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A comparative study on wear behaviour of Cr/Mo surface modified grey cast iron

A.R. Zulhishamuddin [a,*], S.N. Aqida [a,b], M. Mohd Rashidi [a]

[a] Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[b] Automotive Engineering Centre, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

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ABSTRACT

This paper presents laser cladding of grey cast iron with addition of Cr and Mo powder for enhanced wear properties. The laser cladding process was conducted using a Nd:YAG laser system. Sliding wear test were carried out on a linear reciprocating wear testing machine to analyse the wear rate during dry sliding. Based on the metallographic study, graphite phase was eliminated from the clad zone and formed small dendrite structure with fine particles. This phenomenon increased the hardness properties of the cladding surface with a maximum hardness of 945.5 $HV_{0.1}$. Meanwhile, the wear resistance of cladding surface was improved relative to the as-received grey cast iron with weight loss reduction of more than 96 percent. When Cr-Mo mixture was added, the worn surfaces were moderately smooth with only slight scratches and minimal adhesive attribute because of the formation of carbide phase. The improvement of the grey cast iron surface was due to the change of chemical composition and presence of the hard phase, M_2C, M_3C_2 and $M_{23}C_6$ produced by laser cladding.

1. Introduction

Recent advances in materials and process development have focused on the development of more long lasting and sustainability part production. A conventional material as cast iron is among the cheapest and common engineering materials with a broad range of applications in automotive components such as brake disc and cylinder liner. However, cylinder liner of engines exhibits high friction at elevated temperature that requires high wear resistance and high hardness to prevent crack and increase the life of cylinder liner. In extended cycle operation, high wear rate leads to corrosion and produce sulphur in the fuel during operation [1]. Studies have found that disc made from grey cast iron produced flakes which originate from removal of the graphite or as a result of corrosion [2].

Various conventional and advanced processing methods have been used to form hardened layer for high wear resistance including laser surface cladding [3,4]. Laser surface cladding used desired elements that were added to the melt pool to modify the surface chemical composition. During laser processing, pre-placed layer and substrate were melted, and both liquid phases were intensively mixed, resulting in a new desirable surface alloy. This process is known as non-equilibrium synthesis method involving high cooling rates of 10^3–10^8 K·s^{-1} which produces metastable phases by exceeding the solid-solubility limit beyond the equilibrium phase diagram [5].

Laser cladding improves surface properties by forming a new alloy layer with new composition of hard, homogenous and ultra-fine structure [4]. Consequently, enhanced surface hardness, corrosion resistance, thermal fatigue and wear resistance of cast iron were attained by elimination of graphite phase from the surface and formed fine microstructure [4,5,6]. A significant advantage of laser cladding, in comparison to laser melting, is the possibility to obtain surface properties by addition of specific alloying elements. In cladding surface of cast iron, addition of chromium and molybdenum particles forms complex carbides due to carbon (of cast iron) reaction with the powders [7,8]. Cr and Mo are intensively used to overcome challenges of mechanical performance at high temperatures. Thus, this research aims to study sliding wear behaviour of Cr/Mo particles addition on grey cast iron surface at different compositions. Samples were characterised for metallographic study, surface morphology, and sub-surface hardness properties.

2. Materials and methods

As-received grey cast iron was cut into flat samples of 40 mm diameter and 10 mm thickness. The chemical composition of the as-received grey cast iron is shown in Table 1. Fig. 1 shows as-

* Corresponding author.
E-mail address: zulhisham@polisas.edu.my (A.R. Zulhishamuddin).

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Table 1
Chemical composition of the As-received grey cast iron.

Material	Elements (wt.%)				
	C	Si	Mn	S	P
Grey cast iron	3.0–3.6	2.2–3.2	0.7–1.0	<0.10	<0.08

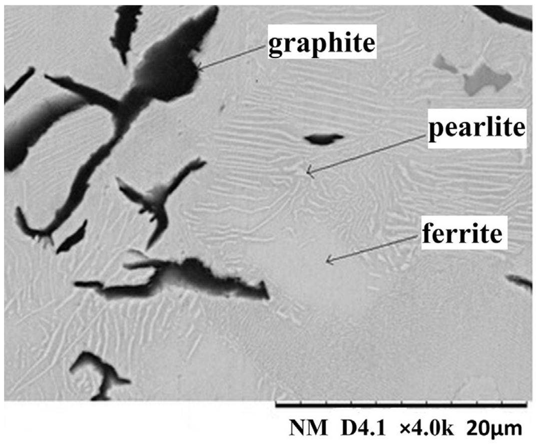

Fig. 1. The microstructure as-received of grey cast iron at 500× magnification.

received grey cast iron microstructure with graphite lamella surrounded by α-ferrite and pearlite phases. The average hardness for as-received cast iron is 278.5 $HV_{0.1}$. Cr and Mo powder of 99.9 percent purity in the particle size range of 71.9–130 µm and 0.96 9–9.62 µm respectively were used.

