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Microstructure and tribological behaviour of TiC-Ni-CaF_2 composite coating produced by TIG cladding process

Chinmaya Kumar Sahoo, Manoj Masanta *

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

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ABSTRACT

TiC-Ni-CaF_2 self-lubricating composite coating has been deposited on AISI-304 steel substrate by TIG cladding process using powder mixture of TiC, Ni and CaF_2. Effect of CaF_2 percentage in the precurser has been emphasized for metallurgical and mechanical characteristic of the produced coating. Owing to the fluxing effect of CaF_2, heat accumulation in the coating zone augmented and solid lubricant behaviour of CaF_2 improved the tribological properties of the coating. SEM and EDS analysis of the coating revealed that processing current and CaF_2 percentage in the precursor have a significant influence on the microstructure and corresponding mechanical properties of the coating. Based on the heat input, which is synergic effect of processing current and CaF_2 content, dilution of the coating material in steel matrix altered and consequently the microhardness and corresponding wear properties of the coating varied. Sliding abrasive wear test performed against alumina abrasive disc show that wear rate of the composite coating expressively governed by the processing condition of the coating. Further, to assess the coefficient of friction (COF) of the coating sliding wear test have been performed against hardened steel disc, which clearly exhibited that with the increase in CaF_2 percentage in the precursor, COF significantly reduced.

1. Introduction

Hard carbide/ceramic reinforced metal matrix composite (MMC) coatings are well recognized for their superior wear resistance and enriched fracture resistance. Katipelli et al. (2000) demonstrated that TiC is a preferred reinforced material in composite coating owing to its high hardness, high melting temperature, thermal stability, and relatively low coefficient of friction. Earlier, TiC reinforced Co, Ni or Fe based MMC coating was successfully fabricated by various researcher utilizing laser cladding and TIG cladding methods and significant improvement in the surface hardness and wear resistance of the coating has been reported. Nevertheless, frictional force or COF value of these MMC coatings are high enough due to the presence of a metallic binder. It is anticipated that tribological properties of MMC coatings can be improved with the assimilation of CaF_2, in consequence of its specific properties as described.

Liu et al. (2013) shown that among the solid lubricants, organic alkali fluorides (LiF_2, CaF_2, BaF_2), metallic-disulfides (MoS_2, WS_2) are favorable owing to their low density, low shear strength, stable thermo-physical and thermo-chemical properties at a higher temperature in combination with their low cost. A recent study by Yan et al. (2013) revealed that CaF_2 is a well- known and widely used solid lubricant, utilized in self-lubricating ceramic composites for the anti-wear and anti-frictional application. The authors also demonstrated that CaF_2 has a lamellar structure with low shear strength, which prevent adhesion wear for the composites and assist in tribochemical reaction to facilitate a reduction in wear. Additionally, its high chemical stability at elevated temperature and inertness against reinforced materials like TiC, constrained to produce any undesired new phases in the composite/composite coating. Yan et al. (2012) further revealed that CaF_2 can be used as flux material and enhances the fluidity of melt-pool when employed in laser coating process. Experimental analysis of Muthuraja and Senthilvelan (2015) revealed that incorporation of CaF_2 significantly enhanced the tribology properties of the composites even at room temperature by reducing the frictional force against metallic counterpart.

Jeng and Soong (1993) revealed that accumulation of Ag and BaF_2-CaF_2 solid lubricants with Cr_3C_2-NiAl coating produced by laser cladding method, reduces the COF value from 0.38 (Cr_3C_2-NiAl) to 0.23 (Ag/BaF_2-CaF_2 Cr_3C_2-NiAl). CaF_2-Al_2O_3 ceramic matrix composite coating produced by Wang et al. (2002) on Al_2O_3 substrates through laser cladding process also indicate that

* Corresponding author.
E-mail addresses: manoj.masanta@gmail.com, masantam@nitrkl.ac.in (M. Masanta).

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addition of CaF_2 reduces the COF value from 0.6 to 0.48 and enhances the wear resistance 29 times compared to only Al_2O_3 coating. Ouyang et al. (2001) through their experiments revealed that CaF_2 effectively act as a solid lubricant, and COF value of ZrO_2-CaF_2 composite coating produced on AISI304 stainless steel exhibited significant improvement in wear resistance and frictional characteristics compared to the uncoated base material. Yan et al. (2012, 2013) prepared Ni-Cr/TiB_2/CaF_2 and Co-based alloy/TiC/CaF_2 composite coatings on Cr-Zr-Cu alloy by laser cladding process and revealed that both the coatings exhibited lower COF value and superior wear resistance up to 400 °C temperature. Liu et al. (2009b) during deposition of NiCr-Cr_3C_2-CaF_2 self-lubricant composite coating on TiAl by laser coating process revealed that friction coefficient reduced to 0.25 from 0.45 (NiCr-Cr_3C_2 coating) and wear resistance of the coated substrate improved up 33 times as compared to NiCr-Cr_3C_2 coating (5times). Liu et al. (2009a) through their analysis revealed that fine isolated spherical shaped CaF_2 particles uniformly dispersed in NiCrAlTi matrix of the Ni-Cr-C-CaF_2 layer produced on γ-TiAl substrate by laser cladding process. The average micro-hardness value of the composite coating found nearly two times higher than the TiAl substrate. Liu et al. (2013) also revealed that NiCr/Cr_3C_2-WS_2-CaF_2 composite coating fabricated on austenitic stainless steel by laser cladding process exhibits excellent tribological performance at 300 °C temperature. Due to the presence of solid lubricants (WS_2, CaF_2), frictional coefficient of the coating reduced to 0.29 as compared to the base material (0.37).

