Results in Physics 10 (2018) 339–345

Contents lists available at ScienceDirect

Results in Physics

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

Microstructure and wear behaviour of Ni-based alloy coated onto grey cast iron using a multi-step induction cladding process

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ARTICLE INFO

Keywords:
Grey cast iron
Induction cladding
Ni-based alloy coating

ABSTRACT

The purpose of this work was to develop an innovative approach to remanufacturing grey cast iron cylinder liners. Ni-based alloy coatings were fabricated on HT 300 cast iron substrates using a multi-step induction cladding technique. Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS) and X-ray Diffraction (XRD) were employed to analyse the microstructure, elemental distribution and phase composition of the coating. The results indicated that the coatings were metallurgically bonded to the substrate, and there were no visible defects and cracks at the interface resulting in failure of the coating. The portion closest to the substrate was rich in γ-Ni solid solution, whereas the intermediate and top portions consisted of boride-, carbide- and Ni-based solid solution eutectics. The microhardness from the top layer of the coating to the interface exhibited a gradual decrease, and the average microhardness of the coating is 877.12 $HV_{0.2}$, which was four times higher than that of the substrate. The results of dry sliding wear tests showed that the friction coefficient of the Ni-based alloy coating was much more consistent than that of the HT 300 substrate, and the wear loss and roughness of the coating was lower than that of the substrate. The wear mechanism for the coating is light abrasive wear, whereas for the substrate, the wear mechanism is a mixture of severe abrasive and adhesive wear.

Due to its good machinability, castability, thermal conductivity, shock absorption, self-lubrication, and low price, grey cast irons [1] are widely used in cylinder liners for medium- and large-scale marine diesel engines [2]. In recent years, increasing technical requirements for diesel engines, such as higher combustion pressures and operating temperatures to achieve higher power and lower fuel consumption, have accelerated the wear and cavitation of cylinder liners. Therefore, it is crucial to remanufacture used cylinder liners to enhance the utilization ratio of marine machinery components. To remanufacturing cylinder liners either in service or retired, surface technology can be applied to recover the original dimensions and performance [3], including electroplating, thermal spraying, welding, laser cladding and induction cladding. Among them, the coatings deposited by electroplating and thermal spraying are mechanical bonding to the substrate, and therefore the thickness of coating is limited; in contrast, the coatings fabricated by welding, laser cladding and induction cladding have dense microstructure and are metallurgical bonding to the substrate.

Induction cladding is an emerging environmentally friendly surface cladding technology that combines the advantages of induction heating and surface coating technologies [4]. This technique can fabricate coatings with high resistances to wear and corrosion and has the advantage of being used in many previous studies to prepare Ni-based and Fe-based alloy coatings on steel substrates. Chang et al. fabricated a Ni-based alloy coating on a steel substrate using vacuum induction melting and analysed the influence of the sliding distance and velocity on the wear mechanism under dry sliding conditions [5]. Hu et al. studied the microstructure and wear resistance of a Ni-based alloy coating on a medium carbon steel substrate. The results showed that the main wear mechanism for the coating was mild adhesive wear, whereas the dominant wear mechanism for the substrate was severe abrasive wear [6]. Grey cast irons, common materials for cylinder liners, contain a large amount of graphite and have poor weldability, commonly resulting in cracks at the interface between the cladding layer and the substrate [7]. Furthermore, the melting point of grey cast iron is low and close to that of the alloy powder, making it difficult to the control processing parameters during induction cladding. Therefore, it is vital to extensively discuss fabricating alloy coating on the grey cast iron using induction cladding. However, depositing alloy coatings on grey cast irons has rarely been investigated [8].

In this study, Ni-based alloy coatings were fabricated on HT 300 cast

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https://doi.org/10.1016/j.rinp.2018.06.042
Received 12 April 2018; Received in revised form 15 June 2018; Accepted 16 June 2018
Available online 21 June 2018

Table 1
Chemical compositions (wt.%) of the substrate and coating alloy.

Content/wt.%	Element						
	C	Cr	B	Si	Mn	Ni	Fe
HT 300	2.5–4.0	–	–	1.0–2.5	0.5–1.4	–	Bal.
SH-Ni 60A	0.6–1.0	15–20	3.0–4.5	4.0–5.5	–	Bal.	≤5

Table 2
Optimal parameters for the induction cladding process.

	Plan A			Plan B
	Preheating	Heating 1	Heating 2	Heating
Current/A	10	20	30	10
Heating Time/s	90	90	11	303
Frequency/kHz		32–36		

iron substrates using a multi-step induction cladding method. The microstructure, phase composition, and elemental distribution of the coating and interface were analysed. To evaluate the wear resistance, ball-on-disc experiments without lubrication were carried out at room temperature. The findings from this study are expected to provide an innovative approach for remanufacturing cylinder liners.

