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Fabricating TiC particles reinforced Fe-based composite coatings produced by GTAW multi-layers melting process

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Abstract

The present study aims to analyze microstructure and properties of TiC particles reinforced Fe-based surface composite coatings produced by gas tungsten arc welding (GTAW) multi-layers melting process. The mixture powder of graphite and ferrotitanium (FeTi) was deposited evenly on an AISI 1045 steel substrate, which was then heated by GTAW heat source. The results showed that in situ synthesized TiC particle reinforced composite coatings can be achieved under suitable welding parameters. Cubic TiC carbides and fine needle-shape eutectic TiC carbides are formed by ternary eutectic reaction between FeTi and graphite powders. Together with these TiC carbides, radially grown dendrites of primary TiC particles are also found in the composite coatings. These TiC particles are evenly distributed in the composite coatings. Because of the generation of these carbide particles and their homogeneous distribution in the matrix, the composite coatings give very high hardness and excellent wear resistance. The wear resistance of multi-layers composite coatings is about three to four times higher than that of 1045 steel substrate. Moreover, the wear resistance of the composite coatings and the substrate increased with increasing wear sliding distance.

Keywords: Gas tungsten arc welding; Surface composite coating; TiC particles; Wear properties; Multi-layer melting process

1. Introduction

It was reported that the surface layer of components is reinforced by ceramic particles to offer high wear resistance. In recent years, metal carbides have been widely used as reinforcement in metal matrix composites (MMCs) [1–3]. In all of ceramic particles, TiC particle crystallize in the cubic NaCl structure has lower density (4.90–4.93 g/cm^3) and high hardness (3200 kg/mm^2), as well as high thermal stability and more negative standard Gibbs formation free energy, which has been received interest worldwide as reinforcement in MMCs [4,5].

There are mainly two techniques available to incorporate reinforcement particles in the matrix of MMCs. One is mechanical mixing of the reinforcement externally [6–8]; the other is in situ formation of the reinforcement phase within the matrix [9–12]. The additional reinforcement ceramic particles are directly added into the coating materials, however, the shape and chemical composition of additives hardly remain unchanged due to the dissolution into metal liquid or metallurgical reactions with the environment resulting in the deterioration of the toughness and crack resistance of MMCs. The latter is realized through creating conditions favorable for reaction of elements to form the particles. The eminent advantage of the in situ synthesis technology is that it eliminates interfacial incompatibility of matrices with reinforcements by creating more thermodynamically stable reinforcements based on their nucleation and growth from the matrix phase. In recent years, many researchers are focusing on in situ synthesis TiC particles reinforced Ni- or Fe-based surface composite coatings by using laser beam to enhance surface quality [13–15]. However, problems always exist owing to differences in the laser beam absorption rates of different cladded powders. Furthermore, compared to gas tungsten arc welding (GTAW) process, the components of laser beam is complex and expensive.

Recently, new attempts have been made by using GTAW to achieve surface composites or surface alloying, in which an alloy powder of a desirable composition and a thin surface layer of

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the substrate material are simultaneously melted and then rapidly solidified to form a dense coating, metallurgical bonded to the base material [16–21]. Wang et al. [16] 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 W clad layer had superior wear performance under low sliding speed condition. Eroğlu et al. [17] 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 [18,19] has 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; and it has been demonstrated for Fe-, Co-, and Ni-based alloy coatings synthesized on various traditional substrate materials. However, a limited application of this process is updated in the literature on the formation of TiC particles via liquid reaction.

In the present study, an attempt has been made to prepare TiC reinforced Fe-based composite coatings by direct melting of the mixture of graphite and ferrotitanium powders on an AISI 1045 steel substrate during GTAW process under a non-oxidizing atmosphere, rather than the TiC particles being directly added into the GTAW weld pool.

