IOP Conf. Series: Materials Science and Engineering **248** (2017) 012016 doi:10.1088/1757-899X/248/1/012016

Laser clad NiCrBSi alloy wear-resistance coating with RE addition on heavy duty spur gear flank

N Zhao[1, 2], L Tao[1, 2*], H Guo[1, 2] and M Q Zhang[1, 2]

1 School of Mechatronics, Northwestern Polytechnical University, Xi'an 710072, China;
2 Shaanxi Engineering Laboratory for Transmissions and Controls, Xi'an 710072, China

Abstract. In this research the wear-resistance composite coating successfully produced on heavy duty gear work surface by laser was reported. The coating containing 99 wt.% NiCrBSi alloy and 1 wt.% RE (rare earth element) oxidation powder. The RE addition coupled with laser operating parameters optimization caused elimination of both cracks and pores meanwhile further enhanced comprehensive properties of the laser layer. The coating microhardness, microstructure, phase construction and wear behaviors were tested by hardness tester, SEM equipped with EDS, XRD and tribometer, respectively. The results reflected the fact that the RE addition enhanced the coating ability of wear resistance and laser clad layer properly bonded with the gear flank. The wear volume loss rate of coating was half of that of the gear flank metal the COF curve of coating kept bellow that of the gear flank steel.

1. Introduction

The heavy duty gear have undergone sever abrasive wear and this cost huge amount of money and time in the replacement of failure gears. Laser cladding have been widely utilized in the production of protective wear resistance layers [1-14]. Laser layer applications range from aviation engine, unclear industry to navy defensive marine. The fine microstructure and small crystal size caused by quick heating and solidification cycle which are unique in laser processing and the metallurgical bond which allowed the cladded gear flank qualified the power transmission underground, based on the above reasons laser clad wear-resistance coating has become a hot research topic recently. Bearing these merits of laser coatings in mind, the laser produced layer is competent for solving the problem of gear abrasive and fatigue failure.

RE has been proved to be able to refine the grain size of laser clad alloy layer [7-17]. MMC (metal matrix composite) coatings reinforced by RE has attracted lots of research interests. The laser clad alloy layer has finer grain than other conventional approaches like thermal spray, TIG welding and so on, however, the added RE can further refine grain size. Laser clad RE reinforced wear resistance layer exhibited excellent properties if the amount of RE addition is controlled properly in permissible content otherwise the RE particle aggregation would damage the mechanical properties of MMC coating.

2. Experiment details

The gear flanks were grind by sand wheel and the fatigue layer were completely removed before cleaned and fixed on fixture for laser processing. The mixed composite alloy powders were commercially

IOP Conf. Series: Materials Science and Engineering **248** (2017) 012016 doi:10.1088/1757-899X/248/1/012016

available NiCrBSi self-fluxing alloy blended with 1 wt.% RE oxidation particles. All the data used in cladding procedure were listed in table 1.

Table 1. Laser cladding parameters.

Parameter	Laser Parameter Value
Power	1.8 kW
Laser Track Wide	3 mm
Laser beam diameter	2 mm
Overlap Rate	30 %
Cladding Mode	Single layer, straight line
Max Angle of Inclination	30°
Feed Powder	6.0 rpm
Shield Argon	600 ml/min
Laser Scan Speed	8 mm/s

In addition, the nominal compositions of base metal gear steel and NiCrBSi alloy were shown in table 2.

Table 2. Nominal compositions of NiCrBSi alloy powder and substrate steel 17CrMoNi6 in wt.%.

	Cr	S	P	Si	B	C	Fe	Ni	Mn	Mo
NiCrBSi Alloy	17	-	-	4.2	3.7	0.85	7.1	Bal.	-	-
17CrMoNi6	1.50-1.80	0.035	0.035	<0.40	-	0.15-0.20	Bal.	1.40-1.70	0.40-0.60	0.25-0.35

2.1. Gear flank processing

The gear steel used in this study is 17CrMoNi6. The work surfaces were grind and polished until 0.2mm depth was removed from original involute profile before laser cladding. This process was designed to ensure the cladded layer surface can match the original gear flank involute shape with proper post processing.

2.2. Powder blending and drying

The NiCrBSi alloy mixed with 1 wt.% La_2O_3 powder and fully blended in yttrium stabled zircon balls in 750 rpm for 12h. Then mixed powders were heated to 150℃ in a vacuum furnace and kept for 3h for dehumidification.

2.3. The laser cladding on gear flank

The cladding procedure was shown in figure 1. The coating tracks were cladded from gear root to gear top.

In this part it is important to note that there must be a certain angle of inclination (from the normal direction of the cladding involute surface) to make sure the laser beam could reach the roots of gear flank. The maximum deviation angle could be 30° in this case.

