Journal of Materials Processing Tech. 262 (2018) 551–561

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

journal homepage: www.elsevier.com/locate/jmatprotec

NiTi coating on Ti-6Al-4V alloy by TIG cladding process for improvement of wear resistance: Microstructure evolution and mechanical performances

Dipak Tanaji Waghmare, Chinmaya Kumar Padhee, Ritesh Prasad, Manoj Masanta*

Department of Mechanical Engineering, National Institute of Technology Rourkela, Rourkela, 769 008, India

ARTICLE INFO

Keywords:
NiTi alloy
TIG cladding
Ti-6Al-4V alloy
Microstructure
Wear resistance

ABSTRACT

A thick layer of Ni_XTi_Y (NiTi and $NiTi_2$) was deposited on Ti-6Al-4V alloy by tungsten inert gas (TIG) cladding process using Ni and Ti powder mixture prepared by ball milling route as precursor. The analysis shows that the microstructure of the produced NiTi coating principally governs by the heat input, which was controlled through the employed processing current. The hardness of the NiTi clad layer measured by Vickers micro-indentation method was found reasonably higher as compared to Ti-6Al-4V alloy substrate. The XRD and EDS analysis of the clad layer revealed the formation of NiTi and $NiTi_2$ as major phases along with some unreacted Ti and $TiAl_3$ intermetallic. The sliding abrasive wear of the coating performed against abrasive disc shows upto 9.5 times reduction in the wear value as compared to the uncoated Ti-6Al-4V alloy as measured by its height loss. The experimental results revealed an ample effect of the TIG current on the hardness value and wear characteristic of the clad layer, which is predominantly dependent on the morphology and percentage of phase constituent formed. The produced NiTi coating has prospective applications in biomedical, where inadequate wear resistance of Ti-6Al-4V alloy is the major concern for its use.

1. Introduction

Nickel-Titanium alloys (NiTi) have received attraction as a functional and structural material owing to its specific properties, i.e. shape memory effect, superelasticity, high damping capacity, low stiffness, and high fatigue strength. In addition, as suggested by Elahinia et al. (2016), the material possesses high corrosion resistance and admirable cavitation erosion resistance in combination with its excellent biocompatibility. Thus, NiTi alloy became one of the most suitable materials for the components or parts used in corrosion and erosion environment i.e. nuclear, aviation, mining and naval industry. Besides, NiTi alloy is also applied for use in orthopedic implant, where both corrosion and wear are major concerns. Despite its attractive properties, as demonstrated by Lin et al. (2000), applications of NiTi restrained in bulk component owing to its high cost and poor machinability. Additionally, fabrication of NiTi parts is also challenging due to its high reactivity and processing difficulties. Hence, according to Man et al. (2006), NiTi should be used as cladding material rather than in entire component.

Several research groups have attempted the NiTi cladding on various graded steel through various cladding routs including tungsten inert gas (TIG) and laser cladding methods. Among these, laser cladding method found most promising method to fabricate a thick layer attributed to formation of strong bonding with the substrate and controlled dilution ratio. Cheng et al. (2004) deposited NiTi coating by melting of NiTi wire on the AISI 316 steel substrate using high power Nd:YAG laser. Through continuation of the work Chiu et al. (2005a) revealed that the produced coating exhibited hardness value in the range of 600–1000 HV and the cavitation erosion of the clad layer enhanced upto 29 times than that of AISI 316 L steel. In addition, Chiu et al. (2005b) fabricated NiTi layer by melting NiTi strip (0.2 mm thick) on AISI 316 L steel by laser cladding process, which exhibited microhardness value upto 750 HV. In addition, NiTi alloy was deposited on various graded Ti alloy by laser surface alloying routes. Mokgalaka et al. (2015) deposited NiTi intermetallic coatings on Ti-6Al-4 V alloy by melting of Ni and Ti powder mixture (at different ratio) through laser metal deposition process. The analysis revealed the presence of NiTi, $NiTi_2$ and $NiTi_3$ intermetallic phases those are responsible for enhanced corrosion resistance of the coating. To improve the high-temperature oxidation resistance of TA2 titanium alloy, Liu et al. (2016) deposited gradient NiTi coating on it by laser cladding method. It was revealed that presence of NiTi, $NiTi_2$, $NiTi_3$ intermetallic compounds enhanced the hardness value of the clad layer (upto 720 HV) significantly as compared to the substrate material (158 HV).

