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Laser cladding of continuous caster lateral rolls: Microstructure, wear and corrosion characterisation and on-field performance evaluation

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ABSTRACT

Laser cladding has been used to improve the service life of lateral rolls which experience high temperature wear and corrosion in the zero segment zone of continuous slab caster. Three different compositions of nickel base powders with varying chromium, molybdenum, boron and niobium content with different wear and corrosion resistance properties have been used as cladding consumables. The microstructure of the clad layers shows a two phase cellular dendritic structure, with nickel–chrome dendrites surrounded by hard phases rich in chromium and boron or niobium. Hard precipitates contribute to wear resistance whereas the presence of chromium along with molybdenum in nickel-rich matrix improves resistance to corrosion. Actual performance results suggest that the powder material with higher wear resistance property gives the maximum life when the corrosion conditions are less hostile. In rolls cladded with highest boron and nickel containing powders, the layers were intact, whereas fine cracks and de-lamination was observed in the other rolls.

1. Introduction

Foot rolls and lateral rolls are used in the zero segment zone of continuous slab caster to support the first solidified slab exiting from the water cooled copper mould. These rolls are generally made of chrome–molybdenum steel, and come in contact with partially solidified slab (10–22 mm skin thickness) with a surface temperature of around 1000–1200 °C. Subsequent air and water cooling of the rolls generate surface stresses (up to 900 N/mm^2) that lead to thermal cracking. Moreover, mould fluxes contain inorganic fluorides such as CaF_2 and create reaction products like HCl, CO_2, H^+ and HF which in turn, generate a very acidic (an acidity of 3–4 pH) and corrosive environment. Thus the combined effect of high temperatures, mould powder chemicals with high basicity, and elevated chloride levels in cooling water limit the roll's service life.

Laser cladding is a recent technology which is superior to the conventional hard-facing process in terms of reduced consumable consumption, good adherence with the substrate, high productivity and low distortion. A melt pool is formed on the roll substrate by a moving laser beam and an appropriately selected cladding material is added and fused onto the substrate (Fig. 1). High heating and cooling rates result in a fine microstructure and metastable phases during solidification of the clad layer. Post laser application, rapid quenching of the layer provides a defect-free deposit and a small heat-affected zone (HAZ). A high performance surface can be obtained with no undesirable effects on the substrate. Process depth is well-defined and a thin clad layer also makes it more cost effective with adequate wear properties (Schneider, 1998).

For years, martensitic stainless steels (5–12% Cr) have been the preferred weld-overlay materials for minimisation of roll surface corrosion and abrasion (Hetzner, 2005). Iron based chromium carbides have been found to have wear and corrosion resistant at 650 °C but above that temperature the corrosion resistant properties deteriorate. Non-ferrous materials are the preferred overlays at high temperature for wear and corrosive environments. A wide variety of commercial metallic or ceramic powders are available in the market for laser cladding. The particle size distribution is the key to optimising quality. Spherical particles of size between 40 and 100 μm are preferred as efficiency of powder catchment depends on the size range of the powder particles with the smaller spherical particles having improved efficiency. Schneider (1998) had shown that nickel and cobalt based alloys retain their mechanical properties at elevated temperatures by producing a tough, more crack and corrosion resistant hard-facing layer. Plewka and Donet (2004) reported an increase in caster roll life of up to 280 ktons by using nickel base overlay (Ni > 50%) over 160 ktons service life for conventional submerge arc welded (SAW)

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Table 1
Optimised parameters for laser cladding.

Parameters	Laser power	Spot diameter	Traverse speed	Track overlap	Argon shield gas	Argon transport gas	Powder feed
Value	4 kW	6 mm	0.8 m/min	2.6 mm	10 l/min	6.5 l/min	48.5 g/min

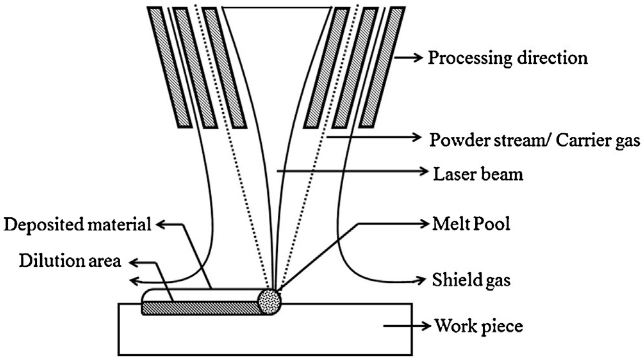

Fig. 1. Schematic of laser cladding process.

martensitic stainless steel (MSS) cladding. Probability of roll failure from the base material and weldment interface (particularly from the wide HAZ of SAW joints) was also indicated (Plewka and Donet, 2004). Failure may trigger by stress corrosion cracking (SCC) due to depletion of chromium carbide in the HAZ. On the other hand, laser cladding technology results in a small HAZ because of low heat input. Narrow HAZ leads to less SCC and in turn greater campaign life of the rolls. Kazadi et al. (2006) also investigated some promising capabilities of laser refurbishment technology with different combination of parent and weld-overlaying material for sleeve shoulders, foot rolls, descaler cassette, idler sleeve and foot roll shaft.

