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On the modeling of dry sliding adhesive wear parameters of vanadium additive iron-based alloys at elevated temperatures

Yogesh Kumar Singla, D.K. Dwivedi, Navneet Arora *

IIT Roorkee, Roorkee, Uttarakhand 247667, India

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ABSTRACT

In this paper, three different vanadium additive iron based hardfacing alloys were developed using shielded metal arc welding process with pre-placement technique — a newly developed approach to produce hardfaced coatings. The influence of the increased vanadium content on the hardness and dry sliding adhesive wear characteristics of alloys was investigated. A reciprocating wear test rig was used to study the effect of load and temperature on the alloys having variation in their vanadium content using a full factorial design of experiment approach. The increased vanadium content was found to be beneficial to enhance the macrohardness and adhesive wear resistance of the vanadium additive alloys in comparison to the non-vanadium additive alloy with no evidence of cracks or porosity. A significant reduction in weight loss of alloys containing higher vanadium content was observed from the main effect plots. Based on the significance of interactions, the regression equation was developed and validated with a number of test cases. The optimization of the control factors was also performed using a multi-response optimization technique. The confirmatory tests carried between the predicted and the experimental results exhibited the accuracy of the optimized input variables within ±4.63% against an output of 0.007 g.

1. Introduction

Vanadium is known to be a strong grain refiner and the hardening element. Its addition has shown that vanadium rich carbides give excellent results in enhancing the wear resistance [1]. Vanadium carbide has the ability to obtain finely dispersed precipitates [2]. Moreover, the strength of vanadium carbides is about three times that of iron carbide [1]. Vanadium has the property to form granular carbides that can decrease the carbon content in the matrix which gives rise to increased toughness [3]. The increased matrix toughness ensures better embedding of hard phases, necessary to improve the wear resistance. Zumgarh [4] has also stated that both hardness and toughness are the important parameters that can greatly enhance the wear resistance. Otherwise, the cracks may induce which causes the carbides to remove at a faster rate during wear.

Several wear studies have been conducted on iron based alloys using a combination of various alloying elements and their percentages. In recent years, much attention has been paid to the utilization of the rare earth elements (CeO_2 and La_2O_3) due to their favorable effect on the mechanical, metallurgical and tribological properties [5–9]. Most of the tribological studies are focused on investigating the abrasive wear behavior of the modified hardsurfacings [3,10–21]. Researchers have performed both uni-directional [22–25] and bi-directional [26–27] adhesive wear testings using either block-on-ring or pin-on-plate test setups. An extensive use of iron based hardfacing alloys for high temperature applications has also been reported where galling resistance is of prime importance [28–32]. Among all the wear testing parameters (load, counter surface, sliding distance, sliding speed) that can be varied, sliding distance gained much more attention than any other wear parameter in most of the studies, either adhesive or abrasive. Each parameter has its own influence on the wear behavior and varied on the basis of the application under which the surface is subjected to. For example, the vanadium additive materials having typical applications in steel rollers, hammer, jaw, rotor (in crushing industry) made of high speed steels, the load and temperature are the two major influencing factors. Very few studies are available in which authors have shown the effect of more than one parameter on the wear behavior of alloys [29,32]. However, no literature is available on modeling the reciprocating dry sliding adhesive wear parameters using the full factorial approach. Previous studies showed the effect of vanadium content variation on the microstructure and wear resistance of weld surfacings at room temperature only [33]. But, no one has ascertained the effect of high temperature on the dry sliding wear behavior of vanadium additive iron based alloys.

The intent of the present study is thus to determine the reciprocating dry sliding adhesive wear behavior of 0, 0.6 and 1.5 wt.% vanadium additive alloys and to develop a regression model. A full factorial approach was followed to determine the influence of temperature, load and wt.% of the vanadium on wear loss. The significance of each

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* Corresponding author.
E-mail address: navneetroorkee@gmail.com (N. Arora).

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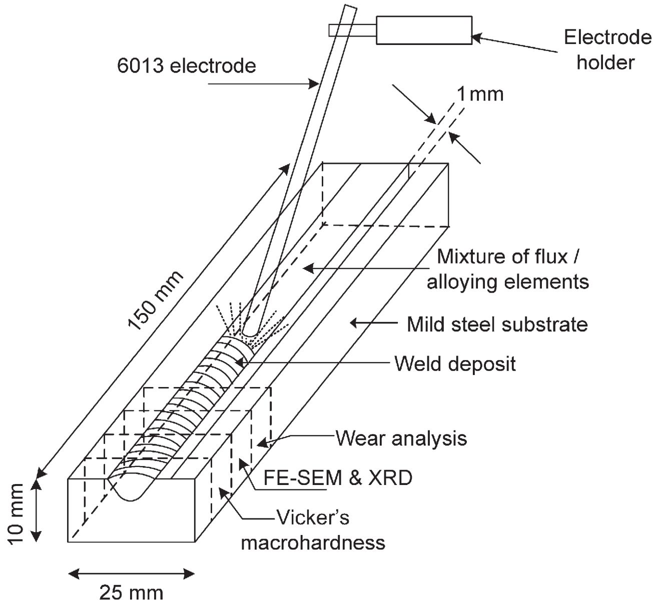

Fig. 1. Schematic of pre-placement technique and analytical positions used for various testings.

control factor was analysed through the main effect plots which were developed from the experimental values. The regression equation of the model was also developed and to optimize adhesive wear characteristics, multi-response optimization was done.

