Surface & Coatings Technology 286 (2016) 383–387

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Applying FeAl coating on the low carbon steel substrate through self-propagation high temperature synthesis (SHS) process

S. Mohammadkhani *, E. Jajarmi, H. Nasiri, J. Vahdati-Khaki, M. Haddad-Sabzevar

Materials and Metallurgical Engineering Department, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad 91775-1111, Iran

ARTICLE INFO

Article history:
Received 27 August 2015
Revised 2 December 2015
Accepted in revised form 11 December 2015
Available online 12 December 2015

Keywords:
FeAl coating
Low carbon steel
Self-propagating high-temperature synthesis (SHS)
SEM
XRD
Wear test

ABSTRACT

In this research, a self-propagating high temperature synthesis method was applied for coating FeAl on the low carbon steel substrate. This technique is a combination of material fabrication with the coating process, simultaneously. Al and Fe were mixed regarding to have the stoichiometry of the reaction. The mixture was cold pressed at 150 MPa and was put just on the substrate at 950 °C in the air furnace without external pressure. The combustion synthesis occurred after 45–60 s and the coating was formed. Microstructure of synthesized powders and coatings was investigated by scanning electron microscopy equipped with EDS and X-ray diffraction, respectively. Wear resistance of coatings and substrate was measured by using a pin-on-disk tribometer. The results illustrated that high temperature of SHS reaction led to appropriate adherence of the coating and substrate. In addition, the tribological properties of coated specimens significantly improved. The results of the wear test demonstrated that the mass loss percentage of the substrate was almost 4 times more than that of coated specimen. The corrosion evaluations using potentiodynamic polarization test disclosed that the obtained coating had better performance than that of low carbon steel.

1. Introduction

In recent years, using combustion synthesis for coating materials has been widely studied [1–4]. According to these studies, several types of materials, including advanced materials, ceramics, cermets and intermetallic compounds could be produced by self-propagating high-temperature synthesis (SHS) process [5–7]. This method has received considerable attention as an alternative to conventional furnace technology considering the extreme simplicity of the process, relatively low energy requirement, high purity of the products obtained, the possibility to obtain metastable phases, and the possibility of simultaneous synthesis and densification [8–10]. The high purity of products is the consequence of high temperature associated with the combustion and volatile impurities are expelled as the wave propagates through the sample. The possibility of metastable phases' formation is based on high thermal gradients and rapid cooling rate associated with the reaction [11–17]. Moreover, through the SHS process, intermetallic compounds can be produced at relatively low operating temperatures and in very short processing times. The economic benefits are widely recognized and, moreover, it is possible to fabricate products that only contain the selected compounds [18–20].

FeAl, which is an intermetallic compound, is attractive because of its appropriate metallurgical, mechanical and tribological properties [21–26]. In addition, iron aluminides show a wide range of applications. They form protective oxide scales in hostile environments. They exhibit lower densities and good high-temperature properties compared with many structural alloys currently used. However, cold working of these materials is restricted since they exhibit brittle fracture and low ductility at room temperature. Their usage as engineering materials has, thus far, been restricted owing to these limitations [27–30]. The application of SHS process for coating substrate by FeAl and its tribological, time and cost advantages have not yet been determined.

In this work, FeAl was coated on a low carbon steel substrate by SHS. The chemical composition and phase detection in the produced coating, substrate and their interface were investigated using optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD) and Energy Dispersive Spectroscopy on the SEM (EDS). Applying such analyses shows different phases in the coating and interface. The thickness of coating and interface layers were measured thorough SEM. Wear resistance and corrosion behavior of coated samples were compared to an uncoated surface before coating process.

2. Experimental procedure

2.1. SHS process and preparation of powders

Powders of iron (99.9%, 9 μm) and aluminum (99.9%, 3 μm) were chosen as raw materials. According to the phase diagram of Fe–Al, FeAl which has the widest range of stability and the best wear and corrosion resistance properties among other Fe–Al phases, was taken as the coating. The molar ratio of powders was 1:1 according to the stoichiometry

* Corresponding author.
E-mail address: saeed_mkh88@yahoo.com (S. Mohammadkhani).

http://dx.doi.org/10.1016/j.surfcoat.2015.12.029
0257-8972/

Table 1
Chemical composition of steel substrate (DIN Code: 1.7131).

Element	Ni	Cr	Mn	P	S	Si	C
wt.%	0.114	0.839	1.102	0.015	0.027	0.374	0.203
Element	Al	Co	Sn	Ti	W	V	Mo
wt.%	0.06	0.014	0.005	0.001	0.006	0.003	0.015

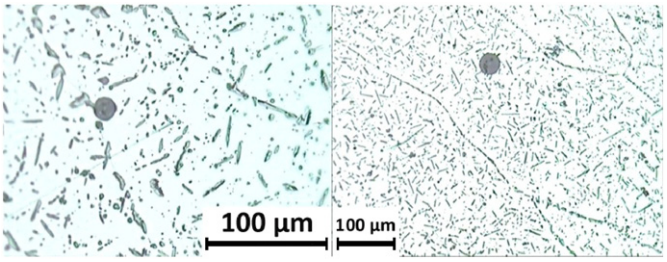

Fig. 1. Microstructure of the FeAl coating as determined from OM in different scales.

