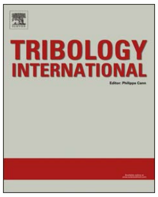
Tribology International 105 (2017) 229–240

Contents lists available at ScienceDirect

Tribology International

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



# Dry sliding adhesive wear characteristics of Fe-based hardfacing alloys with different $CeO_2$ additives – A statistical analysis

Yogesh Kumar Singla[a,b,*], Navneet Arora[a], D.K. Dwivedi[a]

[a] Mechanical and Industrial Engineering Department, IITR, Roorkee 247667, Uttarakhand, India
[b] Mechanical Engineering Department, Maharishi Makandeshwar University, Sadopur, Ambala 134007, Haryana

## ARTICLE INFO

*Keywords:*
Hard coating
Wear
Scanning electron microscopy
Surface modification

## ABSTRACT

In the present investigation, four different rare earth (RE) additive iron-based hardfacing alloys were prepared by the shielded metal arc welding process with pre-placement technique. The objective was to examine the effect of dry sliding wear parameters and to develop a statistical regression model using full factorial approach. A regression equation was developed and validated with a number of test cases. The morphology of worn surfaces and corresponding wear debris was studied in order to examine the wear mechanism using SEM. The RE additive alloys exhibited a significant improvement in macrohardness and wear resistance. The microstructure was refined at first and then coarsened with the increase of RE additions. The optimal amount of RE was found to be 4 wt%.

## 1. Introduction

Several wear studies have been conducted on iron based alloys using a combination of various alloying elements and their percentages. Most of the tribological studies are focused on investigating the wear behavior of the Fe-Cr-C based hardfacings [1–5]. Researchers have performed both uni-directional [2–7] and bi-directional [8,9] wear tests using block-on-ring, dry sand rubber wheel tester and pin-on-plate testing machines. An extensive use of iron based hardfacing alloys for high temperature applications has also been reported where galling resistance is of prime importance [10–14]. Fe-Cr-C hardfacings are known as one of the wear resistance materials with excellent comprehensive property and are widely applied in mineral processing, metallurgy, and machinery industries [15]. In recent years, rare earth (RE) elements have gained much importance due to their excellent grain refining properties. The refinement in grain structure is generally achieved by the tendency of the rare earth elements to promote more number of nucleation sites with fine particles of inclusion. Most commonly rare earths being used are cerium oxide and lanthanum oxide in the form of oxides [15–24]. It is well known that the RE element is very active and gets readily oxidize even in the air. Therefore, it is impractical to use directly into the hardfacing layer [24]. Besides, the excessive burning of RE element during hardfacing and the low transition coefficient are one of the reasons for using RE oxide in lieu of RE element [19]. Previous investigations have shown the positive effect of cerium addition on the microstructural, mechanical and tribological properties. Yang et al. [23] studied the effect of cerium oxide and lanthanum oxide on growth dynamics of the primary austenite grain in hardfacing layer of medium-high carbon steel. Hao et al. [18] investigated the influence of cerium oxide on the morphology of carbides in hardfacing metal of high chromium cast iron. Shule et al. [2] presented the effect of different amounts of ceria aimed at understanding its effect on the abrasive wear behavior of Fe-Cr13-Mn-Nb hardfacing alloy. Zhang et al. [25] found the microstructural and corrosion resistance properties of cerium oxide additive of TiC-VC reinforced Fe-based laser cladding layers. Fu et al. [26] improved the qualities of Fe–V–W–Mo alloy rolls by changing eutectic structure from network carbides to spheroidized carbides with the cerium oxide addition and suitable heat treatment. Zhang et al. [27] have studied the effect of cerium and lanthanum oxide on the microstructure of plasma clad Fe-based alloy coatings in order to offer an experimental basis to expand a more promising application field of rare earth. Apart from the cerium oxide, researchers have also used yttrium and lanthanum oxide to investigate the effect of RE on the microstructural properties of iron-based alloys [16,17,19,24]. Very few researches have been carried to analyze the wear behavior of RE additive iron based alloys and that too are on the abrasive [2,15,20,21] and erosive wear [22]. No one has ascertained the effect of RE additive iron-based alloys on the dry sliding adhesive wear behavior. Therefore, it is of great significance to investigate the adhesive wear properties of rare earth additive iron based alloys. In our preliminary work, three vanadium additive hardfacings were developed by the pre-placement method, in which, the

---

[*] Corresponding author.
*E-mail address:* yogesh12360@gmail.com (Y.K. Singla).

http://dx.doi.org/10.1016/j.triboint.2016.10.015
Received 24 February 2016; Received in revised form 11 July 2016; Accepted 9 October 2016

microstructure of the hardfacings was refined with the increase of vanadium and enhanced the adhesive wear resistance of newly developed alloys [28]. However, the proper amount of grain refining element (vanadium) was not studied in details. Since both RE and vanadium are known to refine the microstructure of the materials, therefore a vanadium free hardfacing alloy (Fe-18Cr-1.1Nb-2.1C-0V) has been selected for rare earth modification.

In this investigation, the effect of cerium oxide addition was studied on the dry sliding adhesive wear behavior of hardfaced Fe-18Cr-1.1Nb-2.1C alloy. A full factorial approach was followed to determine the influence of temperature, load and wt% of cerium oxide on the wear behavior of hardfacings, A mathematical regression equation of the model was developed and validated with a number of test cases. An attempt has also been made to correlate the adhesive wear characteristics of hardfaced alloys with microstructural variations, hardness and morphology of worn surfaces and wear debris. The aim of this paper is to optimize the RE amount in order to attain enhanced wear performance and to make a comparison between the experimental and statistical results.

