ELSEVIER

Materials Science and Engineering A 421 (2006) 182–190

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Corrosion resistance of TiN/TiAlN-coated ADI by cathodic arc deposition

Cheng-Hsun Hsu *, Ming-Li Chen, Kuei-Laing Lai

Department of Materials Engineering, Tatung University, 40 Chungshan North 3rd Sec., Taipei 10451, Taiwan ROC

Received 17 September 2005; received in revised form 3 December 2005; accepted 3 December 2005

Abstract

Because of its low cost, high tensile strength, fatigue resistance, and wear resistance, austempered ductile iron (ADI) has been utilized in a wide variety of mechanical applications. However, in opposition to the versatility of the above-mentioned mechanical properties, the shortcomings of ADI are its surface hardness (Hv: 396) and corrosion resistance. And, because its relatively low austempering temperature falls in the range of Ms–450 °C (Ms: the martensite start temperature), ADI cannot be case hardened using traditional high temperature heat treatment. This study explored the effects of TiN and TiAlN coatings on ADI, with respect to surface hardness and corrosion resistance. The process employed for coating TiN/TiAlN onto ADI involved variable target current low temperature cathodic arc deposition (CAD). The coating characteristics and corrosion resistance of TiN/TiAlN-coated ADI were analyzed for further understanding of the feasibility of the low temperature CAD coating process. The analysis showed that TiN and TiAlN films could successfully be coated onto ADI through CAD technology without altering the unique microstructure of ADI. Utilizing a variety of target currents in the coating process yielded an acceptable level of adhesion while raising the surface hardness of ADI by a factor of 2–4 (Hv: 396 versus 1356–1910). It was observed that as target current increased, the surface roughness of the specimens also increased. TiN/TiAlN-coated ADI specimens exhibited higher corrosion resistance than uncoated ones when both were immersed in separate solutions of both 3.5 wt% NaCl and 10 vol.% HCl. Conclusively, the application of TiN and TiAlN films to ADI through the coating process of low temperature CAD is a viable surface modification for ADI applications that require increased surface hardness and corrosion resistance.

Keywords: Austempered ductile iron; Cathodic arc deposition; Target current; TiN/TiAlN coatings; Corrosion resistance

1. Introduction

Austempered ductile iron (ADI) is a promising material due to its unique microstructure containing acicular ausferrite and retained austenite constituents, which combines mechanical strength and wearability comparable to some wrought steels and possesses the low cost and design flexibility of cast iron. Thus, the subject of many researches is to develop ADI's applications in gears, heavy machinery, transportation industries, etc. [1–4]. It is well-known that coatings are applied to iron castings to provide both a pleasing appearance and functional resistance to deteriorate from processes such as corrosion, erosion, and wear. For instance, the methods of electroplating and electroless plating have been generally used to treat cast irons for the modification of mechanical and corrosive properties [5]. Unfortunately, these processes will be usually along with a series of problems about the environmental pollution. Another coating system called chemical vapor deposition (CVD) has no above problem and is also often adopted to treat metallic materials for surface modification, but it is a pity that the surface-treating process is not suitable for ADI. The main cause is that austempering is properly carried out at temperatures between Ms (the martensite start temperature) and 450 °C, while the CVD processing temperature is too high (up to 1000 °C or so) to improve ADI because the higher temperature effect can result in the microstructural alteration and mechanical properties deterioration.

One effective means to overcome these disadvantages is to utilize physical vapor deposition (PVD) technology of low-temperature process to coat the material's surface with various films [6,7]. For instance in previous studies [8–10], some coatings such as diamond-like carbon (DLC), CrN, and TiN have been successfully synthesized by PVD sputtering process to improve material's fatigue strength and corrosion resistance. In

* Corresponding author. Tel.: +886 2 2586 6410; fax: +886 2 2593 6897.
E-mail address: chhsu@ttu.edu.tw (C.-H. Hsu).

0921-5093/$ – see front matter
doi:10.1016/j.msea.2005.12.014

contrast to sputtering, cathodic arc deposition (CAD) process is a recent developed PVD technology which has a rapider coating rate and also plays an important role in PVD coating methods [6,11]. Therefore, the purpose of this study is to deposit TiN and TiAlN coatings on ADI by CAD process with the different target currents and then to evaluate the feasibility of the coating performance on ADI. Characteristics of the resultant films such as coating structure, roughness, and hardness were analyzed, and microstructures of ADI before and after CAD treatment were observed. Also, polarization measurement and immersion test were carried out for further understanding the coating effects on the corrosion resistance of ADI.

