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Enhancing surface integrity and corrosion resistance of laser cladded Cr–Ni alloys by hard turning and low plasticity burnishing

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ABSTRACT

In this research, the enhancements of surface integrity and corrosion resistance of the laser cladded parts by combined hard turning with low plasticity burnishing (LPB) were presented by both potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) methods. The investigated results indicated that the corrosion resistance of the laser cladded parts could be improved by combined hard turning with LPB than by sole hard turning. An innovative model was proposed to explain the corrosion mechanism of the laser cladded parts after hybrid machining. Both surface adsorption and passive film were observed to dominate the corrosion resistance of the hybrid machined Cr–Ni alloys by laser cladding. The surface integrity led to the inhomogeneity of passive film, and then altered the corrosion resistance of the machined samples. In terms of the surface integrity factors, residual compressive stresses and surface finish were found to play more important roles in improving the corrosion resistance than the grain refinement and microhardness of the machined surface layer materials did. Based on the research results, anti-corrosion parts with laser cladded alloys could be fabricated by hybrid machining using the combination of hard turning and LPB.

1. Introduction

More attentions have been paid to laser cladding for a wide range of industrial applications including metallurgy, traffic, petrochemistry, and mining industries, which can help improve special performance of components, such as wear resistance [1], corrosion resistance [2] and fatigue life [3]. This is due to the unremitting exploration to improve productivity, provide better service, as well as protect environment. Table 1 indicates that laser cladding can generate surfaces with high precision and integrity, as well as low distortion and dilution compared to other coating techniques. However, these techniques, including laser cladding, result in irregular surface profile and poor dimensional accuracy compared to conventional machining processes. This disadvantage has been restricted laser cladding technique into the roughing operations of the aforementioned applications. It is no more necessary to develop finish machining techniques for the laser cladded components to meet their tight accuracy as well as surface roughness requirements. However, machining of laser cladded components with high precision and high surface integrity is always a challenge work due to their difficult-to-cut properties [4,5]. Both the surface integrity and service performance need further improvements.

Machining parameters are usually planned for the betterment of surface quality in the form of reducing surface roughness, residual stresses, and modifying sub-surface microstructure, etc. All these responses would finally affect the corrosion performance of the material. It is important to understand the overall effects of surface texture, grain size and residual stresses after mechanical machining on corrosion resistance. Uddin et al. [6] reported that the enhanced surface integrity via machining was able to increase the corrosion resistance when compared to the as-received surface without machining. Prakash et al. [7,8] studied the electrochemical response of mild steel as a function of machining configurations. They found a better corrosion resistance of samples could be machined with smoother surface finish and strain-relieved surface grains. Bissey-Breton et al. [9] experimentally demonstrated that the average pit density was much lower after machining than that on the bulk material, owning to the fact that the machined surface was under compression. It was also reported that a larger residual tensile stresses remained in the machining-affected layer could result in a higher corrosion rate [10]. Moreover, the high residual compressive stress generated in the subsurface by burnishing was claimed to reduce the corrosion rate [11,12]. Also, the reduction of grain size

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Table 1
Comparison between laser cladding and other coating techniques.

Techniques	Thickness (mm)	Distortion	Dilution (%)	Precision	Integrity
Laser cladding	0.2–2.0	Low	1–5	High	High
Plasma spraying	0.1–0.2	Low	5–30	Med.	Low
Flame spraying	0.8–2.0	High	1–10	Low	Med.
HVOF spraying	0.3–1.5	Low	Low	Low	Med.
TIG welding	0.5–3.0	High	10–20	Med.	Med.
SMA welding	1.6–10	Med.	15–25	Low	High
SA welding	2–10	High	10–50	Low	High

was confirmed to be another factor resulting in an improvement in corrosion resistance [11,13].

While the relationship between machining process and corrosion resistance has been focused in published studies, the corrosion resistance of remanufactured parts by hybrid additive and subtract manufacturing is always overlooked as to our knowledge. As a matter of fact, corrosion resistant coatings have already been deposited by laser cladding [2] and thermal spraying [14,15] techniques successfully. Wang et al. [15] reported that the thermal sprayed coating could provide superior corrosion resistance than AISI 304L stainless steel. Liu et al. [16] also confirmed that the corrosion resistance was improved by laser cladding method compared to the substrate. Moreover, the corrosion resistance could be further improved by controlling the spray/clad parameters [17]. However, the aforementioned researches on corrosion performance of remanufactured parts were commonly by polishing treatment. The effect of post hybrid mechanical machining processes on corrosion resistance has never been reported yet.

