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Influence of SiC-Ti/Al on the Microstructural and Mechanical Properties of Deposited Ti-6V-4Al Alloy with Cold Spray Technique

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Abstract

Titanium alloy (Ti-6Al-4V) is widely used in aeronautical and biomedical industries owing to its wide variety of properties such as bio compatibility, corrosion and mechanical resistance. However, titanium is known to have low hardness and wear resistance properties required for aerospace applications. In this research, cold gas dynamic spray (CGDS) of titanium alloy with SIC-based cermet was studied and performed for improved surface properties. The characterizations of the fabricated coatings where obtained using the optical microscopy (OM), scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis. An investigation of various properties of coatings such as wear resistance and hardness was also carried. The microstructures of the coatings were constituted by phases such as SiC, Ti; SiC and SiC, Al. Experimental results indicated that the developed SiC based cermet coating contributed to improved properties in contrast to the untreated Ti-6Al-4V alloy. An improvement in hardness was attained in all the coatings with the best performing coating having a 120 % improvement. High hardness values were attributed to the percentage of SiC powder in the matrix branded by a combination of high hardness and wear properties.

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Keywords**:** Cold gas dynamic spraying CGDS, SiC-based cermets, hardness and wear.

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1. Introduction

Poor wear and hardness properties of Ti alloy Ti6Al4V has become a major concern for its wide variety of applications in spite its enormous bulk properties [1]. In recent years, carbides and metallic materials are used as metal matrix composite (MMC) coatings on various materials to improve the surface properties and performance in [1-2]. Furthermore, addition of other hard particles such as nitrites and borides in fabrication of (MMC) coatings can also significantly improve hardness and wear properties of engineering materials [2-3]. In this work, SiC cermet with enhanced mechanical properties was successfully produced starting from finely dispersed powder mixtures containing (SiC-5Al-5Ti, SiC-10Al-10Ti and SiC-15Al-15Ti). The cermet was prepared by mixing using planetary ball mill followed by (CGDS). The fabricated materials are heterogeneous compound materials containing SiC and lightweight corrosion resistant component - Al. SiC is known for high wear resistance, high hardness, high melting point and corrosion resistance, while Ti is useful where corrosion resistance, ductility and lightweight properties are required [3-4].

Over the past 10 years, enormous interest has increased in the cold spray technology and significant effort has been devoted to process the development for metals such as Ti and Al [4-5]. The CGDS technology uses high velocity jet at supersonic speed, the particles of 1-50 µm in size are accelerated within a supersonic gas stream towards the substrate [5] and as a result, particles will have the ability to deposit on the substrate to form a coating. One of the practical methods for metal coatings is the thermal spray techniques, such as plasma spraying and high velocity oxy-fuel (HVOF) [6]. In the thermal spray processes, a significant degree of melting of the feedstock powder occurs [7]. The melting in coatings results in high residual stress, crack formation, material oxidation, and phase transformation, which can all influence the physical, electrochemical, and mechanical properties of the coatings [8]. The CGDS is a recently developed spraying technique which was initially developed at the Institute of Theoretical and Applied Mechanics in Russia in the mid-1980s [9]. In contrast to the thermal spray technologies, powder melting is relatively absent and kinetic energy is the primary driving force of powder consolidation and adhesion to the substrate [9-10]. The relatively low temperatures involved in cold spray increases the possibility of retaining the microstructural, and properties of the feedstock [14]. Different materials such as metals, ceramics, composites and polymers can be deposited using CGDS, creating a wealth of interesting opportunities towards harvesting particular properties [11]. CGDS is a novel and promising technology to obtain surface coating, offering several technological advantages over thermal spray since it utilizes kinetic rather than thermal energy for deposition. As a result, tensile residual stresses, oxidation and undesired chemical reactions can be avoided [12].

Limited studies on titanium alloy (Ti6V4Al) coatings consolidated by cold spray have been performed, and cold spray deposition SIC-based cermets has so far not been studied and investigated to a higher degree. Therefore, the purpose of this work is to employ CGDS process to increase the mechanical properties of Ti6V4Al using different powder compositions of Ti, SiC and Al. The wear and hardness properties of titanium alloy are known to be very low. Thus, the objective of this study is to improve the mechanical properties of titanium alloy Ti6V4Al.

2. Experimental details

Starting materials of titanium alloy Ti6V4Al, powder blend of 70SiC + 15Ti +15Al, 80SiC + 10Ti + 10Al, 90SiC + 5Ti + 5Al and coarse Al_2O_3 were initially prepared.