The weld surfacings were developed using the elemental pre-placement method in which shielded metal arc welding (SMAW) process was used to incorporate the alloying elements into the weld deposits. The effect of increased vanadium content on hardness variation has also been investigated and an attempt has also been made to correlate the hardness and wear properties of alloys.

2. Experimental details

A mild steel plate having dimensions 150 × 25 × 10 mm was used as a substrate material. The alloying elements (in the form of ferro-alloys) were transferred into the weld deposits via pre-placement technique (Fig. 1). The chemical composition of as received ferro-alloys is presented in the Table 1.

Prior to the placement of alloying elements onto the substrate, all the elements were baked at a temperature of 200 °C for 2 h and then mixed together properly to obtain a uniform mixture. The dry mixture of elements was then placed onto the mild steel substrate with a thickness of 1 mm as depicted in Fig. 1. To obtain hardfaced weld deposits, a rutile type E6013 electrode having a diameter of 3.15 mm was moved onto the placed elements using shielded metal arc welding process. Before welding, the electrodes were also baked at a temperature of 200 °C for 2 h. The shielded metal arc welding parameters used are as follows: AC 175 A, arc voltage 20–25 V and welding speed 3–5 mm/s. In the present investigation, as hardfaced weld deposits have been obtained with the single layer deposition process, therefore, the effect of dilution (the percentage of base metal in the weld metal deposit) cannot be neglected. The metallurgical effect of dilution is to reduce the amount of carbon and carbide forming elements in the weld deposit, which reduces the hardness and wear resistance. In order to calculate the dilution level, the macrograph of the hardfaced weld deposit was visualized using the low magnification stereoscope (Fig. 2).

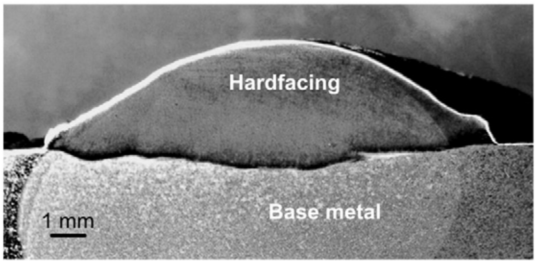

Fig. 2. Macrograph of hardfaced weld deposit.

The calculated dilution level of the hardfaced weld deposit was approximately 19%. The dilution level is considered to be more or less the same for all the specimens, as the heat input was kept constant throughout experimentation. Further, it is recommended that to minimize the dilution levels, either use more than one layer deposition process or employ the buffer layers between the substrate and the hardfaced weld deposit.

In order to study the effect of vanadium addition on hardness and wear characteristics of alloys, the weight percentage of the vanadium was varied from 0 to 1.5 wt.%. The chemical composition of weld beads was measured with an Optical Emission Spectrometer (OES) and is shown in the Table 2.

3. Characterization techniques

For microstructural characterization, the transverse sections were obtained through the cutting operation and specimens were metallographically prepared using the standard polishing procedure followed by the cloth polishing. The specimens were then etched with Villela's reagent prepared from one part of HNO_3 (nitric acid), two parts of HCl (hydrochloric acid) and three parts of glycerol. After etching, all the specimens were examined under FE-SEM (Field Emission Scanning Electron Microscopy) to analyse the distribution of the carbides. To determine the type of carbides, XRD (X-ray diffraction) analysis was carried in the angle range of 10° to 120°. The presence of carbides was also confirmed by the EDS (energy dispersive spectroscopy) analysis.

The Vickers macrohardness testing was performed in the welded region at 5 kg load, which was kept constant for all the specimens. The average of 10 readings has been reported to examine the effect of increased vanadium content on the macrohardness of alloys.

To determine the wear characteristics, the specimens of size 8 × 8 × 10 mm were obtained from the welded region and held against a quenched high speed tool steel plate (counter surface) of size 65 × 150 × 14 mm having a hardness of 70 HRC (Rockwell hardness on C scale). A standard and recommended ASM (American society for metals) procedure was used to heat treat (quench) the tool steel followed by annealing, stress relieving, hardening, stabilizing, and finally tempering [34]. The chemical composition of the counter surface (tool steel M2 grade) is shown in the Table 3. Prior to wear, both the specimen and the counter surface were polished with a silicon carbide abrasive paper to achieve a surface roughness of R_a 0.3 μm which was

Table 1
Weight percentage of various elements contained in as received ferro-alloys.

Elements	Cr	Si	C	S	P	V	Nb	Al	Fe
Fe–Cr (wt.%)	66–70	1.5 max.	7–10	0.04	0.03	–	–	–	Balance
Fe–Si (wt.%)	–	45–50	0.10 max.	0.02 max.	0.04 max.	–	–	–	Balance
Fe–V (wt.%)	–	1.5 max.	0.10 max.	0.05 max.	0.05 max.	50 min.	–	1.0 max.	Balance
Fe–Nb (wt.%)	–	–	0.15 max.	0.05 max.	0.10 max.	–	60–70	–	Balance