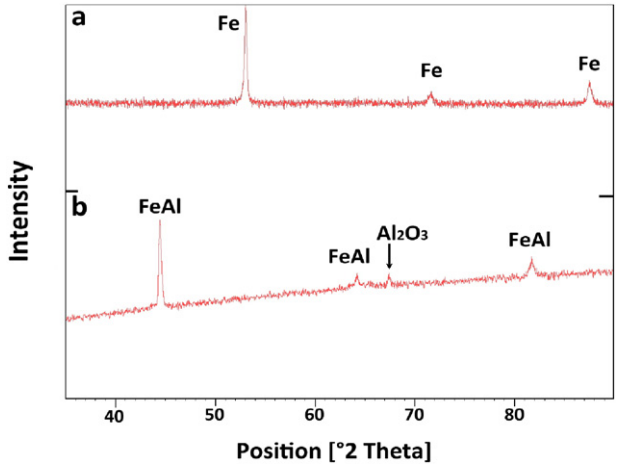

Fig. 2. a) XRD of the substrate and b) XRD of coated layer.

of reaction (1). This is the main reaction of SHS procedure. Nevertheless, the occurrence of reaction (2) releases a significant quantity of heat in the process at short time. This heat is remarkable, according to the large amount of $-\Delta H$ of the reaction which assures the possibility of local melting of the coating and the substrate in the interface and the occurrence of the combustion synthesis.

$$Fe + Al \leftrightarrow FeAl, \quad \Delta H^{\circ} = -51.24 \ \left(kJ \cdot mol^{-1}\right) \tag{1}$$

$$4Al + 3O_2 \leftrightarrow 2Al_2O_3, \quad \Delta H^{\circ} = -3340 \ \left(kJ \cdot mol^{-1}\right) \tag{2}$$

The powders were weighed and dry-mixed for 15 min in a low energy ball-mixing mill. Commercial low carbon steel (cementation) was used as the substrate, which was machined as a disk 40 mm in diameter and 10 mm in thickness. Before coating, it was cleaned with acetone for 10 min to remove grease and dirt from its surface. The result of the Quantometer analysis of the substrate was listed in Table 1 which indicates its chemical composition. The mixed powder was cold-pressed under a 150 MPa uniaxial pressure into a pellet to increase the intimate contact between reactants. The reactant powder mixture was stacked on top of the substrate without any pressure. The pellet was placed into the air furnace at 950 °C temperature to perform combustion synthesis. After 45–60 s the reaction happened. It could be considered from producing intense light, sound and smoke. The combustion wave propagated from the top to the bottom of the reactant compact. The reaction was finished when the combustion wave arrived at the bottom of the powder compact. The synthesized sample was taken out of furnace immediately and cooled in air.

2.2. Characterization and mechanical tests

The coated samples with coating were analyzed by X-ray diffraction (XRD). Microstructure of the coating, substrate and their interfaces were observed by optical microscope (OM) and scanning electron microscopy (LEO-Germany Model VP 1450) equipped with an Energy-Dispersive X-ray Spectrometer (EDS). Samples were prepared by polishing and etching with an etchant solution (CH_3COOH 33%, HNO_3 33%, HF 1%, H_2O 33%).

A pin-on-disk tribometer was used for wear tests under dry sliding condition. For this test the coated and uncoated samples were cut with the dimension of 19 mm × 19 mm × 4 mm. In the wear tests, samples were pressed against a rotating abrasive paper (100-grit sandpaper) making a circular path. The load was 5 N and the rotating speed was 200 rpm. The specimens were cleaned with acetone and dried in air every 50 m and weighed on a balance with a sensitivity of 0.01 mg. This process was conducted for 1000 m totally and the wear loss was calculated [31].

In order to investigate the corrosion behavior of the synthesized coating, potentiodynamic polarization test was performed. In this method, the sample firstly was cold mounted in a self-cure epoxy resin resulting in 1 cm^2 exposed areas. Afterward, the specimen was mechanically ground up to 1000 grit emery paper, and then washed in distilled water. After immersing the sample into corrosive solution, here in 3.5 wt.% NaCl, for 45 min to approach a steady state, its potential was swept in the range of −250 to +250 mV around corrosion potential at a constant rate of 1 mV/s. The reference electrode was saturated calomel electrode (SCE) and a platinum wire served as auxiliary electrode.

3. Result and discussion

In this research the combustion synthesis and deposition process were carried out at the same time and in a single stage. The occurrence

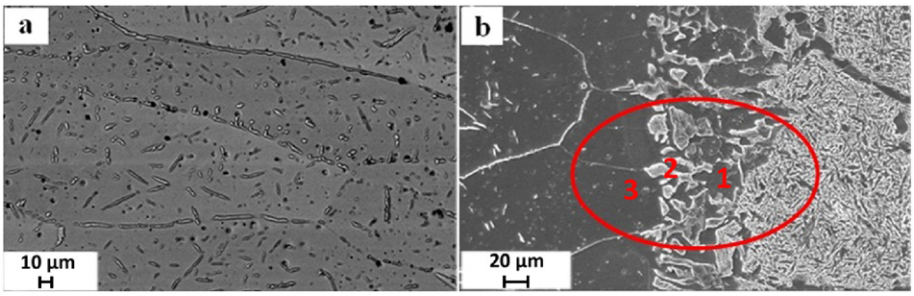

Fig. 3. a) Microstructure of the FeAl coating as determined from SEM and b) SEM micrograph of the studied area by EDS analysis (substrate, coating, and their interface).