Development of Nanostructured Alumina-based Metal Matrix Functionally Graded Composite Coatings

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Abstract

Coatings are increasingly being used for material surface protection. Unlike many other techniques including fusion welding, cladding, and surface heat treatment, the development of coatings does not change the underlying substrate surface grain structure, as they are not exposed to melting and re-solidification, thereby changing the surface characteristics completely. The use of thermal spraying as a method to develop coatings is based on propelling feedstock powders into a high velocity combustion flame environment. The high kinetic energy of the particles leads to dense coatings due to formation of the particles in the plastic state. The conventional feedstock manufacturing involves spray drying and sintering of microcrystalline cermets. However, high-energy milling represents a low cost single step process to produce nanocrystalline composite feedstock. Moreover, many material combinations such as alumina do not permit a sintering process at sufficient temperature for compound particle densification. This study presents the results of synthesis and processing of nanostructured alumina-Ni(Cr) cermet particle in a cryogenic environment. The method of design-of-experiment is used to obtain samples of investigated nano-cermets. Results obtained from XRD, SEM/TEM and nanoindentation relating the particle interatomic bond breakage kinetics during the plastic deformation, formation and growth of crystal and re-crystallized structures, and stress relaxation during the alloying process are highlighted. Analytical models pertinent to milling and its applicability to estimate the size of particles in prepared nanocrystalline feedstock as a function of milling parameters are approached. The ultimate goal is the use of feedstock to develop functionally graded (FG) thermal sprayed coatings by gradually changing the coating material properties, namely the coefficient of thermal expansion (CTE) and elastic modulus. This will help to decrease the thermal/residual stresses generated between the coating and the substrate. Further, the optimization techniques based on genetic algorithm and heuristic method are used to adopt a general framework for optimizing the FG coating configuration for their high-temperature oxidation/corrosion behaviour simulation and analysis.

Keywords: Nanoparticles, High-energy mechanical alloying, Thermal spraying, Functionally-graded coatings, Microstructure characterization

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Introduction

Cermets are composites in which ceramic and metal bond together to deliver combination of material properties: ceramic reinforcement provides microhardenss and wear resistance and strength and fracture toughness coming from the metallic binder. Therefore, industries that require materials with great strength and flexibility as well as resistance to high temperature corrosion often use cermet coatings. Nickel-based alloys is widely used in the chemical plant, nuclear power plant, oilfield and turbine engine corrosive environments thanks to their favorable properties such as strength and ductility over a wide range of service temperatures and, especially, their superior corrosion resistance. On the other hand, aluminum oxide is widely known for its hardness, strength, and chemically inert nature. These attractive properties of alumina when combined with nickel-chrome based alloys have potential to produce surface protective coatings applicable for severe abrasion-corrosion environment. However, the challenge is how to synthesize the Al_2O_3-NiCr cermet particle at a nanometric scale that is flowable through the HVOF thermal spray process.

Fig. 1: (a) Union Process attritor mill used at CANMET Materials Lab, (b) enclosure to safely handle the alloyed powder

Recent work has shown that microcrystalline WC-Co system provides one of the most abrasive wear resistant coatings when used at low temperatures [1]. The use of nanocrystalline WC-Co can potentially increase the hardness and toughness of the coatings [2,3]. The novelty of this research is that there has never been an attempt to synthesize and process alumina-nickel-chrome based nanostructured cermets to develop HVOF thermal sprayed coatings with high temperature erosion-corrosion resistance properties in mind.

This research focuses on the high energy mechanical alloying (ball milling) of elemental Al_2O_3 and Ni(Cr) blends to obtain nanocrystalline composite particles through cold welding, fragmenting, and grain recrystallization of the feedstock.

Experimental Procedure/Results

As startup powder, a batch size composed of 595 g α-Al_2O_3 was added with 255 g γ-Al_2O_3 and 150 g NiCr alloy particles to obtain a cumulative total of 1,000 g composition. The α-Al_2O_3 was heated at 120^{o}C for 24 hrs to reduce the particle clump. The mixture was then put in a planetary mill (tumbler) for 30 minutes at 50 rpm starting at 1:20pm. This was to provide a more homogeneous solid solution before it went for mechanical alloying / milling.

The composite was introduced to a 2.5 gallon tank capacity Union Process attritor mill for grinding (see Fig. 1a). A timed grinding was established by setting up of desired number of cycles

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to 144. Each cycle was equivalent to a 10-minute run. It was decided to run a timed grind for 24 hrs, followed by an additional 24 hrs at 150 rpm continuous cycle. The designed agitator shaft speed (150 rpm) was obtained by programming 25.7 Hz on the VFD (variable frequency drive) keypad. 3/16 in diameter high chrome stainless steel ball at a ratio to charge (material) 10:1 was used as the milling media. 1 ml stearic acid as surfactant was added to the charge as the milling catalyst. During the processing, adequate nanomaterials handling techniques were made available (see Fig. 1b).

Samples of the milled material were collected at pre-designed time schedules and characterized under the SEM/EDX analysis.

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