Experimental procedure

Materials

The materials used here were HT 300 cast iron as the substrate and a Ni-based alloy powder (SH-Ni 60A) to prepare the induction cladding coating. The Ni-based alloy powder is composed of spherical particles with diameters in the range from 45 to 106 µm. The chemical compositions of these metals are listed in Table 1. Cylindrical specimens were machined with a diameter of 22 mm and height of 100 mm. To clean, roughen, and activate the surface of the substrate, grit blasting was used, followed by ultrasonic cleaning in an alcohol solution before drying in hot air. The Ni-based alloy powder was mixed with a supersaturated solution of sodium silicate and then deposited on the substrate using a 3D printed mould to form a pre-coated layer with a thickness of 1 mm, as shown in Fig. 1(a). The substrate with a precoated layer was dried at 200 °C for 3 h and then directly placed inside a graphite crucible for induction cladding.

Induction cladding process

The induction cladding experimental system was composed of a induction cladding equipment (maximum current of 150 A; maximum frequency of 40 kHz), a rotary platform, a helical heating coil, cooling, and temperature monitoring systems, as shown in Fig. 1(b). The temperature was measured using two non-contact infrared pyrometers, which could measure temperatures in ranges from 250 to 2000 °C and 500 to 2500 °C at the surface and substrate, respectively. During the cladding process, the Ni-based alloy layer was heated to 1254 °C until it was red and glowing. After performing numerous initial experiments, we determined that an optimized multi-step heating process with varying power increments (Plan A) or with low and constant power heating for a long period (Plan B) resulted in the highest quality coatings, as listed in Table 2. However, for prolonged heating times, a large quantity of heat is conducted to the substrate, resulting in significant heat damage. Considering this, the optimal cladding process parameters are described in Plan A.

Characterization of the Ni-based alloy coating

Metallographic samples were cut along the radial direction of the induction cladding specimens and subsequently mounted in an epoxy resin. The surface was polished with #200 to #1500 emery papers, buffed to a mirror finish, and polished using1µm diamond powder. The samples were etched with a mixture of 50 ml hydrochloric acid, 50 ml distilled water, and 5 g cupric sulphate. The morphology and microstructure of the transverse section were observed using SEM (SUPRA 55 SAPPHIRE, ZEISS International, Germany). The elemental distribution at the interface between the coating and substrate was determined using EDS coupled to the SEM. The phase composition of the coating was identified using XRD (EMPYEAN, PANalytical B.V., the Netherlands).

The transverse cross-section microhardness of the coating from the layer surface to the substrate was measured using a semi-automatic Vickers microhardness tester (LW-HV 1000, Beijing Leweiwulian Science and Technology Co., Ltd., China) with a 200 g load and a dwell time of 20 s. The distance between each measured point was 50 µm, and each microhardness value was derived from three measurement points.

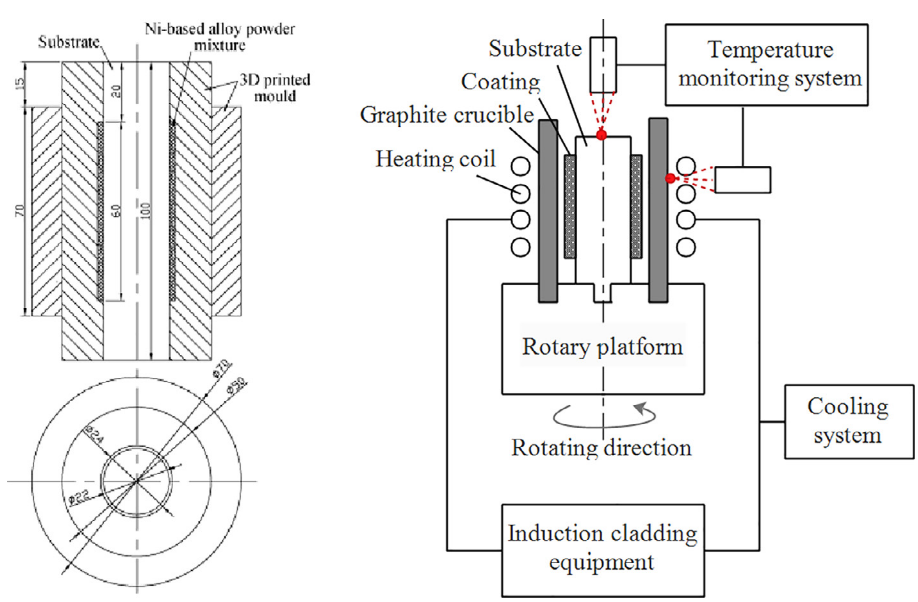

Fig. 1. Schematic illustration of (a) the coating deposition mould and (b) the experimental system.