RESEARCH ON LASER CLADDING REMANUFACTURING OF HIGH THARMAL CONDUCTIVITY MANGANESE BRONZE COMPONENTS

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Abstract

In order to maintenance the Manganese bronze components, preliminary remanufacturing research was applied by laser cladding technique. Wear-resistant coatings were fabricated by laser cladding with direct injection of the Ni-Cr-B-Si powder. Laser cladding was conducted with a Rofin-Sinar CW025 YAG laser. Laser clad coatings were characterized by scanning electron microscopy (SEM, LEO1450), EDS and XRD. It was investigated that there was a good metallurgical bonding between the coating and the C86300 bronze substrate without pores and cracks. The laser clad Ni–Cr–B–Si alloy coating was mainly γ-Ni 、Cr_7C_3 、Ni_2B 、Ni_3B together with lesser proportions of CrB_2 and Cr_3Si. The basic elements (Cr, Fe, Ni, Cu and Zn) content from the bronze substrate to the coatings varied regularly. Near the interface, the main elements were gradient distributed. The hardness of the laser clad layer was HV680, the transition layer was HV300-550 and gradient distributed, and the base metal was HV230.

Key words: remanufacturing; laser technique; manganese bronze; Ni－base alloy; microstructure

1. Introduction

Remanufacturing engineering was the best method to resolve resource waste, environmental pollution, repairing disabled equipment, and is the environmental friendly systematic engineering which meets the nation's persistent development strategy [1-3]. Remanufacturing engineering including the techniques such as thermal spraying, plating, build-up welding, was widely used, especially the laser cladding technique. In an effort to increase the service life of the components, laser cladding with wear-resistant alloy has been proposed to remanufacture the eroded or abrasive regions of the components surface. Laser source of the energy can be localized accurately and the size of laser beam can be controlled with precision. Besides that laser cladding involving the superficial melting of the substrate could lead to a perfect metallurgical bonding between the clad layer and substrate. So, laser cladding is one of the most advanced remanufacturing techniques which can obtain metallurgical bonding with lower heating effect and distortion [4-7].

Copper alloy was used in special situations by virtue of its good corrosion resistance and reasonably good mechanical strength. However, owing to low hardness, copper alloy suffers from abrasion effects. It was expected that the wear resistance of copper alloy may be improved by applying hardfacing material to the component surface. Laser surface treatments have emerged as a popular technique in surface modification owing to their well known special features. Laser cladding was performed to improve the surface properties of metallic machine parts locally. A cladding material with the desired properties was fused onto a substrate by means of a laser beam.

Owing to high reflectivity and thermal conductivity, laser treatment of copper alloy presents a certain degree of difficulty [8-11]，and studies on the laser surface modification of copper and copper alloy were much less common than studies on other engineering alloys. Reports on the laser surface modification of copper alloys for enhancing wear resistance are scarce in the literature [12-17]. In pursuit of higher wear resistance, the present study will examine a Ni-Cr-B-Si alloy in the surface modification of copper alloy [18-19].

2. Experimental details

The base metal used for experiment was Manganese bronze UNS C86300 (SAE 430B) with nominal composition 60-66%Cu, 22-28%Zn, 5-7.5%Al, 2.5-5％Mn, 2-4%Fe, and 1.0%Ni. Samples before laser cladding were machined into rectangular plates with dimensions 60×30×10mm. The particle size of the Ni-Cr-B-Si powder ranged from 40 to 90 μm.