2. Experimental procedures

2.1. ADI substrate preparation

The experimental iron was produced as the Y-block castings from the raw materials (30% steel scrap + 60% iron returns + 10% pig iron) and the addition of 1.1 wt% nodularizer and 0.3 wt% inoculant by a regular foundry practice. The chemical compositions of nodularizer, inoculant, and the experimental iron are, respectively, listed in Table 1. The specimens were cut and machined from the Y-block castings and then ground and polished after heat treatment to obtain ADI substrate.

According to the previous experiences [12–14], a single austempering temperature of 360 °C was adopted in order to obtain ADI material in this work. The heat treatment was carried out as the following procedures: (1) preheating at 550 °C for 15 min, (2) austenitizing at 900 °C for 1.5 h, (3) immediately quenched in a salt bath of 360 °C for 2 h, and finally, (4) air-cooled to room temperature. The schematic austempering process is depicted in Fig. 1.

2.2. Specimen and coating treatment

In the study, the specimen size of 15 mm × 15 mm × 5 mm was used for corrosive analysis consisting of the polarization curve and immersion tests. All of the pre-coating specimens were polished to the same surface roughness (Ra = 0.3 μm) and then cleaned in ultrasonic bath with acetone before dried by hot air. In the PVD-CAD process, both targets of titanium (99.9%) metal and 50%Ti–50%Al alloy were, respectively, used to deposit TiN and TiAlN coatings. In order to understand the effect of target current on coating characteristics, there was a change in target current, respectively, using 50 and 75 A both conditions. Prior to deposition, the vacuum chamber was pumped down to 2.5 Pa, and argon ion bombarded at the bias of −1000 V for 10 min was used to further clean the surface of substrates. Details of the processing parameter are listed in Table 2.

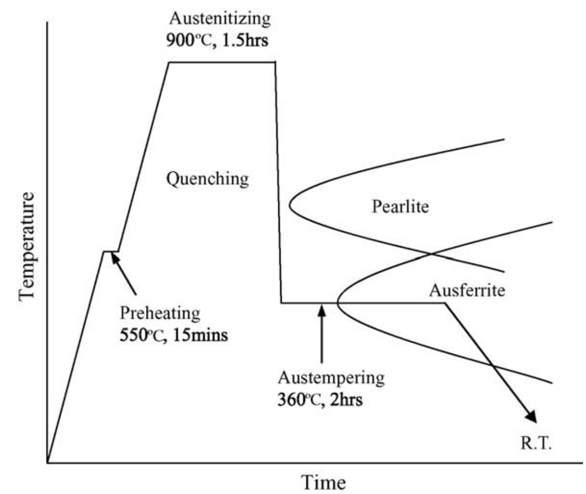

Fig. 1. Schematic diagram of the ADI's heat treatment in this experiment.

Table 2
Processing parameters of TiN and TiAlN coatings in this experiment

	Coating type	
	TiN	TiAlN
Target material	Ti (99.9%)	50%Ti–50%Al
Reactive gas	N_2	
Target current (A)	50, 75	
Substrate bias (V)	−150	
Chamber pressure (Pa)	2.5	
Chamber temperature (°C)	270–300	
Deposition time (min)	30	

2.3. Microstructure and coating analysis

Optical microscopy (OM) was utilized to identify the microstructure of ADI substrate before and after CAD coating treatment. Scanning electron microscopy (SEM) was used to observe surface morphology and thickness of the coatings. From both the different measured positions, specimen's superficial and inside, two sets of the X-ray diffraction (XRD) pattern were respectively obtained by using a Rigaku D/MAX-3A diffractmeter with Cu Kα radiation in order to analyze the coating structure and calculate the amount of retained austenite in ADI. A profilometer surfacorded analyzer (model AY-41) was used to measure average surface roughness (Ra value) of the specimens.

Table 1
Chemical compositions of nodularizer, inoculant, and the resulting iron (wt%)

Element	C	Si	Mn	P	S	Mg	Ca	R.E[a]	Fe
Nodularizer	–	42–47	–	–	–	5.0–5.5	1.5–2.0	1.8–2.2	Bal.
Inoculant	–	70–75	–	–	–	–	–	–	Bal.
The iron	3.56	2.83	0.22	0.039	0.008	0.042	–	–	Bal.

[a] R.E, rare earth elements.