2. Experimental procedures

In this study, AISI 1045 steel in a quenched and tempered condition with hardness HRC 32–35 was used for the substrate material; it contains (wt.%) 0.45C, 0.25Si, 0.66Mn, and balance Fe. The dimensions of the substrate are 100 mm × 25 mm × 10 mm. A powder mixture of ferrotitanium (FeTi) alloy and crystalline graphite (99.5% purity) was used as the raw coating alloy. The chemical composition of FeTi is (wt.%): 41.5Ti, 0.08C, 0.035P, 0.025S, and balance Fe. The ratio of FeTi alloy to graphite powder corresponds to that of stoichiometric TiC, thus, the weight ratio $w_{FeTi} : w_C$ was 9.5:1. The average size of the FeTi and graphite particles was less than10 μm. In order to obtain homogeneous distribution, the combined powders attrition-milled for 1 h using agate ball mill with an agate container and balls operated at 300 rpm. The blended powders were mixed with a small amount of sodium silicate to keep the powders on the surface under the flow of argon during GTAW process. 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, which were thoroughly cleaned, dried and finally rinsed by acetone, to give a thickness of about 1.5 mm for a single pass. To decrease the effect of dilution of the substrate, some specimens were cladded two or three pass under the same welding parameters. The thickness of second and third pass is also about 1.5 mm. For convenience, specimen clad single pass, two pass and three pass are referred to as “S1”, “S2”, and “S3”, respectively.

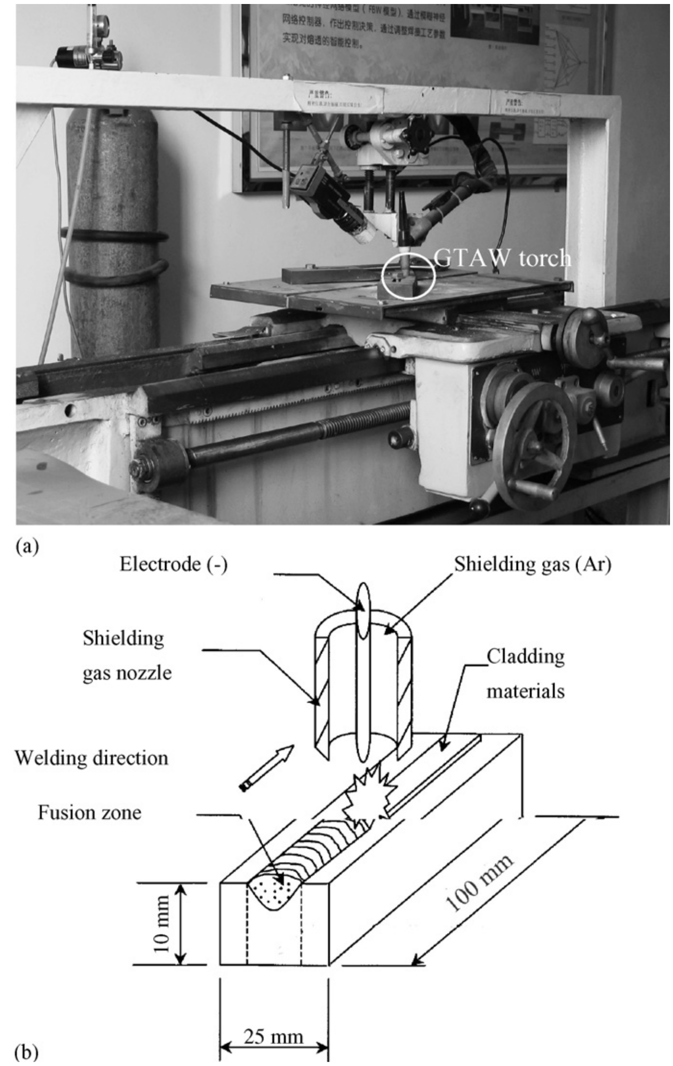

Fig. 1. A schematic of the GTAW process: (a) photo of apparatus and (b) schematic welding area.

Cladding was carried out by GTAW process to produce a series of clad tracks, which is presented in Fig. 1. Table 1 lists the parameters of the cladding process used in this work. GTAW torch was held stationary above the moving specimens, while a shielding gas of pure argon was supplied. Tracks were produced along the length of the specimens.

After surface alloying, samples were cut from the alloyed specimens for microstructural examination and hardness measurement. The samples were prepared for metallographic exam-

Table 1
Welding parameters of GTAW processing

Welding current (A)	150
Welding speed (cm/min)	5.5
Arc voltage (V)	15–17
Arc gap (mm)	2
Electrode	W-2% thorium
Electrode polarity	DCSP
Argon flow rate (L/min)	8