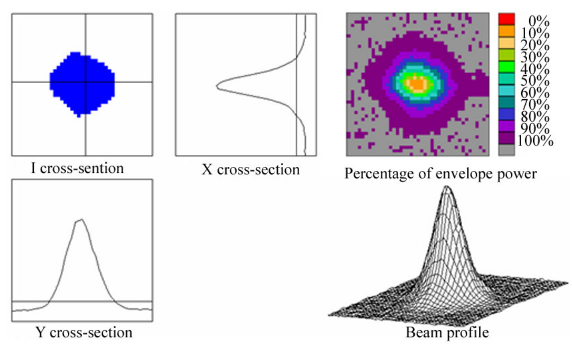


Fig. 1 The pattern of CW025 YAG laser beam and energy distribution

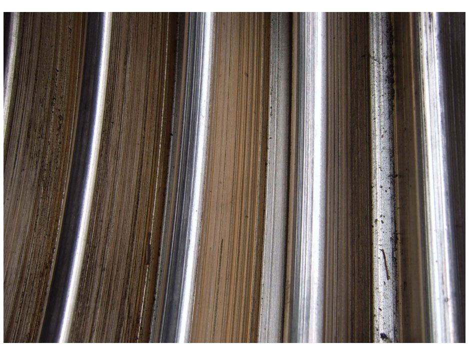
Laser cladding was conducted with a Rofin-Sinar CW025 YAG laser (wavelength 1.06um) operated at a laser power of 1.5-2.5KW and scanning speed of 4–5 mm/s. The pattern of the laser beam was detected by an LQD-I laser beam quality diagnostic apparatus. The intensity pattern of the beam profile is shown in Fig1. The beam quality of K_f was 8.67 mm·mrad. Ni-Cr-B-Si self-fluxing powder was directly injected into the molten pool with a feed rate of 7–8 g/min. The metallographic sample was etched with a reagent (50 ml H_2O, 40 ml HCl, 10g $FeCl_3$). Laser clad coatings were characterized by scanning electron microscopy (SEM, LEO 1450) and EDX. The phase present in the laser cladding layer were identified by XRD (D8 Advance). The hardness of the coating was tested by HXD-1000 microhardness tester under the condition of load 100g and time 15s. The test point interval is 50um which perpendicular to the coating.

3. Results and discussion

3.1 The wearing of screw down nuts

Manganese bronze UNS C86300 is a high strength, non-heat treatable copper alloy intended for use in applications requiring a good combination of outstanding wear characteristics and high bearing strength for heavy loads and slow speeds. Typical applications include slow speed heavy duty load bearings, gears, screw down nuts and hydraulic cylinder parts. Fig 2(a) shows a manganese bronze C86300 screw down nut with a weight of about 4 Tons. The screw fitted with a screw bolt on one end of a spline shaft which was made of SNCM439 (40CrNiMoA). The screw fits in the nut under high pressure, and that caused the wearing of the internal screw thread, shown in Fig.2 (b). A suitable material had to be identified to repair the internal screw thread of the nut. It was detected that the friction coefficient between the lubricated bronze nut material and steel was 0.10～0.15, and the friction coefficient between the lubricated Ni-base material and steel was 0.11～0.17. A Ni-base material can be chosen to repair the bronze nut.

(a)



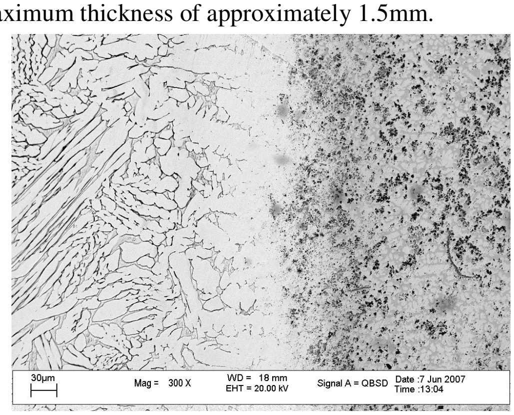
(b)

Fig.2. The photo of screw down nut (a) and the internal screw thread (b) female screw thread.

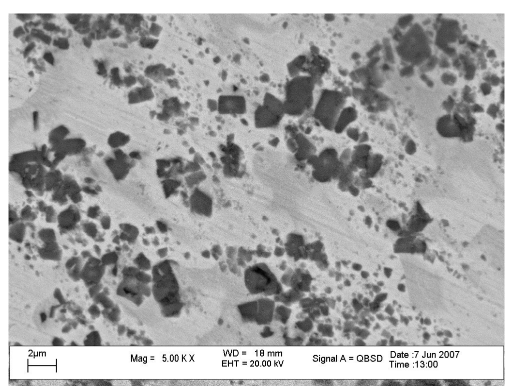
According to the binary phase diagram，Ni can form a solid solution with Cu in any proportion. With laser cladding Ni-base powder material on copper alloy, good metallurgical bonding can be produced. Elements that are commonly mixed with nickel are chromium, boron, carbon, and silicon. The formation of hard borides and silicon carbide improves the wear resistance and hardness. The addition of boron and silicon improves the self-fluxing nature. Hence, very smooth surfaces can be achieved. So conclusion was made that Ni-Cr-B-Si powder was an ideal candidate for laser cladding on copper alloy.