Effect of CaF_2 as self-lubricant in plasma spray coating was also studied by various research groups. Huang et al. (2009) revealed that NiCr/Cr_3C_2/BaF_2-CaF_2 coating fabricated by plasma spray technology, exhibited superior tribological properties at elevated temperature, due to physical and chemical resemblance between the BaF_2-CaF_2 and the matrix materials as well as fine and dense microstructure of the composite coating. Cai et al. (2013) demonstrated that graphite/CaF_2/TiC/Ni-base alloy composite coating prepared by plasma spray method diminished the COF of the composite coating by 53%, and improved the wear resistance by 70% as compared to pure Ni-base alloy coating.

Ouyang et al. (2005) revealed that COF value of the self-lubricating $ZrO_2(Y_2O_3)$-CaF_2 composite produced by spark-plasma-sintering method reduces significantly for incorporation of CaF_2. Jianxin et al. (2006) demonstrated that with the additions of CaF_2 as a solid lubricant in Al_2O_3/TiC ceramic cutting tool, the coefficient of friction at the tool–chip interface reduces significantly during dry machining of hardened steel and cast iron. Study of Muthuraja and Senthilvelan (2015) showed that addition of limited quantity CaF_2 in Co based WC composite fabricated by sintering process could improve its wear resistance properties by reducing the coefficient of friction from 0.4 (without CaF_2) to 0.24.

Review of literature depicted that reduction in coefficient of friction attained in composite coatings produced by laser cladding, plasma-spraying route, or in the bulk composite component fabricated by means of different sintering methods after incorporating CaF_2 as a solid lubricant. However, hardly any effort was made so far to produce a hard and wear resistance composite coating by incorporating solid lubricant, especially CaF_2 via tungsten inert gas (TIG) cladding route. Furthermore, analysis on the effect of CaF_2 percentage in the composite coating on its mechanical and tribological properties is also rare. Very recently, Peng and Kang (2015) produced TiC-BN composite coating on AISI 1020 steel by TIG cladding process, where BN act as a solid lubricant, and reduces the COF value of the coating as compared to TiC coating, and consequently improved the wear resistance property of the coating. Being an economical method to produce a hard and wear resistance overlay coating, it is pertinent to study the effect of CaF_2 in the TiC-Ni coating produced by TIG cladding process.

Sahoo et al. (2016) and Sahoo and Masanta (2017) in their earlier work developed TiC and TiC-Ni composite coating on AISI 304 steel substrate by TIG coating process and discussed its various metallurgical and mechanical aspects with respect to the processing condition. In this phase of work TiC-Ni-CaF_2 composite coating has been produced on AISI 304 steel substrate by TIG cladding process. It is expected that with the incorporation of CaF_2 in TiC-Ni composite system, along with the reduction in COF value, owing to fluxing effect coating layer could be deposited on the substrate with relatively low heat input. The effect of different percentage of CaF_2 on the formation of the coating as well as their mechanical and tribological properties has also been analyzed. The macrostructure of the coating morphology, as well as the performance of the coating produced at various TIG current condition, and with different percentage of CaF_2 has been analyzed in terms of wear resistance and frictional resistance.

2. Experimental procedure

The current research work utilized ground AISI 304 stainless steel plates of $100 \times 45 \times 8\,mm^3$ as substrate material to deposit TiC-Ni-CaF_2 composite coating by TIG cladding process. At first the surface of steel plates was polished with 220 grade SiC emery paper and then cleaned with acetone. TiC (average particle size ~2–5 μm), Ni (average particle size ~74 μm), and CaF_2 powders (average particle size ~10 μm) were used as precursors mixture to create a preplaced layer on the AISI 304 stainless steel substrate surface. At first TiC and Ni powder mixed in 1:1 weight ratio, and then 5, 10, 15 and 20 wt.% CaF_2 powder added with TiC-Ni powder mixture separately to make precursor containing different percentage of CaF_2. These precursor powders were then mixed with a polyurithin based organic binder and a specific quantity of acetone to make a semi-solid solution. The paste-like solution then dispersed uniformly on the steel substrate and dried at room temperature for curing the binder. The thickness of the preplaced layer was maintained by using the appropriate amount of powder mixture required to cover the surface of the substrate. Thus, approximately 350 ± 20 μm thick preplaced layer was produced on the substrate surface, as measured from the difference in thickness of the substrate before and after the preplacing of powder layer using a Vernier calliper.

A Fronius A-4600 (Magic Wave 2200) welding machine attached with a tungsten inert gas (TIG) torch consisting a 2.4 mm diameter tungsten-thoriated electrode was used for the present experimentation. The gap between the preplaced powder layer and tungsten electrode was fixed at 3 mm to maintain a uniform arc throughout the experiment. Ar shrouding gas was used with a flow rate of 10 l/min and negative polarity i.e. direct current electrode negative (DCEN) was considered for all the experiments. The TIG torch was fitted with a speed-controlled linearly moving trolley. Table 1 indicates the processing condition for deposition of TiC-Ni-CaF_2 coating on AISI 304 steel substrate using preplaced TiC/Ni/CaF_2 powder mixture. For the present work, the scan speed of the heat source kept fixed and TIG welding current considered as 60, 80 and 100 A for each type of preplaced mixture. The TIG heat source or arc was scanned over the preplaced steel substrate that resulted in melting of the preplaced powder mixture and a thin layer of the substrate underneath the coating layer. Fig. 1 shows the schematic diagram of TIG cladding process by powder preplacement method. After performing the TIG coating, the samples were cut at the transverse direction of arc scanning by using wire-EDM for further analysis. The cross section of the samples was metallurgically polished with different graded SiC emery paper followed by final polishing with diamond paste (average size: 1 μm) suspended polishing cloth. The SEM (JEOL, JSM-6084LV) analysis at the cross section of the coat-