diameter. The nano-features in the matrix of ODS

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or NFA materials make them highly resistant to degradation by irradiation such as void swelling. Therefore, the future of nuclear energy may find the use of ODS/NFA materials highly desirable.

Recent studies in the realm of accident-tolerant fuel cladding for current light water reactors showed that NFA materials comparable to 14YWT are highly resistant to general corrosion and to stress corrosion cracking in high temperature water, and resistant to oxidation in superheated steam.⁶⁻⁸

The first paper by G.R. Odette is entitled “Recent Progress in Developing and Qualifying Nanostructured Ferritic Alloys for Advanced Fission and Fusion Applications.” This paper reviews recent evolution in the developing nanostructured ferritic materials, which are leading candidates for advanced fission and fusion energy applications. By their own nature, these materials have outstanding high-temperature properties, along with unique irradiation tolerance, especially in the way they handle helium concentrations.

The second paper by Baker and Brewer, “Joining of Oxide Dispersion Strengthened Steels for Advanced Reactors” summarizes the properties and characteristics of different variants of oxide dispersion strengthened steels and addresses the ability of these materials to offer high-temperature strength, corrosion performance, and resistance to irradiation damage. Baker and Brewer also address the issue of joining, often called the limiting factor in the application of these materials. They describe friction stir welding as a promising method of joining, since it does not create oxide depleted areas as observed in the case of traditional fusion joining.

The third paper, “Development of ODS FeCrAl for Compatibility in Fusion and Fission Energy Applications” by Pint et al., describes the efforts to develop an oxide dispersion strengthened material with base iron and containing chromium and aluminum as main alloying elements. The application of this material is aimed at liquid metal fusion energy, and it is also as a current candidate for cladding in the DOE ATF program, since it offers outstanding resistance to reactions with superheated steam. Initial results show that the newer materials offer excellent creep and high-temperature mechanical properties. The final composition of the ideal material for accident-tolerant fuel cladding is still being optimized.

The fourth paper, by Yablinsky et al., is “Concepts for the Development of Nanoscale Stable Precipitation-Strengthened Steels Manufactured by Conventional Methods.” It describes the recent developments in mechanically alloyed oxide dispersion strengthened materials with specific microstructural features that include controlled volume fractions of fine, stable precipitates and dislocation sinks. This is achieved via specific alloying and processing paths that can be defined as conventional

practices. The aim is to obtain materials that have increased thermal stability and irradiation resistance while maintaining considerably lower cost.

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The following papers being published under the topic of Nuclear Applications of ODS and NFA Alloys provide excellent details and research on the subject. To download any of the papers, follow the url <http://link.springer.com/journal/11837/66/12/page/1> to the table of contents page for the December 2014 issue (vol. 66, no. 12).

- “Recent Progress in Developing and Qualifying Nanostructured Ferritic Alloys for Advanced Fission and Fusion Applications” G.R. Odette
- “Joining of Oxide Dispersion Strengthened Steels for Advanced Reactors” B.W. Baker and L.N. Brewer
- “Development of ODS FeCrAl for Compatibility in Fusion and Fission Energy Applications” B.A. Pint, S. Dryepondt, K.A. Unocic, and D.T. Hoelzer
- “Concepts for the Development of Nanoscale Stable Precipitation-Strengthened Steels Manufactured by Conventional Methods” C.A. Yablinsky, K.E. Tippey, S. Vaynman, O. Anderoglu, M.E. Fine, Y.-W. Chung, J.G. Speer, K.O. Findley, O.N. Dogan, P.D. Jablonski, S.A. Maloy, R.E. Hackenberg, A.J. Clarke, and K.D. Clarke

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5. J. Carmack and F. Goldner, *J. Nucl. Mater.* 448, 373 (2014).
6. P.L. Andresen, R.B. Rebak, E.J. Dolley, "SCC Resistance of Irradiated and Unirradiated High Cr Ferritic Steels," paper 3760 (Paper presented at Corrosion/2014, Houston, TX, 9–13 March 2014).
7. R.B. Rebak, "Alloy Selection for Accident Tolerant Fuel Cladding in Commercial Light Water Reactors" (unpublished work, 2014).
8. R.B. Rebak, R.J. Blair, P.J. Martiniano, F. Wagenbaugh, E.J. Dolley, "Resistance of Advanced Steels to Reaction with High Temperature Steam as Accident Tolerant Fuel Cladding Materials," paper 3924 (Paper presented at Corrosion/2014, Houston, TX, 9–13 March 2014).