3.2 Microstructure of the laser cladding Ni-base alloy on bronze

Manganese bronze C86300 has high reflectivity and thermal conductivity. Accordingly it will need a higher power density than other common base metals to form a molten pool in the laser cladding process. Before laser cladding, the surface of bronze was ground and then cleaned with alcohol. The laser cladding process was implemented with an off-axis nozzle that could generate a concentrated powder stream. There was direct injection of the Ni-Cr-B-Si powder into the molten pool. Optimum laser cladding conditions were determined after preliminary experiments, in which the conditions were laser power of 2KW, scanning speed 4 mm/s, and a powder feed rate 8 g/min. The clad coating was built up by overlapping single tracks. A porosity-free coating was produced using the optimized processing parameters. The thickness and shape of the clad tracks were controlled by laser power, scanning speed, and overlapping fraction. The overlapping coating had a maximum thickness of approximately 1.5mm.



(a)



(b)

Fig.3 The SEM image of the laser cladding layer with the power of 2KW, scanning speed of 4 mm/s, feed rate of 8 g/min (a)interface (b)laser clad coating

As demonstrated in Fig.3 (a), there was a good metallurgical bonding between the coating and the bronze substrate. The coating produced under the optimized processing conditions had uniform structure and excellent bonding with the substrate and was free of pores and cracks. The morphology of the laser clad coating showed that the low melting point elements (Zn etc.) were not evaporated to form pores under the laser irradiation. The dark feature in the laser clad coating was Cr_7C_3 hard phase which was detected by EDS analysis, as shown in Fig3 (b). The Cr_7C_3 hard phase was dispersed in the clad layer with the dimension about 2um. It was well known that Cr_7C_3 hard phase have high hardness (HV1700) and increased the wear resistant of the clad coating.

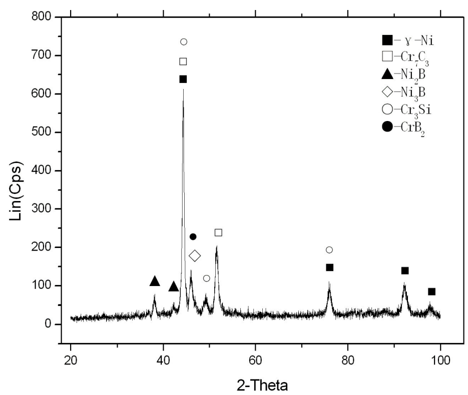


Fig.4 XRD spectrum of the laser clad Ni-Cr-B-Si alloy

According to the X-ray spectrum shown in Fig. 4, the laser clad Ni–Cr–B–Si alloy coating was mainly a solid solution of γ-Ni with different nickel intermetallics, fundamentally Ni_2B 、Ni_3B, together with the chromium carbides Cr_7C_3 and with lesser proportions of CrB_2 and Cr_3Si. The intermetallics of Ni_2B 、Ni_3B、CrB_2 and Cr_3Si appeared in the clad layer have very high hardness, and also have contributions to the wear resistant of the coating.

3.3 EDS analysis of the cladding layer

EDS line-scan analysis was applied perpendicular to the coating interface, and the length of the analysis line was 600um. The basic element (Cr, Fe, Ni, Cu and Zn) content from the bronze substrate to the coatings varied regularly, as shown in Fig.5. Near the interface, the main elements were gradient distributed, this illustrates the dilution of the base material into the cladding. Metallurgical bonding was obtained between the clad layer and bronze substrate.

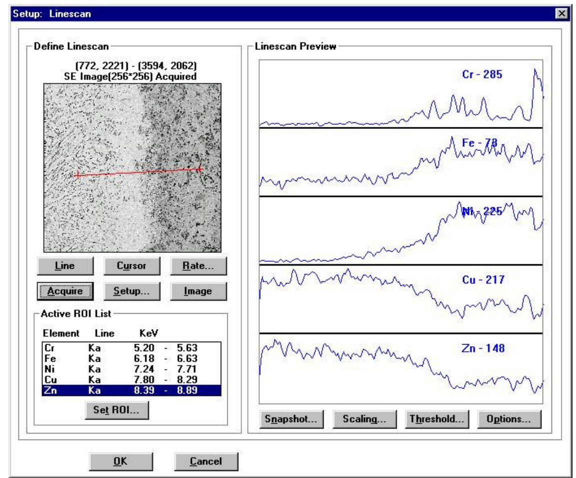


Fig.5 EDS line-scan analysis of the clad layer and substrate in the transition region

