Oxide-Nanoparticle Containing Coatings for High Temperature Alloys

There is a significant need for materials with good mechanical strength including creep resistance along with oxidation resistance or other corrosion resistant properties for operation at high temperatures. For example, high temperature materials with good creep properties are needed for multiple applications across various industries such as in heat exchangers, radiant burner tubes, and hydrogen reforming tubes. In such applications, an increase in temperature capability of the materials used will result in increased energy efficiency of the associated processes thus resulting in energy and cost benefits. Ferritic/martensitic alloys can typically be used for temperatures up to about 625°C but fail to meet the required strength and oxidation/corrosion resistance requirements for higher temperatures. Oxide Dispersion Strengthened (ODS) ferritic alloys provide improved mechanical strength and corrosion resistance at temperatures up to and exceeding 1000°C and are a good candidate material for applications such as heat exchanger tubes, gas turbine chambers, ultrasupercritical reactors, and diesel engine components, and thus have immense potential to have significant impact on the energy intensive industries. However, widespread use of these alloys has been hampered by difficulties in processing. In fact, despite the excellent market potential, currently there are no commercial producers of these materials in the world due to processing difficulties.

There are two major factors related to the processing of ODS alloys:

1. Due to problems with agglomeration, non-uniform distribution of the strengthening nanophase oxide particles occurs in traditional solidification processing, and a solid-state process is used for the production, resulting in limited throughput along with directionality in properties.
2. Difficulties are encountered in retaining the fine distribution of nanoparticles during welding processes.

The objective of this nanomanufacturing concept definition study is to examine the feasibility of using Electromagnetic Stirring (EMS) techniques in dispersing the oxide nanoparticles uniformly within the liquid steel. Alternate techniques to agitate the molten pool will also be explored. Processing of both coatings and bulk materials will be subject of this work. Although the initial work is focused on applications to manufacture of ODS alloys, this technique has a wider application in processing and distributing nanoparticles in any liquid matrix and thus of significant importance to nanomanufacturing.

Electromagnetic stirring techniques have been adopted in the past for removing inclusions in steel and are known to affect the motion of particles in liquid steel. Thus, although the effect of electromagnetic forces on oxide particles in steel and its effect on removal of undesirable impurities and inclusions are known, it has not been applied for distributing nanoparticles within the liquid. This project will use a combination of computational models and experimental work to compare the distribution of nanoparticles in a solidified steel in the presence and absence of magnetic stirring combined with alternate agitation techniques. If this technology is successful, it will be marketed to various manufacturers of steels and specialty materials such as Carpenter Technologies, Special Metals, and Mittal Steel and funding will be sought from DOE and industrial partners with appropriate cost-share contributions to further the development of this technology.

A preliminary evaluation of the energy and cost savings has been performed with primary emphasis on heat exchanger applications. It is anticipated that this will constitute only a small fraction of the potential applications of materials produced using the new processing technique.

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