Although laser cladding was successfully employed to deposit NiTi layer on various types of structural material, it is wide open that high

* Corresponding author.
E-mail address: masantam@nitrkl.ac.in (M. Masanta).

https://doi.org/10.1016/j.jmatprotec.2018.07.033
Received 24 January 2018; Received in revised form 23 June 2018; Accepted 27 July 2018
Available online 29 July 2018

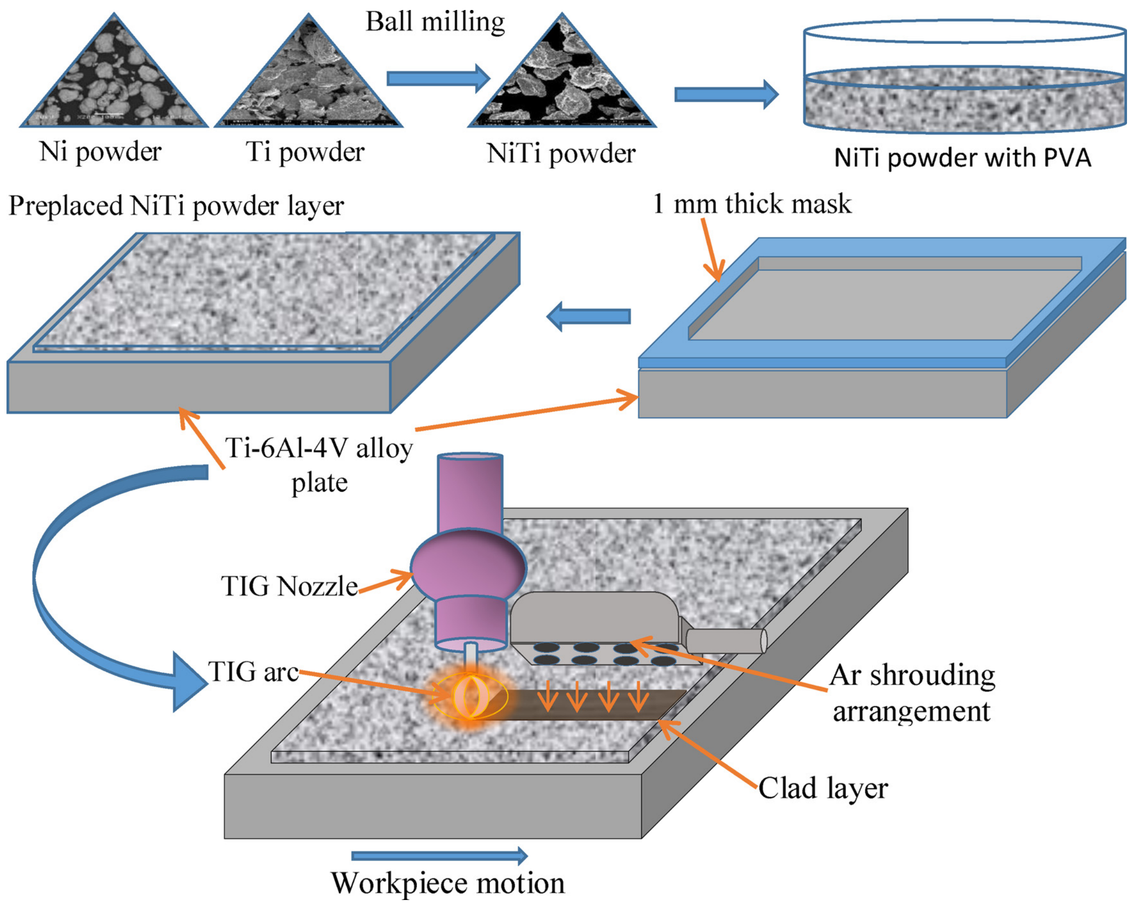

Fig. 1. Flow diagram for present TIG cladding process and schematic of experimental setup.