What's the most important, state-of-the-art in mechanical industry implies that the outlook of manufacture should be comprised of both additive and subtractive manufacturing processes. This process chain is expected to extend the service life cycle of service-worn parts. AISI 1045 steel is widely used for all industrial applications requiring good strength, toughness and wear resistance. Typical applications of this steel grade include axles, shafts, spindles, crankshafts and torsion bars, etc. However, the weak corrosion resistance of the AISI 1045 steel promotes its premature failure in a service period. The best way to solve this problem is to produce an anti-corrosion coating onto its surface for protection, which comes back to the topic issues of this research.

In the present study, the hybrid machining by using the combination of hard turning and low plasticity burnishing (LPB) is adopted as a finish process to machine the laser cladded Cr–Ni alloy onto AISI 1045 steel. The enhancements of both surface integrity and corrosion resistance of the laser cladded parts by post machining are experimentally investigated. The significances of this work can be summarized into two folds as following: firstly, this study will address the effect of post machining on corrosion resistance of a laser cladded part. Secondly, the service-worn parts are successfully renovated to extend the service life cycles, which promotes the development of sustainability in terms of the environment and energy issues.

2. Materials and methods

2.1. Materials and laser cladding

The substrate rod bar was AISI 1045 medium carbon steel with dimensions of Φ120 mm in diameter and 300 mm in length. In prior to laser cladding, the rod bar was thoroughly descaled by sanding, degreased with acetone and dried in air. The Cr–Ni alloy powders were used as the clad material. The powder had the nominal compositions of 0.27 wt.% C, 1.53 wt.% Si, 16.33 wt.% Cr, 0.82 wt.% Mn, 3.45 wt.% Ni, 2.24 wt.% Mo and Fe in balance. In addition, the powder particles were spherical in shape and within the range of 75–100 μm in size.

As shown in Fig. 1a, the substrate rod bar was mounted on a three-jaw chuck rotating around a horizontal axis and was set in front of a lateral synchronous feeder device which, in turn, could be traversed horizontally. The laser cladding parameters were summarized as follows: laser power 3 kW, scanning velocity 5.1 mm/s, footstep 7 mm, carrier/shielding gas (N_2) pressure 0.5 MPa, and powder feeder rate 450 g/min. The thickness of the final cladding layer was in a range of 1.0–2.5 mm under the experimental conditions (Fig. 1b).

2.2. Combined hard turning and low plasticity burnishing

Hard turning and LPB experiments were carried out on a computer numerical control (CNC) center (PUMA200MA, Daewoo). This CNC turning center is equipped with a spindle power of 28 kW and the maximum spindle speed of 6000 rpm. The original cladding was firstly peeled off to eliminate the surface irregularity and defects. In hard turning, the carbide insert was mounted on a right-hand tool holder PCLNR2525M12, with rake angle 15°, clearance angle 6°, side cutting edge angle −5°, end cutting edge angle 5°, inclination angle −6°, followed by the LPB. It should be noted that the carbide tool was a wiper insert (i.e., multi-radii design for the nose of cutting insert) to improve productivity as well as surface integrity of the machined part. The burnishing tool was equipped with a ceramic ball made of silicon nitride (Si_3N_4) on the tip. This ceramic ball sit on a pressurized hydro cushion which was capable of

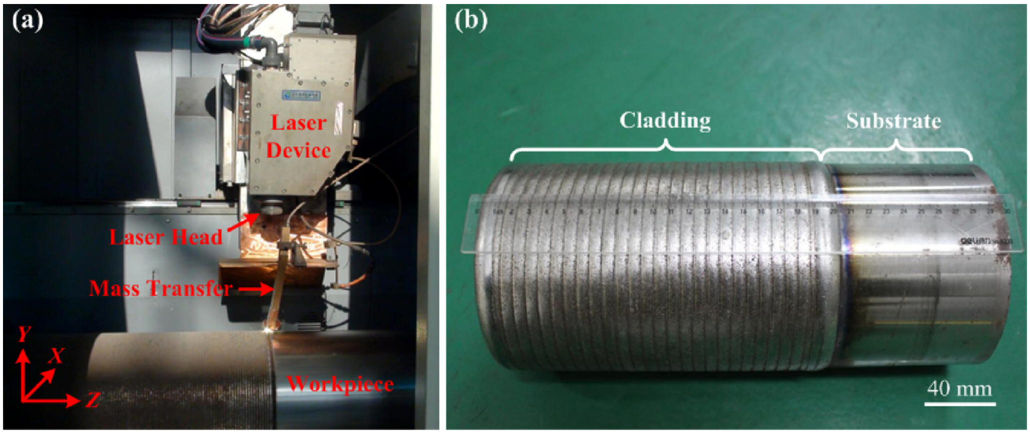

Fig. 1. (a) Worn part repaired with a laser cladding process and (b) macro geometry of the as-received laser cladded part.