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The effect of Ta substitution for Nb on the microstructure and wear resistance of an Fe-Cr-C hardfacing alloy

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ABSTRACT

The effect of Ta substitution for Nb on the microstructure and wear resistance of an Fe-Cr-C hardfacing alloy deposited with gas tungsten arc welding (GTAW) process was investigated. Results showed that the microstructure of the base composition was a hypoeutectic one consisting of primary austenite dendrites and eutectic constituents of $\gamma + M_7C_3$. Addition of Nb did not change the hypoeutectic nature of the microstructure. However, coarse semi-cuboidal NbC was formed in the microstructure. Moreover, compared with the base composition, higher eutectic content and finer austenite dendrites were observed as a result of Nb addition. Ta substitution for Nb has changed the microstructure from hypoeutectic to hypereutectic containing primary hexagonal M_7C_3 carbides in an eutectic matrix along with coarse semi-cuboidal TaC particles. Hardness test results revealed that the hardness value increased by the addition of Nb or Ta. Maximum hardness value was obtained from Ta-containing coating. Reciprocating wear test results were directly related to the hardness of the hardfacing alloys. Hence, Ta-containing coating exhibited a superior wear resistance mainly due to the formation of primary hexagonal M_7C_3 carbides and coarse TaC precipitates. As well, Scanning Electron Microscopy (SEM) of the worn surfaces revealed evidences of abrasive and delamination wear mechanisms.

1. Introduction

Wear is one of the most important factors controlling the performance and service life of many engineering structures. In that sense, hardfacing is a solution to overcome the wear problem and expand the life time of industrial parts [1]. In terms of the chemical composition, materials used for hardfacing depositions are basically Fe-, Co- or Ni-based alloys. Among iron-based hardfacing alloys, various compositions of Fe-Cr-C alloy systems have found many applications due to their adequate wear resistance and cost-effectiveness [2,3].

Hardface coatings can be deposited using different forms of materials including wires, coated electrodes, pastes and powders. Powder hardfacing provides more flexibility to achieve the preferred composition by selecting an appropriate combination of powders. The use of gas tungsten arc welding (GTAW) process for the deposition of powder mixtures has some advantages including clean deposits and minimal dilution with the base metal. Therefore, many studies have been conducted on powder hardfacing using GTAW process [4–8].

Buytoz et al. [8] have studied the effect of heat input on the composition and microstructure of Fe-Cr-C hardfacing layer deposited on AISI 4340 steel using ferrochromium powder melted by GTAW process. They observed two types of microstructures depending on the carbon content of the coatings. A hypoeutectic microstructure containing primary austenite dendrites and M_7C_3 eutectic carbides was formed in the coatings that contained less than 4 wt% carbon. On the other hand, by increasing the carbon content beyond 4.5 wt%, a hypereutectic microstructure containing M_7C_3 primary carbides and eutectic constituents was formed. Addition of strong carbide-forming elements such as Nb, V and W; to the composition of Fe-Cr-C hardfacing alloys can further enhance wear resistance of the material due to the formation of MC carbides uniformly distributed in the microstructure [3]. Also, Chung et al. [9] investigated the influence of Nb addition on a hypereutectic Fe-Cr-C alloy system with nominal chromium and carbon content of 25 and 4 wt%, respectively. They concluded that the final microstructure evolved from hypereutectic to eutectic and hypoeutectic with increasing niobium content. This was explained to be a result of carbon decrement in the melt due to the Nb carbide (Nb_4C_3) formation. Moreover, fine distribution of Nb_4C_3 led to the superior hardness and wear resistance of the eutectic microstructure.

Tantalum, like niobium, is a strong carbide former that promotes the formation of MC-type carbide. Hence, for some applications niobium is replaced by tantalum. However, this substitution can affect some microstructural features such as the primary phase formed during solidification along with the amount and distribution of phases formed after solidification [10,11]. There is little information about the effect of Ta substitution for Nb in Fe-based hardfacing alloys. Hence, this paper

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Table 1
Chemical composition of the substrate (wt%).

C	Mn	Si	S	P
0.162	0.694	0.158	0.016	0.010

Table 2
Nominal composition of hardfacing coatings (wt%).

Sample	Fe	Cr	C	Nb	V	Ta
1 (Fe-Cr-C)	70	25	5	–	–	–
2 (Fe-Cr-C-Nb)	63	25	5	7	–	–
3 (Fe-Cr-C-Nb-V)	62	25	5	7	1	–
4 (Fe-Cr-C-Ta)	63	25	5	–	–	7

addresses the effect of Nb replacement by Ta on the microstructure and wear resistance of an Fe-Cr-C hardfacing alloy deposited on a plain low-carbon steel.

2. Materials and methods

Plain low-carbon steel samples with the dimensions of 200 × 120 × 10 mm^3, and chemical composition given in Table 1, were used as the substrate material in this study.

