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Wear Resistance and Surface Hardness of Carbon Nanotube Reinforced Alumina Matrix Nanocomposite by Cold Sprayed Process

Winarto Winarto[a,]* Dedi Priadi, Nofrijon Sofyan, Aji Wicaksono

[a]*Department of Metallurgical and Materials Engineering, Universitas Indonesia Kampus Baru — UI, Depok-16424, Indonesia*

Abstract

Carbon nanotube reinforced alumina matrix nanocomposite was fabricated by cold spray process on Al-Si alloys surfaces. The effects of various amounts of CNTs from 0, 2 and 4 wt % on alumina powders were investigated. Results show that the improvement in both wear resistance and hardness was provided by 2 wt. % CNTs reinforcement. The hardness of carbon nanotube reinforced alumina matrix nanocomposite was increased due to an enhanced load sharing of homogeneously distributed carbon nanotubes. Homogeneous distribution of CNTs within the Al_2O_3 matrix and strong interfacial connection between CNTs-Al_2O_3 give nanocomposites with superior wear properties.

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Keywords: Carbon Nanotubes; Nanocomposite; Cold Spray; Wear Resistance; and Hardness

1. Introduction

Cold spray (CS) belongs to a wide family of thermal spray technology with the difference that CS is a solid state process in which spray particles are deposited via supersonic velocity impact at a temperature much below the melting point of the spray material [1]. Cold spray has been applied for deposition of a wide range of materials for industrial protective wear coatings of components such as those used in automobile, power plant, and aerospace. Most of applications that use this method are within a thickness of coatings more than 50 µm [2].

Alumina (Al_2O_3) has been used in a wide range of applications such as in high speed cutting tools, chemical and electrical insulators, wear resistance parts and various coatings due to its high hardness and high thermal insulation properties. However, due to its inferior fracture toughness, alumina is not considered as a good candidate for advanced structural and aerospace applications. Various materials such as metals, ceramics and carbon fibers have been reinforced to improve the fracture toughness of monolithic Al_2O_3 and notable improvement was reported [3].

One of the reinforcement elements is carbon nanotubes (CNTs) that have attracted much interest in science and technology since its invention in 1991 [4]. Most of investigations have been focused especially on the mechanical characteristics of CNTs since CNTs with a tubular structure exhibit almost 5 times of elastic modulus (~1 TPa) and nearly 100 times tensile strength compared to high strength steels [5]. When multi-walled carbon nanotube (MWCNT), coated as nanocomposite on steel ball bearing by chemical method, increased the interlocking capabilities of the coating and acted as a solid lubricant, hence yielded a higher wear resistance than that of the ordinary ball bearings [6]. CNTs are also often applied as reinforcement in most of materials such as ceramics [7]. Therefore, it is expected that CNTs can upgrade the mechanical properties of Al_2O_3 and make it suitable for numerous advanced applications. Several investigators have shown their interest on CNTs reinforced alumina composites and consolidated by using different sintering processes, but results in a wide difference in the mechanical and physical

* Corresponding author. Tel.: +62-21-7863510; fax: +62-21-7872350
E-mail address: winarto@metal.ui.ac.id

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properties [8]. The main problems associated with the CNTs-ceramics nanocomposites are agglomeration of CNTs, inadequate densification and weak CNTs-ceramic interfacial connections [9]. It has also been reported that there were substantial improvement in the fracture toughness and other mechanical properties with low additions of CNTs (< 2 wt %); however, the higher CNTs additions give unsatisfactory results [10].

2. The object of the study

In this paper, the effects of various amounts of CNTs (0, 2 and 4 wt %) on the mechanical properties of Al_2O_3-CNTs nanocomposites such as hardness and wear resistance are presented. Furthermore, the structural features of nanocomposites and interfacial connections developed during the metal spraying process condition will be discussed.

3. Experimental Methods

3.1. Nanocomposites Coating by Cold Spray Process

Multi-walled Carbon Nanotubes (MWCNT) supplied by Cheap Tubes, Inc., USA with ∅ around 50 nm was used in this study. Non-agglomerated fully dispersed CNTs were prepared by mixing MWCNTs in aqueous dispersion medium. The dispersion medium used was polyethylene glycol (PEG) 4000 with the dispersing agent of dimethyl formaldehyde (DMF). After that, alumina powders having a particle mesh of 325±15 μm were mixed with the number percentage of dispersed CNTs and dry-milled using a planetary ball mill.

Before cold spraying process, as seen in Fig. 2(a), surface of aluminum AC4B cast was pretreated using a shot-blasting process and then cold sprayed by a bond coat of Ni-Al. Dried Al_2O_3/CNTs mixtures were then coated by cold spraying process onto the surface of aluminum AC4B and nanocomposites were finally obtained as can be seen in Fig. 2(b). Monolithic Al_2O_3 powder without CNTs was also cold sprayed under identical experimental conditions for comparison.

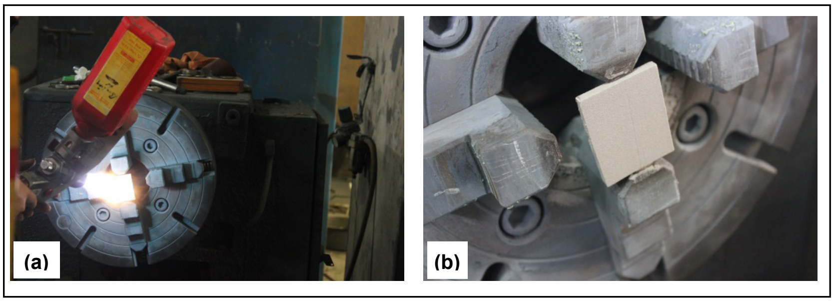

Fig. 1. Picture of (a) cold spraying process and (b) the sample of aluminum alloy coated by nanocomposites

3.2. Structural Characterization

Structural and chemical properties of nanocomposite coated samples were characterized by using scanning electron microscope (SEM/EDX, FEI Inspect F50). Some samples were also observed by SEM after wear tests to indentify the structural features of damage coating due to wear mechanism. In addition, the effect of adsorbed oil lubricants on nanocomposite coating was characterized by Fourier Transform Infrared (FTIR) spectroscopy.

3.3. Mechanical Properties Evaluation

Surface hardness of the coating was examined by using Vickers micro hardness. Wear resistance of nanocomposite samples was tested by using Ogoshi high speed universal wear testing machine. Wear resistance was tested by contacting flat specimen of nanocomposite sample against a 30 mm diameter of revolving disc with a load of 30 N, abrasion speed of 718 rpm. After the testing the samples were then examined under an optical microscope to measure the abraded area of the specimens.