Table 1. Temperature and premixed ratios of starting powders

Powder Constituents	Powder ratio (%)	Temperature(°C)
SiC-Ti-Al	90-5-5	500
SiC-Ti-Al	80-10-10	500
SiC-Ti-Al	70-15-15	500

Very fine powders (sizes range of 45-90 µm) and pure (>99%) from (Centerline, Windsor, Canada) of Ti, SiC and Al were screened before and after blending for a specific size of -53µm. The premixed powder ratio of SiC-Ti-

Al composite was thereafter mixed using planetary ball mill of high Ni-Cr steel balls as mixing media. The planetary ball mill was operated at a vial rotation and disc speed of 300 rpm for 30 mins to avoid possible temperature increase and cold welding [8] in a stainless steel bowl of 500 ml. Coatings of SiC-Ti-Al were achieved on the Ti6Al4V by (CGDS) at 0.99 Mpa and constant temperature of 500 C. The substrate materials of (Ti6Al4V) cross sectioned to (35 x 35 x 5 mm^3) and composition: 6 wt% Al, 4 wt%V , 0.15 wt% Fe, 0.007 wt% C, 0.005 wt% N and a balance of Ti were used. The substrate was initially grit blasted using -300+100 µm Alumina grit (Centerline SST-G0002). The parameters for the coatings deposition where selected according to the study by [2] which are: P=0.99, T=500 C, feed rate setting 30 %, V= 3 ms^{-1}. For Ceramic materials to be successfully coated it is required to have a higher pressure, hence the LPCS was adjusted to a maximum working pressure of (0.99 Mpa). The optical microscope was used to study the microstructure of the cold spray deposited coatings. With the aid of the optical microscope the images were magnified and furthermore, microstructures at a higher magnification were determined using scanning electron microscopy (SEM) technique. The phases in the coating where successfully determined by x-ray diffractometry XRD technique. The CETR tribotester was used for the sliding wear analysis. In this test method, a spherical tungsten carbide (WC) ball with a diameter of 10mm was used to slide against the surface of the coating. The specimens (ball and sample) moved relative to one another in a linear back and forth sliding motion under a load of 20N, with a reciprocating frequency of 20Hz and a sliding distance of 2000 mm for a period of 17 minutes. A vertically downward load is applied through the ball specimen against the horizontal mounted flat specimen while coefficient of friction is measured simultaneously with the sliding of the ball for all samples. The volume loss or wear was expressed by Archard’s wear equation:

$$V = \frac{KLx}{H} \tag{1}$$

Where V is the wear volume, k is the wear coefficient, List L applied load and x is the sliding distance H being the hardness of the sample.

3. Results and discussion

Fig. 1 shows the SEM images of the titanium alloy (Ti-6Al-4V) with microstructure characterized by alpha and beta phases (α and β), and starting powders of (b) Ti (c) Al and (d) SiC

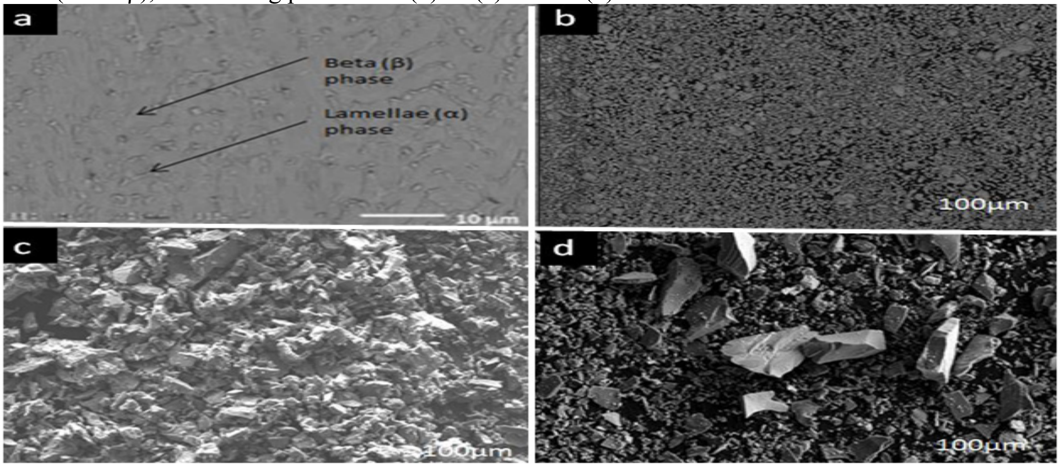

Fig. 1: (a) SEM Micrograph of uncoated Ti-6Al-4V Alloy Substrate and starting materials, (b) Ti Powder, (c) Al powder (d) SiC powder.