In view of the above advantages, the present study aims to study the microstructure and its effect on wear and corrosion properties of different nickel base powder overlaying deposited by laser cladding technology. An attempt has been made to enhance the service life of caster lateral rolls by laser cladding with nickel-base powder consumables.

2. Experimental methodology

The base material for the lateral rolls is 42CrMo steel (0.4C 0.4Si 0.7Mn 1Cr 0.2Mo). First, a 5 mm thick layer of a martensitic stainless steel (MSS) conforming to AISI 414 specification (0.15C 1Si 1Mn 12Cr 2Ni) was deposited by flux-cored arc welding (FCAW) as a buffer layer over 93 mm diameter bare rolls. Finally laser cladding was done by depositing a 2 mm layer on the roll surface by a 4 kW diode laser. Table 1 enlists the key parameters observed for laser cladding. Increasing laser power increases the melt depth and geometrical dilution and also maximises the achievable clad thickness. Each process parameter has thus been optimised to produce porosity free clad layers with low dilution levels (10–15%). Radiography measurements revealed one pore of measurable size in a single clad layer of area 100 × 170 mm with the optimised parameters.

After laser cladding, a stress relieving treatment was carried out at 650 °C for 1 h and thereafter approximately 0.3 mm from the coating diameter was machined to clean up the ripples. For the present study, three different compositions of nickel base alloy powders were used. Powder “M” (58Ni 12Cr 10Mo 0.5B 9 W 4Cu 4Fe) is a high temperature corrosion and mainly, a wear resistant alloy whereas Powder “I” (62Ni 23Cr 10Mo 4Nb) is a high temperature superalloy for corrosion resistance. Powder “Z” (76Ni 12Cr 5Mo 4Si 1B 1Fe) is an alloy designed specifically for laser cladding applications to address both wear and corrosion resistance.

Fig. 2a shows two laser cladded rolls before machining. A disc of 10 mm width was sectioned from the cladded rolls and two types of specimen were prepared according to Fig. 2b, for evaluating the clad layer properties. Type-I specimens were machined for studying the microstructure and for hardness characterisation. Type-II specimens were sliced off from the disc surface for wear and corrosion property investigation. Fig. 2b schematically shows the cross section of the sectioned disc and summarises the arrangement of different clad layers on lateral rolls.

Standard metallographic techniques of grinding and polishing were employed to prepare samples for microstructural study. 2% Nital was used as the etchant to reveal the micro-structure of base and laser-clad material, whereas Villela’s reagent was used to etch the MSS material. An optical microscope and a Scanning Electron Microscope (SEM) with energy dispersive spectroscopy (EDS) facility were used to characterise the microstructure. Electron Probe Micro-Analysis (EPMA) with a 0.01 μm LaB_6 probe was also carried out to find out the elemental distribution of the constituent phases in the laser cladded layers. An X-ray diffractometer (XRD) was used to identify different phases and precipitates in the cladded layers. Macro and micro-hardness variation across the weld layers were also studied.

Considering the small size of specimens, a universal macro-tribometer was utilised to evaluate the wear performance of the clad layers at room temperature. The tribometer generates a linear reciprocating motion with a 3 mm ball indenter under a precisely applied force and in this case, the test was carried out using a load of 8 mN for 1 h. The curved side of the wear specimens which correspond to the outer surface of the laser cladded rolls, were grounded to achieve a flat surface which was subsequently subjected to wear testing. The depth of the indentation scratch was recorded by a Taylor–Hobson profilometer.

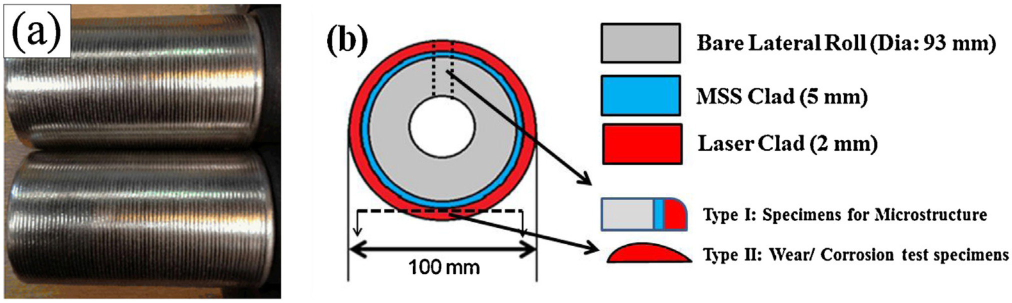

Fig. 2. (a) Laser cladded rolls before machining, (a) weld cladding sequence and (b) wear/corrosion test sample configuration.