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Development of a hard nano-structured multi-component ceramic coating by laser cladding

Manoj Masanta[a], P. Ganesh[b], Rakesh Kaul[b], A.K. Nath[a], A. Roy Choudhury[a,*]

[a] Department of Mechanical Engineering, IIT Kharagpur, West Bengal 721302, India
[b] Laser Material Processing Division, Raja Ramanna Centre for Advanced Technology, Indore, India

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ABSTRACT

The present paper reports laser-assisted synthesis of a multi-component ceramic composite coating consisting of aluminum oxide, titanium di-boride and titanium carbide (Al_2O_3–TiB_2–TiC). A pre-placed powder mixture of aluminum (Al), titanium oxide (TiO_2) and boron carbide (B_4C) was made to undergo self-propagating high-temperature synthesis (SHS) by laser triggering. Laser subsequently effected cladding of the products of SHS on the substrate. The effect of laser scanning speed on the hardness, microstructure and phase composition of the composite coating was investigated. The coating exhibited an increase in hardness and a decrease in grain size with increase in laser scanning speed. A maximum micro-hardness of 2500 $HV_{0.025}$ was obtained. X-ray diffraction (XRD) of the top surface of the coating revealed the presence of aluminum oxide (Al_2O_3), titanium di-boride (TiB_2) and titanium carbide (TiC) along with some non-stoichiometric products of the Ti–Al–B–C–O system. Field emission gun scanning electron microscopy (FESEM) and high-resolution transmission electron microscopic (HRTEM) analysis revealed some nano-structured TiB_2 and Al_2O_3, which are discussed in detail.

1. Introduction

Ceramic materials (e.g. oxides, carbides, nitrides and borides of metals), due to their exceptional hardness, excellent wear resistance and stability at high temperature, find extensive applications in surface modification and coating technology [1]. Hard ceramic composite coatings, involving such ceramic particles embedded in a metallic matrix can be used to provide high wear resistance to metal substrates.

High power lasers are emerging as efficient tools for the deposition of wear-resistant coatings. Laser surface coating technique is a fast process applicable on many engineering components without the requirement of elaborate support systems (e.g. ultra-high vacuum environment, etc.). High cooling rates attainable in laser processing gives rise to extremely fine-grained structures and improved mechanical properties [2]. Laser treatment, in most cases, also ensures strong metallurgical bonding between coating and substrate.

Laser surface modification [3–5], laser cladding [6,7], laser particle injection [8,9] and laser surface alloying of pre-placed powders [10–12] are some examples of laser-assisted coating processes that are recently being used for surface modification of various materials.

The process of laser coating of metallic substrates with pre-placed powders is primarily used as a research tool for testing of novel powder mixtures and for carrying out feasibility studies. Agarwal and Dahotre [2] applied laser surface modification to develop a 200 μm thick uniform and continuous composite coating, comprising of TiB_2 particles and Fe with a sound interface. A maximum knoop hardness of 1772 (load = 300 g) on AISI 1010 steel has been reported. Fe–Ti–B composite coating with TiB_2 as whiskers has been developed on austenitic stainless steel substrate by laser cladding with a powder mixture of B_4C and Fe–Ti alloy. The coating exhibited a maximum micro-hardness of 1300 $HV_{0.3}$ with high resistance to crack propagation [7]. Manna et al. [6] attempted to explore the feasibility of developing an amorphous layer of Fe–B–C, Fe–B–Si and Fe–BC–Si–Al–C on AISI 1010 steel by laser surface cladding for enhanced hardness and wear resistance of the substrate. The resultant specimens exhibited excellent wear resistance with micro-hardness up to 1150 $HV_{0.3}$. Babu et al. [10] investigated laser surface alloying with a mixture of stainless steel and titanium carbide powders on 1020 steel substrate. The treated specimens exhibited a micro-hardness of 670 $HV_{0.3}$. In addition, combined laser and sol–gel technology has been also used to prepare nano-structured metal matrix composite (MMC) coating of TiB_2–Fe_2B on steel substrate with a micro-hardness of about 1450 $HV_{0.1}$ [11].