3.1. Microstructure and Phase Evolution of SiC-Ti-Al coating on Ti6Al4V substrate

From Fig. 1 SEM micrographs, the morphology of the coated samples can be observed and a common feature of all studies is that no phase transformation, alloying, or onset of thermite reaction (on reactive materials) occurred during cold spray deposition. Presence of ceramic (SiC) particles in feedstock showed several advantages with reinforcement of the coating by advancement of a densification and composite structure of the coating and also contributes to improvement of process stability. Coated samples had promising results obtaining dense coating, entrapping more hard particles in the coating and decreasing hard particle fragmentation. The microstructural images of the cross section of the deposited coatings were taken at different places of interest of the coating to understand the microstructure and the distribution of SiC-Al-Ti within the coating. As a result of different cold spray processing parameters mainly, powder composition of Ti, SiC and Al, the quality of the deposited coatings varied in terms of microstructural homogeneity, hardness and wear rate.

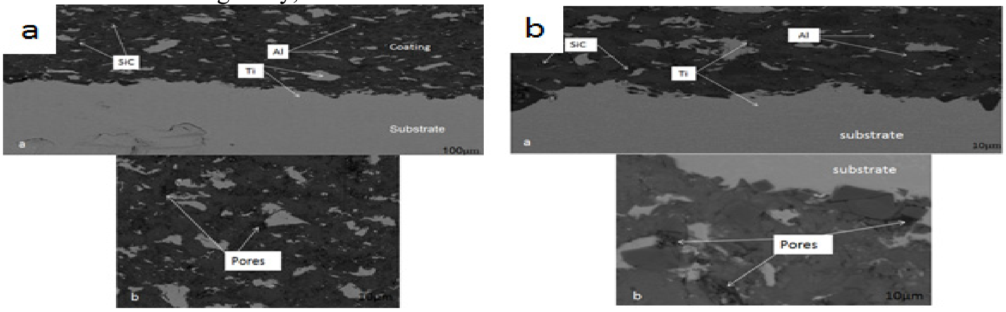

Fig. 2: (a) SEM showing the morphology of the cold spray deposited Sic-15Al-15Ti powder matrix and (b) SEM showing morphology of cold spray deposited SiC- 5Al-5Ti.

Fig. 2(a) shows distribution of the coating constituents, in contrast to fig. 2 (b) it can be observed that the coating with adequate amount of SiC (SiC-5Ti-5Al) shows numerous pores along the coating. However, the hardness of the coatings improved significantly. The cracks may have been as a result of fracture mode change from adhesive to cohesive by increasing the hard phase percentage in ductile matrices, as previously reported by [13]. This may also be due to an increase in the number of weak bonds along the matrix and reinforcement particles. Furthermore, in the case of relatively hard matrices, the reinforcement particles can enhance the plastic deformation and increase the cohesion strength by reducing the porosity. Most often, significant attention is given to increasing the amount of hard particles in the final coating unaware of its possible disadvantages. Optimization principles are crucial consideration for each specific application. Moreover, the differences in material properties of matrix and reinforcement particles are likely to affect the final results of the obtained coating.

3.2. XRD analysis

XRD results recorded for the SiC-15Ti-15Al coating, in the range 2θ from 20˚ to 90˚ is shown in Fig. 3. There are intermetallic phases identified in the coating Ti-SiC, Ti-SiC, SiC-Al, SiC-Al together with the main peaks of Ti-SiC. The elemental Ti peaks were not observed indicating that the Ti and SiC powders reacted with each other to form Ti-SiC cermet phases. The existence of the SiC peaks is attributed to the abundance of SiC in the coating matrix of 70% SiC powder. The main peaks for the Ti-SiC (B19') phase occur at 2θ = (38.25˚, 39.49˚, 45.85˚). A broad peak at 2θ = 48.7˚ is identified as the Ti, SiC (B2) phase.