## 2. Experimental details

The deposition of hardfaced weld beads was carried on the low carbon steel (mild steel) plates having dimensions 15×25×10 mm$^3$. Weld deposits were obtained via pre-placement technique as shown schematically in Fig. 1. In pre-placement technique, the mixture of alloying elements (in the form of ferro-alloys) to be incorporated into the weld deposits was placed onto the mild steel substrate with 1 mm thickness. Prior to this, all the elements were mixed properly in a V-shaped rotating drum mixer. After placing the elements, a rutile type E6013 electrode (3.15 mm diameter) was moved using the shielded metal arc welding process. 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.

A total of four alloys were developed by varying the weight percentage of $CeO_2$. The chemical composition of weld beads was measured with an Optical Emission Spectrometer (OES) and is listed in Table 1.

## 3. Characterization techniques

### 3.1. Microstructure of hardfaced alloys

Microstructural investigations were carried on the transverse sections. A standard polishing procedure was adopted to prepare the metallographic specimens. The specimens were then etched with Villela's reagent made 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 an optical microscope to analyze the grain structure. In order to determine the type of carbides, XRD (X-ray diffraction) analysis was carried in the angle range of 10–120°.

Field emission scanning electron microscopy was also carried to study the morphology of worn surfaces and corresponding wear debris.

### 3.2. Hardness measurements

The macrohardness tests were performed using a Vicker's macrohardness tester at a constant load of 5 kg. The readings reported in the present investigation are the average of 10 values.

### 3.3. Adhesive wear tests

The wear characteristics of hardfacings were determined in the welded region having 8 mm diameter as per ASTM G99-05 standard and 10×10 mm$^2$ (width and height) base material for holding purpose. The specimen was held against a quenched high speed tool steel plate (counter surface) of size 65×150×14 mm$^3$ having a hardness of 70 HRC (Rockwell hardness on C scale). The heat treatment (quenching) of the tool steel plate was performed using a standard and recommended procedure followed by annealing, stress relieving, hardening, stabilizing, and finally tempering [29]. Table 2 shows the chemical composition of the counter surface (tool steel M2 grade). In order to minimize error in the wear loss, both the specimen and the counter surface were polished against an abrasive paper (silicon carbide) of 600 grit size to a surface roughness value of $R_a$ 0.3 µm. The specimens were then cleaned with acetone and weighed on an electronic weighing balance having a least count of 0.1 mg. The wear tested specimens were again weighed to measure the weight loss. A total of three replicate tests were performed to obtain reliable experimental values and average values have been reported.

A pin-on-plate reciprocating wear test rig was used to investigate the tribological characteristics and is shown in Fig. 2 along with its schematic in Fig. 3.

From Figs. 2 and 3, it is seen that lever arm loading system was used to apply load on the specimen using the dead weights at a set value of parameters. A fixture assembly was utilized in which a trolley stand holding the tool steel plate was designed in such a way so that the trolley could move freely in to and fro motion. A slider crank mechanism attached to the DC (direct current) motor having the speed range of 0–1000 rpm (revolutions per minute) was used to move the trolley in guide ways against the stationery specimen. In order to study the effect of temperature on tribological properties of hardfacings, a press fit element (iron press plate) was placed beneath the tool steel plate. The voltage fluctuations, which could damage the heating coil were controlled by utilizing a voltage regulator. A digital temperature controller having a provision of automatic on and off supply was attached to the press fit element so that a set value of temperature could be maintained while performing the wear tests. The accuracy of temperature was ensured by online measurement (through the digital temperature controller) during experimentation.

The details of reciprocating adhesive wear testing parameters are listed in Table 3.

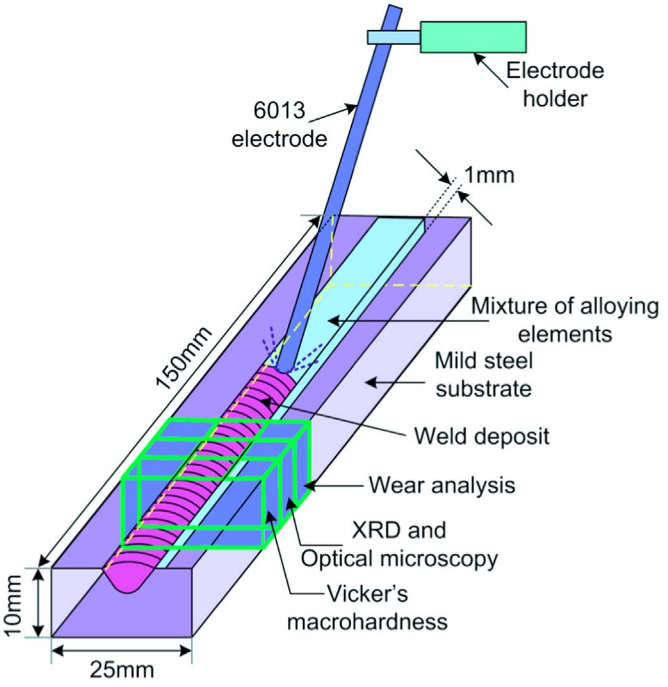


**Fig. 1.** Schematic of pre-placement technique with analytical positions used for characterization.