Surface & Coatings Technology 203 (2009) 976–980

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Fabrication of multiple carbide particles reinforced Fe-based surface hardfacing layer produced by gas tungsten arc welding process

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ARTICLE INFO

Article history:
Received 28 May 2008
Accepted in revised form 9 September 2008
Available online 23 September 2008

Keywords:
Multiple carbides
Gas tungsten arc welding
Wear properties
Surface hardfacing layer

ABSTRACT

In this paper, a multiple carbide particle reinforced Fe-based surface coating has been in situ synthesized by gas tungsten arc welding (GTAW) melting a precursor mixture of graphite, ferrotitanium (Fe–Ti) and ferrovanadium (Fe–V) alloy powders on AISI 1020 steel substrate. The microstructure and wear properties of the Fe-based surface hardfacing layers were investigated by means of a scanning electron microanalysis (SEM), X-ray diffractometer (XRD) and wear tester. The results showed that (Ti,V)C multiple carbide particle and TiC carbide particle can be synthesized via reaction of Fe–Ti, Fe–V and graphite during GTAW melting process. The selection area diffraction pattern (SADP) analysis indicated that (Ti,V)C crystallizes with the cubic structure, which indicates that (Ti,V)C carbides were multiple carbides with V dissolved in the TiC structure. The Fe-based surface hardfacing layer reinforced by multiple carbides gave an excellent wear resistance and appeared a mild wear with fine scratches.

1. Introduction

The service life of components usually relies on their surface wear resistance. Surface coating has been usually employed to increase the wear and corrosion resistance of the components in the industry. To improve wear properties of the component, it is desirable that the surface layer of components is reinforced by carbide particles to offer high wear resistance whilst retaining the high toughness and strength. TiC with high hardness (3200 HV) and thermal stability is a very good reinforcement in iron-based composites, and Fe–TiC composites have been applied in wear resistance parts [1–3].

In recent years, several researches associated with the gas tungsten arc welding (GTAW process have been conducted to modify the properties of steel surface [4–7]. This surface modification by means of cladding and alloying is a process in which an alloy powder of a desirable composition and a thin surface layer of the substrate material are simultaneously melted and then rapidly solidified to form a dense coating, metallurgical bonded to the substrate. Wang et al. [4] have produced the wear resistant clad layers on medium carbon steel by GTAW, where WC and TiC particles were directly added into the specified metal powders. The results showed that the TiC with WC clad layer had superior wear performance under low sliding speed condition. Eroğlu et al. [5] have investigated the tungsten–inert gas surface alloying with pre-placed graphite, chromium and high-carbon-ferro-chromium powders on SAE1020 low carbon steel. Buytoz et al. [6,7] have studied the effect of GTAW parameters on the microstructure properties of SiC-based hardfacing on low alloy steel. It was found that the microstructure of the cladding layer is M_7C_3 primary carbides, Fe_3Si, SiC, and the graphitic carbon precipitates. All of these indicated that GTAW cladding coatings provided remarkable enhancement on the corrosion resistance, wear resistance, and thermal conductivity without impairing the bulk properties.

In our previous studies [8,9], TiC carbide particles were in situ synthesized by GTAW melting a mixture of Fe–Ti30 alloy and graphite. Compared with the methods mentioned above, it was found that adding Fe–Ti alloy and C into the cladding powder has many advantages in the precipitating and distributing of enhancement particles. As a result, the wear property of the surface composite coating was improved. However, the volume fraction of TiC was limited because the content of Ti is only 25–35 (wt.%) in the Fe–Ti30 alloy. In order to increase the carbide volume fraction in the coating, other carbide forming elements should be added into the raw materials to form carbide. Knowledge of the mutual miscibility of the carbides of the IV (Ti, Zr), V (V, Na, Ta) and VI (Cr, Mo, W) groups is of particular interest in hard materials. In addition, VC has also high hardness (2800 HV); and VC as carbide formed in ternary Fe–V–C alloy shows a large deviation from stoichiometry [10].

Therefore, in the present study, an attempt has been made to prepare multiple carbide reinforced Fe-based surface hardfacing layers by direct melting of the mixture of graphite, ferrotitanium

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doi:10.1016/j.surfcoat.2008.09.020

Table 1
The chemical composition of Fe–Ti, Fe–V and AISI 1020 steel (wt.%)

Elements	C	Si	Mn	P	S	Fe	Ti	V	Al
Fe–Ti30	<0.1	–	–	<0.03	<0.3	Bal.	25–30	–	<8
Fe–V50	<0.4	<2.0	<0.5	<0.07	<0.04	Bal.	–	>50	<0.5
1020 steel	0.14–0.22	0.12–0.30	0.40–0.65	<0.03	<0.035	Bal.	–	–	–

and ferrovanadium powders on an AISI 1020 steel substrate by means of GTAW process under a non-oxidizing atmosphere.

2. Materials and experimental procedures

The substrates (100 mm×25 mm×10 mm) were prepared from AISI 1020 steel plates. A powder mixture of ferrotitanium (Fe–Ti), ferrovanadium (Fe–V) alloy powder and crystalline graphite (99.5% purity) powder was used as the raw coating alloy. The chemical compositions of Fe–Ti, Fe–V and AISI 1020 steel are presented in Table 1. The ratio of Fe–Ti alloy to graphite powder and Fe–V alloy to graphite powder corresponds to that of stoichiometric TiC and VC, respectively. Thus, the weight ratios of w_{Fe-Ti}/w_C and w_{Fe-V}/w_C are about 39.8:4 and 39.8:3, respectively. Small amounts of ferromanganese (FeMn) (5 wt.%), ferrosilicon (FeSi) (3 wt.%) and calcium fluoride (CaF_2) (1 wt.%) powders were added into the powder in order to obtain high quality coatings. The FeMn and FeSi are to help deoxidize the molten weld metal. And CaF_2 is to adjust fluidity and solubility of the metal oxides [11].