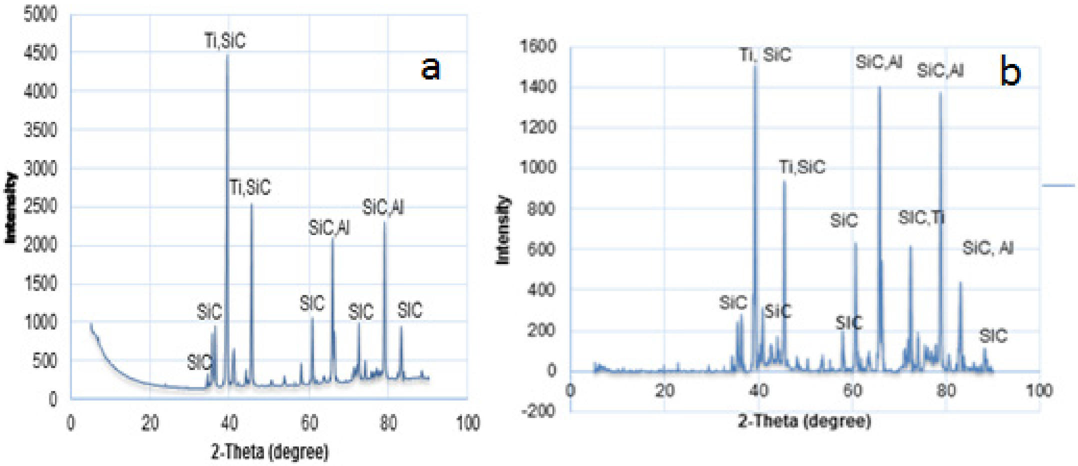

Fig.3: XRD of sample cold sprayed with premixed ratio of (a) 70SiC-15Al-15Ti and (b) 90SiC-5Ti-5Al

3.3. Hardness and wear analysis

Hardness results recorded for the matrices SiC-5Ti-5Al, SiC-10Ti-10Al and SiC-15Ti-15Al are reported in Fig. 4(a). Fig. 4(b) shows that the wear resistance of the substrate was improved only in the matrix SiC-15Ti-15Al and SiC-5Ti-5Al, as a result of lower friction coefficient. Wear just like corrosion and oxidation resistance is a surface phenomenon primarily determined by the surface properties rather than bulk properties [12]. In wear analysis, temperature and friction coefficient are very important parameters in identifying the wear mechanism experienced by the material. Results from previous work reveal that a higher content of reinforcement particles does not necessarily lead to a higher hardness [1]. Also, there was a report that even though the hardness increases by increasing the hard phase in the coating, the wear properties decreased because of a wear mode change. Besides, increasing the reinforcement particle content of the coating could also change the fracture mechanism. Fig. 4 (a) shows the hardness values of each powder matrix and depicts that an increase in the amount of SiC increases with hardness values.

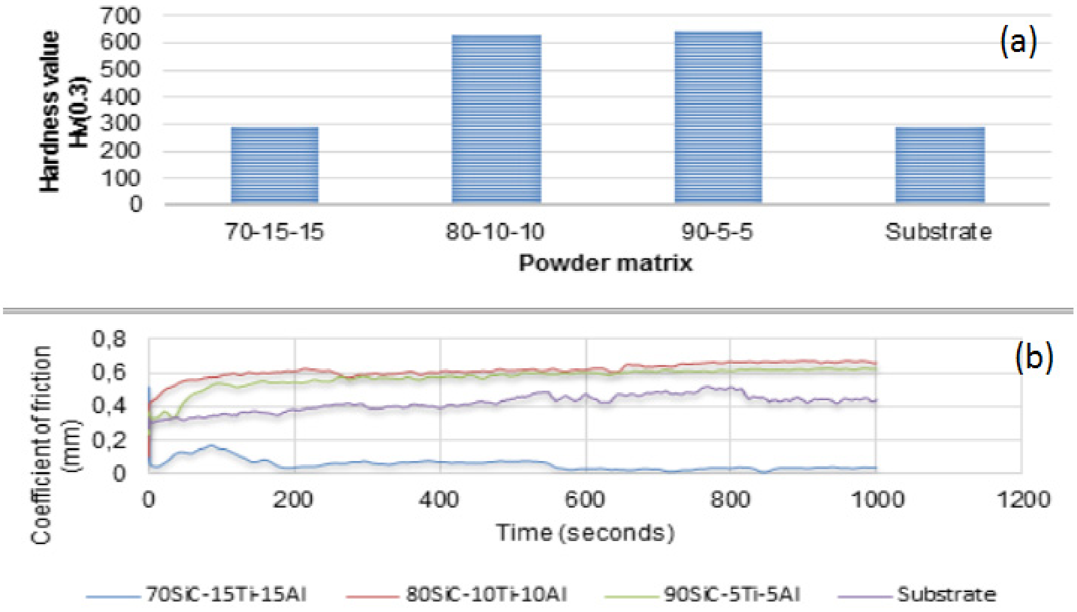

Fig.4. (a) Hardness values Against Powder Matrix and (b) Wear Rate of the Cold Sprayed Ti-6Al-4V coating.

4. Conclusion

Hardness property of the deposited coating is dependent on the microstructure and various phases formed during deposition. Wear resistance is mainly dependent on the hardness of the coating. High hardness values leads to low co-efficient of friction which results in low wear rate. Thin surface coatings of SiC-Ti-Al were successfully deposited on Ti-6Al-4V substrate. An improvement in hardness properties was achieved in all the deposited SiC-Ti-Al coatings and showed significant improvement when compared to the untreated substrate.

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