3.4 Hardness distribution of the cladding layer

The hardness of the clad layer was tested by the HXD-1000 microhardness tester. The hardness distribution curve shown in Fig.6. Average hardness value of the clad layer was HV680. Owing to the existence of Cr_7C_3 hard phase, hardness distributions was uneven and cause the inhomogeneous property in the clad layer. Gradient transition was realized between the clad layer and substrate. The hardness value in the transition region was in the range of HV300-550 and the C86300 matrix was HV230.

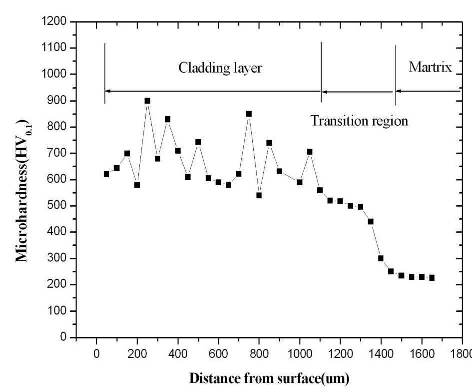


Fig.6 Hardness distribution curve of laser cladding layer

The gradient distribution of hardness from clad layer to the substrate can release the stress that generated in the process of material fabrication and reduce the crack propagation. At the same time, gradient distribution of hardness can release the stress and deformation in the service time, the clad layer would not breaking-off under the heavy-duty, although physical property have apparent difference between the clad layer and substrate.

From the above-mentioned research about process, testing and analysis, we known that laser cladding

Ni–Cr–B–Si alloy meets the tribology requirements. The high strength clad layer formed metallurgical bonding with Manganese bronze, which can subject to the severe relative friction. On the point of material science and property, preliminary technique was got and it would become the foundation for application. It was a difficult work to carry out the research to laser cladding on high reflectivity and thermal conductivity substrate. It will be a new field for related research work. On the occasion to repair the practicable components, the problem about processing parameter and fixture will be the most important.

4. Conclusions

In this study, wear-resistant coatings were fabricated by laser cladding Ni–Cr–B–Si powders on manganese bronze C86300. The morphology of laser surfacing was examined by SEM. There was a good metallurgical bonding between the coating and the bronze substrate without pores and cracks. This illustrated the feasibility of laser clad repairing on the abrasion surface of screw down nuts.

The laser clad Ni–Cr–B–Si alloy coating was mainly a solid solution of γ-Ni with different nickel intermetallics, fundamentally Ni_2B 、Ni_3B together with the chromium carbides Cr_7C_3 and with lesser proportions of Cr_2B and Cr_3Si. The existence of hard phase increased the material wear resistance property.

EDS line-scan analysis was applied perpendicular to the interface. It was found that the basic elements (Cr, Fe, Ni, Cu and Zn) content from the bronze substrate to the coatings varied regularly. Near the interface, the main elements were gradient distributed. Metallurgical bonding was obtained between clad layer and bronze substrate and elements diffusion occurrence.

Average hardness value of the clad layer was HV680. The hardness value in the transition region was in the range of HV300-550 and the C86300 matrix was HV230. The gradient distribution of hardness from clad layer to the substrate can release the stress that generated in the process of material fabrication and reduce the crack propagation.

Acknowledgments

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Reference

[1]XU Binshi. "Remanufacture engineering for equipment and its development", *Journal of the Academy of Equipment Command & Technology,* **14(1)**, pp.1-4, (2003)

[2]Xu Binshi , Ma Shining , Liu Shican , Liang Xiubing. "Progress of surface engineering and remanufacture engineering", *Journal of Tongji University*, **29(9)**, pp. 1085-1091, (2001)

[3]Xu Binshi, Zhu Sheng, Wang Haidou. "Remanufacturing engineering and its failure analysis", *Heat Treatment of Metals*, **32(supplement)**, pp.1-5, (2007)