From the review of the past research on laser surface modification techniques it has been found that the laser coating process is capable of producing metal matrix composites involving dispersion of hard ceramic particles in a relatively softer metal matrix.

* Corresponding author. Tel.: +91 3222 282970; fax: +91 3222 255303.
E-mail address: roychoudhuryasimava@gmail.com (A. Roy Choudhury).

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Due to the presence of the soft metal matrix, the maximum hardness of such laser-treated coatings is generally limited to about 1500–2000 HV. The properties of the laser surface modified region depend mainly on the chemical composition and microstructure resulting from melting and rapid solidification. In this connection, mention may be made of ceramic-matrix composites (CMCs) that have ceramic reinforcements (in the form of fibers or whiskers) inside a ceramic matrix. These reinforcements can enhance the value of fracture toughness of the composite. In addition, multi-component ceramic composite consisting of some nano-particulate phases, can also provide enhanced fracture toughness to the composite [13]. This raises the possibility of obtaining a coating of high hardness with high fracture toughness. Hence, the feasibility of multi-component ceramic coatings on metal substrates has generated considerable interest in surface science [14–16].

Al_2O_3, TiC and TiB_2 are refractory compounds that combine ceramic properties such as high melting point, high hardness, thermal and chemical stability, wear and corrosion resistance with metallic properties such as high electrical and thermal conductivity and low coefficient of friction. This advantageous combination can make these materials promising candidates as constituents of a multi-component protective coating with enhanced resistance against thermal, corrosion and mechanical wear.

Composite ceramic materials like Al_2O_3–TiB_2 [17], Al_2O_3–TiC [18], TiB_2–TiC [20–22], etc. have been developed by several research groups. Such developments resulted in the combination of properties in the products that are otherwise not available in a single ceramic material. Al_2O_3/TiB_2 ceramic cutting tools (prepared by hot pressing), due to their self-lubricating properties, exhibit substantial improvement in dry high-speed machining of hardened steel [17]. Al_2O_3/TiC ceramic composite, prepared by SHS followed by sintering (using TiO_2, Al and C as raw materials) Exhibit 17–20 GPa hardness along with high fracture toughness [18]. Dense nano-crystalline TiB_2–TiC composites formed by field activation from high-energy ball-milled reactants showed a micro-hardness of 20.6 GPa [19]. The same composite has also been synthesized by reaction sintering [20]. Self-propagating high-temperature synthesis (SHS), combined with pseudo hot isostatic pressing using Ti, B_4C and C as starting powder, produces TiC-TiB_2 ceramic composite with hardness in the range 85–93 HRA (Rockwell hardness in scale A) with high fracture toughness [21].

Laser-assisted or laser-triggered SHS has also been investigated by some researchers to obtain in-situ synthesis and coating of hard composite materials [22,23]. Self-propagating high-temperature synthesis (SHS) technique leads to the in-situ formation of refractory ceramic from reactants through exothermic reaction [24]. Compared to other processes, SHS has several advantages, such as high purity of products, rapid formation, and chemical inertness of the products to each other at high temperatures. Further, the need for a high temperature furnace processing is not mandatory for the process. [25,26]. Uniformly dispersed nano-particulate TiN–TiB_2–Al_2O_3 composite coating has been developed by laser-triggered SHS and subsequent laser alloying of the SHS products

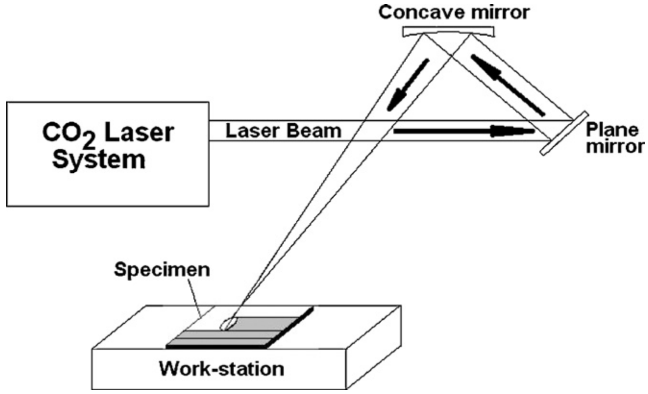

Fig. 1. Schematic illustration of experimental set-up.