The aim was to deposit hardfacing coatings with the nominal base composition of 70 wt% Fe, 25 wt% Cr and 5 wt% C. Nb or Ta and V were added to the base composition in the amounts of 7 and 1 wt%, respectively. Table 2 shows the nominal compositions of the hardfacing coatings. Iron, ferrochromium, ferroniobium, ferrovanadium, tantalum and graphite powders were used to obtain the desired chemical compositions. The powders with specified weight ratios were mixed by a digital mixer for 15 min at a speed of 400 rpm. The pastes obtained from mixing 45 g of each of the mixed powder with 0.2 wt% of binder and 5 ml of distilled water were applied on the substrates. The applied layers had the dimensions of 200 × 20 × 1 mm^3. Finally, to vaporize the binder and water, the samples were dried in an oven at 120 °C for 2 h.

Manual GTAW process with the parameters specified in Table 3 was used to melt the hardfacing layer. The coating process was carried out in 2 steps. After melting of the first layer of the dried paste, the second paste layer with the same dimensions as the first layer was applied. It was then dried and deposited on top of the first layer. Fig. 1 shows the cross section of Fe-Cr-C coating (sample 1) as an example of the deposited coatings.

For microstructural studies, optical and scanning electron microscopy were conducted on the samples etched with Vilella's reagent which included 5 ml HCl, 1 g picric acid and 100 ml ethanol. Scanning electron microscopy was carried out by a MIRA3 TESCAN field emission scanning electron microscope (FESEM) equipped with an energy dispersive spectrometer (EDS). The microstructural images presented in this paper were taken using backscattered electrons (BSE) detector. For phase identification, X-ray diffraction (XRD) was carried out on top surface of the hardfaced layers using Cu Kα radiation.

Table 3
Welding parameters.

Polarity	DCEN
Current (A)	120
Voltage (V)	10–12
Arc length (mm)	3
Electrode	W-2%Th
Electrode diameter (mm)	2.4
Electrode tip angle (degree)	20–30
Welding speed (cm/min)	5
Shielding gas	Ar
Gas flow (lit/min)	10

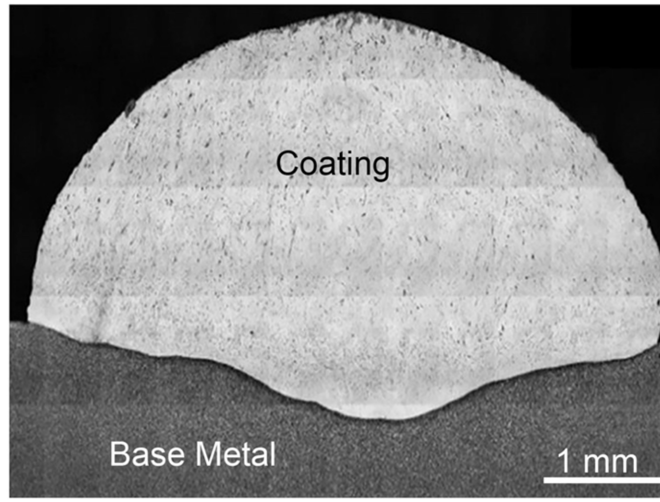

Fig. 1. Cross-section of Fe-Cr-C coating.

To evaluate hardness, Rockwell C hardness tests were performed in different zones of hardfaced layers. Micro-Vickers hardness tests with a load of 300 g were used to measure the hardness of the coarse Ta and Nb carbides.

Room-temperature dry-sliding reciprocating wear test was performed according to American Standard for Testing Materials (ASTM) G133. A bearing steel (with the hardness of 64 HRC) was used against the hardfaced layer under a normal load of 90 N for sliding distances up to 1000 m and at an oscillating frequency of 2 Hz. The results were presented as weight loss vs. sliding distance curves. Furthermore, some worn surfaces were investigated by FESEM using secondary electrons (SE) detector to determine the wear mechanisms.

3. Results and discussion

3.1. Microstructure

The hardfaced layers consisted of three distinct microstructural zones; namely: zones I, II and III. Fig. 2 shows these three zones in the

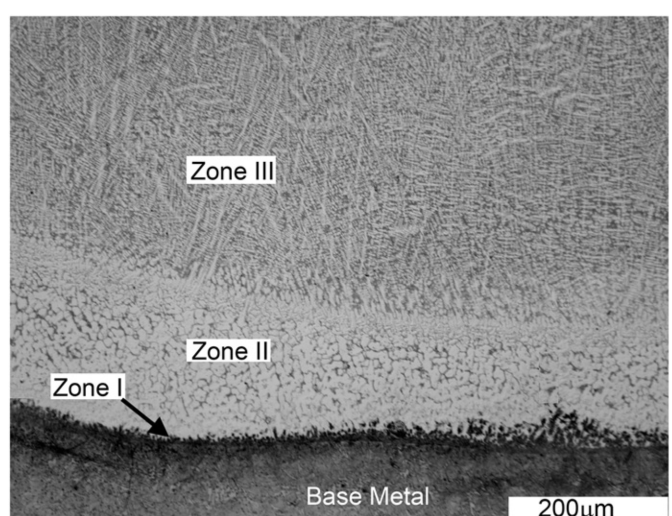

Fig. 2. Optical microscopy of sample 2 representing three distinct zones.