[4]Yang Xichen, Li Hui-shan, Liu Yun-wu, Wang Yunshan, Tang ying, Sun Ronglu. "Laser remanufacturing technology and its industrial application", *China Surface Engineering*, **16(4)** , pp.43 - 46, (2003)

[5]Chen jiang ,Liu Yulan. "The engineering application of laser remanufacturing technology", *China surface Engineering*, **19(5+)**, pp.50-55, (2006)

[6]Yang Xichen, Li Huishan, Wang Yunshan, Liu Yunwu, Tang Ying. "Laser refabricating technology for repairing expensive and important equipments", *Laser & Optoelectronics Progress*, **40(10)**, pp.53～57, (2003)

[4] Wang Maocai, Wu Weitao. "Advanced laser cladding and welding process for GT", *Gas Turbine Technology*, **14(4)**, pp53-56, (2001)

[5] L. Shepeleva, B. Medres, W.D. Kaplan. "Laser cladding of turbine blades", *Surface and Coatings Technology*, **125(1),** pp.45–48, (2000)

[6] P. Bendeich , N. Alam, M. Brandt. "Residual stress measurements in laser clad repaired low pressure turbine blades for the power industry", *Material Science and Enginering*, **A 437(1)**, pp.70–74, (2006)

[7] Y.P. Kathuria. "Some aspects of laser surface cladding in the turbine industry", *Surface and Coatings Technology*, **132(2-3)**, pp. 262－269, (2000)

[8] Guo Yongli, Liang Gongyin, Li Lu. "Laser cladding reparation of aluminum alloy", *Chinese Journal of Lasers*, **35(2)**, pp.303-306, (2008)

[9]Sun Fujuan , Liu Hongjun , Hu Fangyou. "Effect of laser surface remelting on performance of LY12CZ", *Chinese Journal of Lasers*, **34(8)**, pp.1159-1162, (2007)

[10] Gao Yali , Wang Cunshan , Liu Hongbin , Yao Man. "Microstructure and properties of AZ91HP Magnesium alloy treated by high power laser melting", *Chinese Journal of Lasers*, **34(7)**, pp.1019-1024, (2007)

[11] Huang Kaijin , Lin Xin , Chen Chi, Xie Changsheng. "Microstructure and wear behaviour of laser clad $Zr_2Cu_2Ni_2Al$/ TiC composites on AZ91D Magnesium alloy", *Chinese Journal of Lasers*, **34(4)**, pp.549-554, (2007)

[12] G.Dehm, B.Medres, L.Shepeleva. "Microstrucure and tribological properties of Ni-based claddings on Cu substrates", *Wear*, **225-229 (2)**, pp.18-26, (1999)

[13] J. D. Majumdar, I. Manna. "Laser surface alloying of copper with chromium microstructural evolution", *Materials Science and Engineering*, **A268(1-2)**, pp.216-226, (1999)

[14] Gao Yang, Pan Feng , Tong Baiyun , Liang Yong , Shi Changxu. "Laser cladding of thermal barrier coatings on copper", *The Chinese Journal of Nonferrous Metals*, **13(2)**, pp. 315-318, (2003)

[15] Liu Fang, Liu Changsheng, Chen Suiyuan, Tao Xingqi. "Studies of W2C in-situ reinforced Ni-based coating prepared by laser cladding on copper substrate", *Chinese Journal of Material Research*, **21(5)**, pp.496-500, (2007)

[16] K. F Tam, F. T. Cheng, H. C. Man. "Cavitation erosion behavior of laser-clad Ni-Cr-Fe-WC on brass", *Materials Research Bulletin*, **37 (7)** , pp.1341-1351, (2002)

[17] K. F Tam, F. T. Cheng, H. C. Man. "Enhancement

of cavitation erosion and corrosion resistance of brass by laser surface alloying with Ni-Cr-Si-B”, *Surface and Coatings and Technology*, **149(2-3)** , pp.36-44, (2002)
[18] A. Conde, F. Zubiri, J. de Damborenea. “Cladding of Ni-Cr-B-Si coatings with a high power diode laser”, *Materials Science and Engineering*, **A334 (1-2)**, pp.233-238, (2002)
[19] Q. Li, T. C. Lei, W. Z. Chen. “Microstructural characterization of laser-clad TiCp-reinforced Ni-Cr-B-Si-C composite coatings on steel”, *Surface and coatings Technology*, **114 (2-3)**, pp. 278-284, (1999)

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