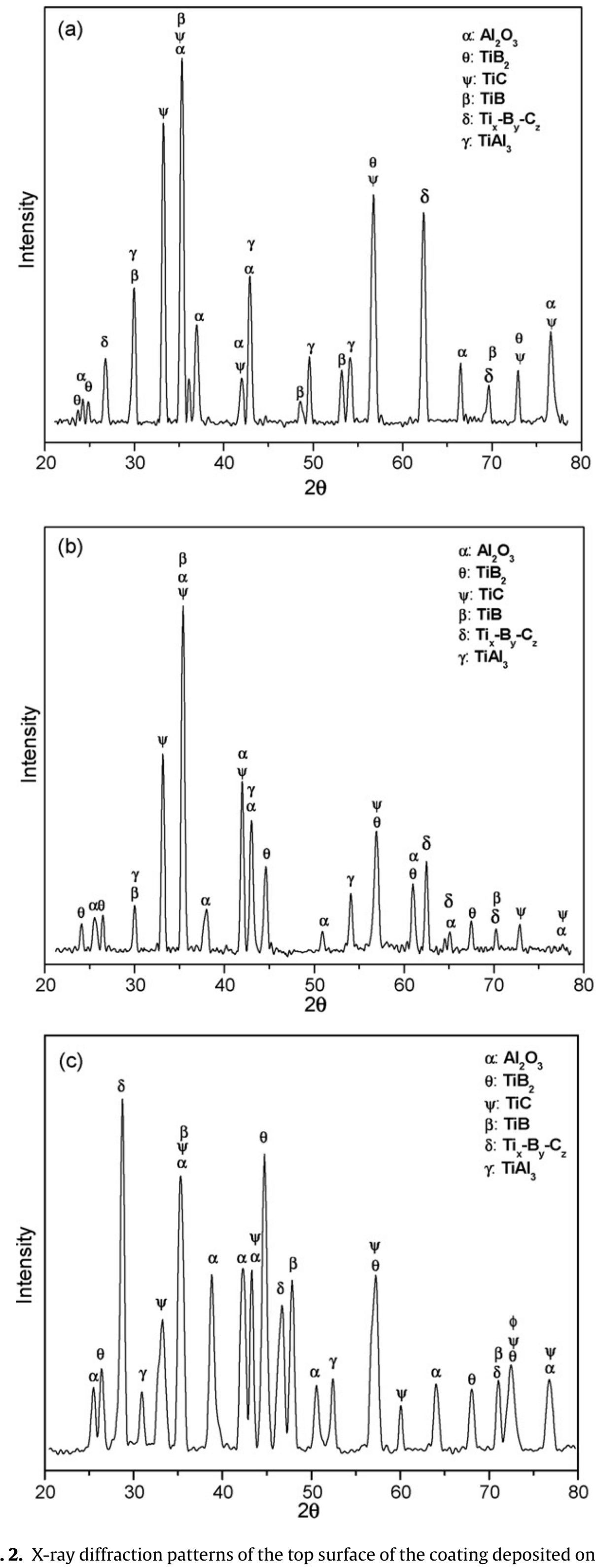

Fig. 2. X-ray diffraction patterns of the top surface of the coating deposited on mild steel substrate by laser power 2.5 kW and laser scanning speed (a) 2.5 mm/s (b) 5 mm/s and (c) 10 mm/s.