The substrate surfaces were ground with 250 grit silica sand paper and then cleaned with ethanol to ensure appropriate roughness, which enhanced the adhesive strength between the coating and substrate. The pre-placement of Cr/Mo powder on grey cast iron sample consistency was aided by a ring mould of 40.2 mm inner diameter and 15.7 mm in height. A small amount of sodium silicate was added to Cr/Mo powder as a binder to form a viscous solution. The paste was then compacted on grey cast iron sample surfaces and dried in a furnace at the temperature of 200 °C for two hours. This technique is done to bind the powders and prevent them from dispersed during laser surface processing [1]. The preplaced layer thickness range was 0.4–0.7 mm. Fig. 2 shows a schematic diagram of the preparation process of preplaced layer on grey cast iron sample surface.

The laser processing was conducted using JK300HPS Nd:YAG twin lamp laser source with pulse TEM_{00} mode, 1064 nm wavelength and 50 W average power. The laser spot size on the surface of the sample during processing was 1.0 mm. The combined mixture components design of experiment simplex lattice model was developed and it yielded 12 parameters. The cladding parameters were laser peak power range of 800–1200 W, pulse repetition frequency range of 80–90 Hz, and scan speed range of 2.4–21.6 mm·s^{-1}. The parameter setting and outcome parameters are summarised in Table 2. The outcome parameters from the settings were pulse energy, residence time and irradiance. Variation of the parameters significantly affected the amount of energy and irradiance penetration into the sample surface to melt the sample. The clad layer composition was prepared as 100 wt% Cr, 100 wt% Mo and 50 wt% Cr – 50 wt% Mo. The sample was processed on a table with linear movement translated by CNC moving control system. Laser processing was assisted by argon gas in a constant flow at 10 L·min^{-1} to prevent surface oxidation.

The sliding wear test was carried out on a custom made linear reciprocating wear testing machine based on the ASTM G133-05 standard. The wear rates of sliding were measured at 17.5 N and 24.5 N load. The mechanism of wear test is in the direction of the relative motion between sliding surface reverses where the load was at the top of the moving part. The speed of the wear test controlled by the frequency converter was linked to the electromotor. Before the wear experiment, grounded sample surface sand paper grade 600 was used to minimise the surface roughness. Speed conditions of this particular experiment were 0.52 ms^{-1}, at the duration of 300 s, sliding distance of 47.9 m and 1260 wear cycles. The sample weight was measured digitally before and after the wear test. A metallographic study was carried out using IM7000 Series Inverted Optical microscopes with Progress Capture 28.8 Jenoptik Optical System image analyser software and scanning electron microscopes (SEM) with energy dispersive X-ray spectroscopy (EDXS). Meanwhile, hardness properties were measured using MMT Matsuzawa Vickers Hardness tester with 100 gf load.

3. Results and discussion

The metallographic study revealed a new clad layer formation on grey cast iron substrate surface as shown in Fig. 3. Micrographs

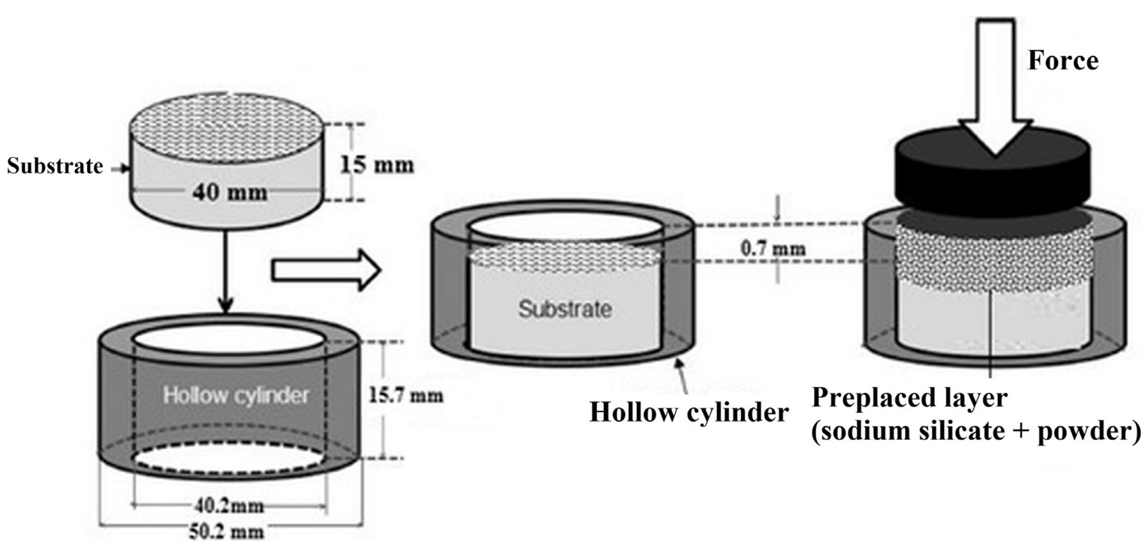

Fig. 2. A schematic drawing of the preparation process of preplaced layers [9].