Hardfacing was carried out by GTAW melting process to produce a series of single hardfacing tracks. Before hardfacing, substrates were ground and cleaned with acetone. The blended powders were mixed with a small amount of sodium silicate to keep the powders on the surface under the flow of argon. Then, the blended powders with sodium silicate were dried in hot air. Finally, the blended powders were pre-placed on the surface of the substrate. Fig. 1 shows the schematic diagram of the hardfacing method. GTAW torch was held stationary above the moving specimens. Tracks were produced along the length of the specimens. During the process, Ar gas (purity was 99.999%, flow rate was maintained constantly at 10 l/min) was used as protection gas to flow over the GTAW processing region. A tungsten electrode with a diameter of 2.4 mm was used to create an arc between the tip of the electrode and the substrate surface. The current (I) and voltage (U) to the electrode were maintained at 150A and 15–17V, respectively. The traversing speed (v) was about 70–85 mm/min. The electrode height from the substrate surface was about 2 mm and the electrode polarity was chosen as direct current straight-polarity (DCSP).

Microstructure investigations were carried out on the top surface of the coatings and the transverse direction after polishing and etching. All samples were etched with a solution of 3% nital. Microstructure was observed by scanning electron microscope (SEM) and transmission electron microscope (TEM). Elements line distribution was examined by electron probe microanalyser (EPMA). A type of D/Max-Rc X-ray diffraction with Cu-Kα radiation operated at 60 kV and 40 mA was used to analyze the coating phase structure. Microhardness along the depth of the cross-section was measured by using a Shimadzu HMV-2000 type micro Vickers. The load used was 200 g and loading time was set at 15 s.

The block-on-ring wear testing machine (Model M2000, China) was carried out without lubrication at room temperature using a friction and wear tester. The ring material of the wear couple was W18Cr4V high-speed steel. Its hardness is about 62 HRC. The outer radius of the circular test ring is 40 mm, and the width is 10 mm. The test specimens were machined to block with size of 35 mm× 6 mm×8 mm. The wear conditions were a normal load of 49 N, a sliding speed of 0.84 m s^{-1} and a sliding distance of 1008 m.

3. Results and discussion

3.1. Microstructure of the coating

Result of EPMA line scanning analysis for carbides of the top surface of the hardfacing layer is shown in Fig. 2. It can be found that there are two typical types of carbide morphology in the matrix. One appears with a dark contrast (marked A in Fig. 2), the other appears with a grey color (marked B in Fig. 2). According to the results of EPMA, these dark particles are rich in Ti, V and C. It can be identified that the reinforcement of these dark particles in composite coating is the complex carbide particles. However, the grey particles are only rich in Ti and C, which indicates that these grey particles are TiC carbides. In addition, Fe is strongly concentrated in the matrix of the cladding layer.

The X-ray diffraction pattern of the surface hardfacing layer was shown in Fig. 3. From Fig. 3, it can be seen that the presence of VC and TiC diffraction peaks can clearly be seen, indicating formation of VC and TiC particles during the GTAW melting process. In addition, beside these carbide phases, a few of Fe_3C diffraction peaks are also found, which reveals the presence of the Fe_3C phase in the surface hardfacing layer. For the Fe–Ti–V–C system, C may not be able to fully react with Fe–Ti and Fe–V, a small amount of C reacts with Fe to form the Fe_3C

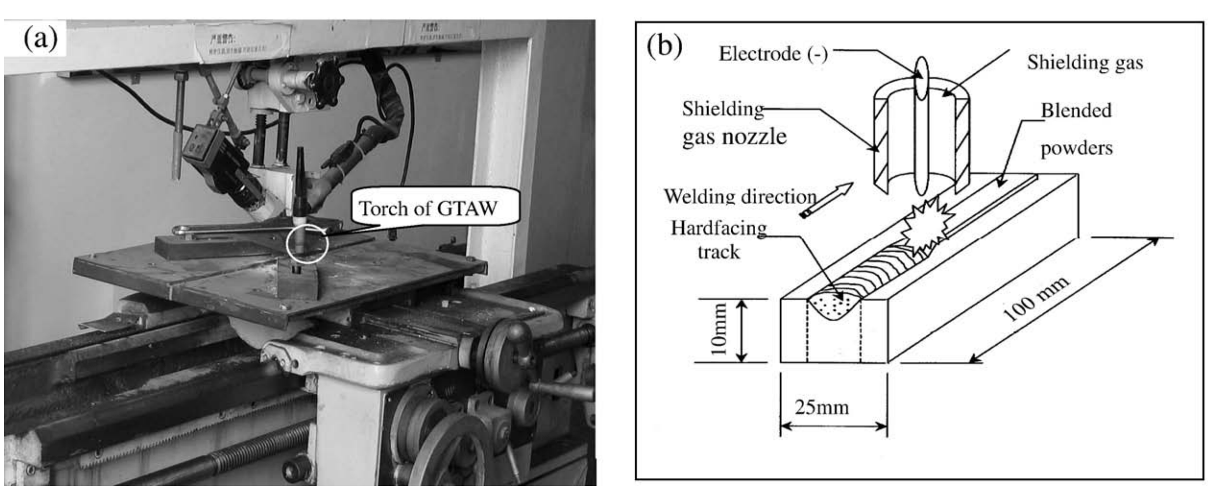

Fig. 1. A schematic of the GTAW process (a) photo of apparatus; (b) schematic hardfacing track.