equipment cost and operating complexity of laser cladding method made the process quite uneconomical in specific cases. On the contrary, owing to low cost and simplicity, TIG cladding is an alternate and emerging method to produce thick wear and corrosion resistance coating on various structural materials. Cheng et al. (2003a) fabricated NiTi cladding on AISI 316 stainless steel by the tungsten inert gas (TIG) surfacing method. The clad layer shows hardness value more than 700 HV, which is considerably higher than that of AISI 316 steel (200 HV). Cheng et al. (2003b) also revealed that the cavitation erosion rate of NiTi clad layer is significantly lower (more than 9 times) than that of AISI 316 and the corrosion resistance in NaCl solution is comparable to AISI 316 steel. Although laser cladded NiTi layer exhibited higher erosion resistance than TIG cladded layer, Chiu et al. (2005b) demonstrated that for both the cases indentation properties and superelastic behavior of the clad layer retained almost similar to that of typical austenitic NiTi alloy.

Ti-6Al-4V alloy is a structural material used in aerospace and biomedical industries thanks to its high specific strength and bio-compatibility. However, Weng et al. (2015) suggested that relatively low hardness of Ti-6Al-4 V alloy restrained its application where sliding wear against a hard counter-body is the foremost concern. Furthermore, Mokgalaka et al. (2015) showed that due to a potential difference of $\alpha + \beta$ phase and formation of vanadium oxide, under specific condition, the corrosion behavior of Ti-6Al-4V alloy is also a major concern for specific applications. Henceforth, amendment in the surface characteristic of Ti-6Al-4 V alloy becomes indispensable for its prolonged use in severe wear and corrosive environment. An et al. (2017) accomplished surface modification of Ti-6Al-4V by TIG cladding method by depositing TiB_2/Ti-6Al-4V composite coating, which shows the potential of the process to improve the surface properties of Ti based alloy. Recently, Tijo et al. (2018) deposited TiC-TiB_2 composite coating on Ti-6Al-4V by TIG cladding method through in-situ reaction of reactant powder mixture, and attained remarkable improvement in hardness and wear resistance of the substrate.

Based on the recent literature, it is revealed that NiTi alloy has extensive potential to work in corrosion environment. Additionally, higher hardness of the NiTi alloy coating as compared to Ti-6Al-4V alloy, improves its wear resistance significantly. Although several researchers attempted to develop NiTi coating on various graded steel by laser surface modification technique, no specific work emphasizes on the deposition of NiTi coating by TIG cladding process, specifically on Ti-6Al-4V alloy. The present investigation is an endeavor to deposit a thick NiTi clad layer on Ti-6Al-4V alloy by TIG cladding method to enhance its surface mechanical properties. The Effect of TIG current on the formation of the clad layer, its microstructure, and mechanical properties, i.e. micro-hardness and sliding wear characteristic were analyzed in-depth.

2. Experimental procedure

Ti chips obtained from turning operation of pure Ti bar and commercial Ni powder (Make: Loba Cheme, particle size- 74 μm) were used to prepare Ni-Ti powder mixture. The Ti chips were first cleaned in ultrasonic bath submerged in acetone for 1 h, to remove the contamination acquired during the turning process and then ball milled in a planetary ball mill within toluene for 1 h using high chromium steel ball. After 1 h milling, when the Ti chips transformed in to fine flake like structure, specific amount of Ni powder was added in the mill and run for another 1 h, so that Ti flakes and Ni powder blended homogeneously and produces Ni-Ti powder mixture. The solution of produced Ni-Ti powder mixture (with toluene) was then dried at room temperature for 48 h to attain dry powder mixture by evaporating the