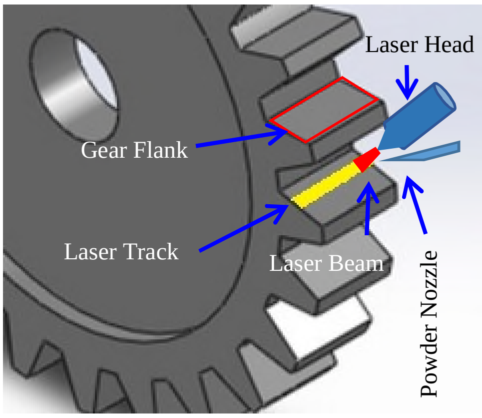

Figure 1. Sketch map for laser cladding on heavy duty spur gear flank.

3. Results and Discussion

3.1. Microstructure analyze

The SEM of overlap area of cladded layer with RE addition should be seen as follows:

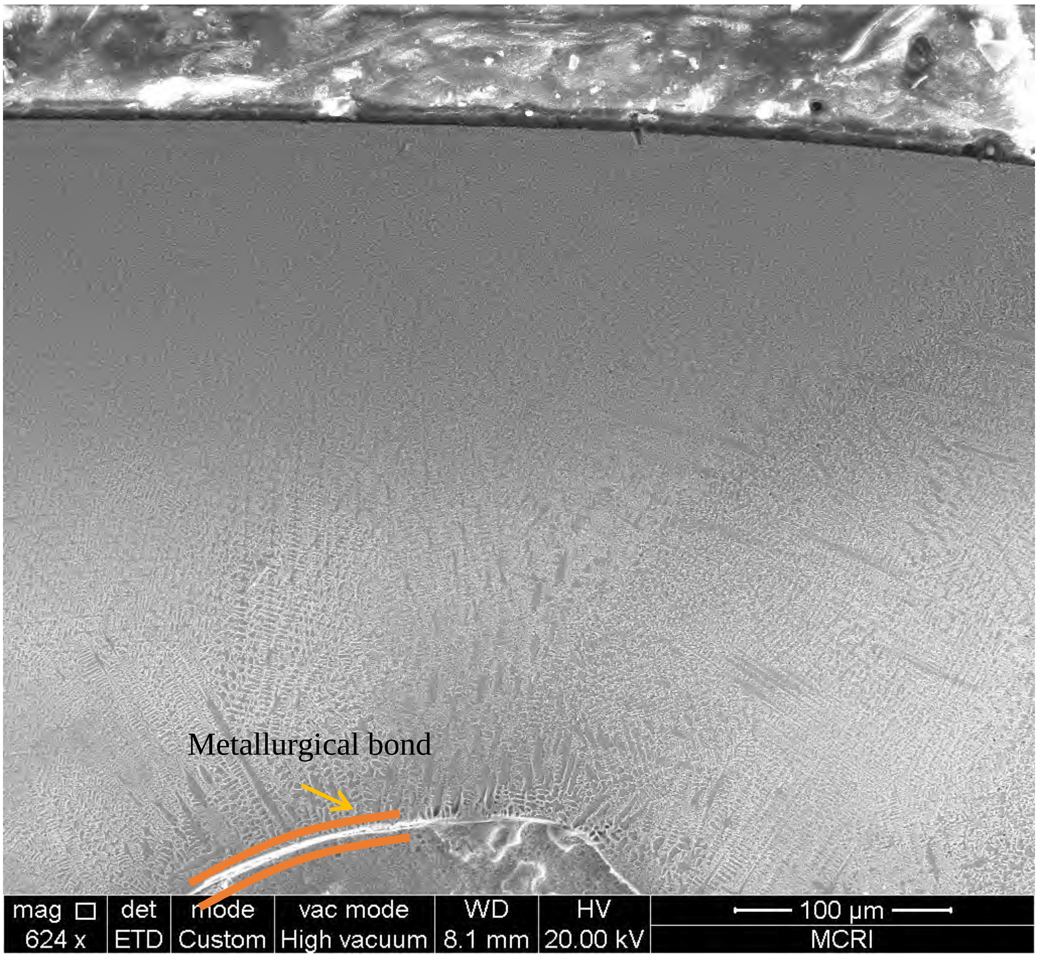

Figure 2. SEM of overlap area of laser clad layer.

It is universally known that the overlap area is the weakest part in laser produced layer. Therefore, this study focus on the microstructure of this overlapped region. It can be seen the top of the layer is flat and neat. The dendrites distribution were homogeneous and compact. This can be explained by the nature of La element: the La atoms is active and are inclined to chemical react with sulfur and phosphorous elements forming low-density chemical reaction product on laser clad layer top. Such compound of lanthanum increased liquid density in solidification cycle and restricted grain growth [7-12]. The dendrites in top area were tinier than that in bottom area. The arrow marked white belt curve was the sign of metallurgically bonding laser coating [7, 8].

3.2. Lanthanum distribution

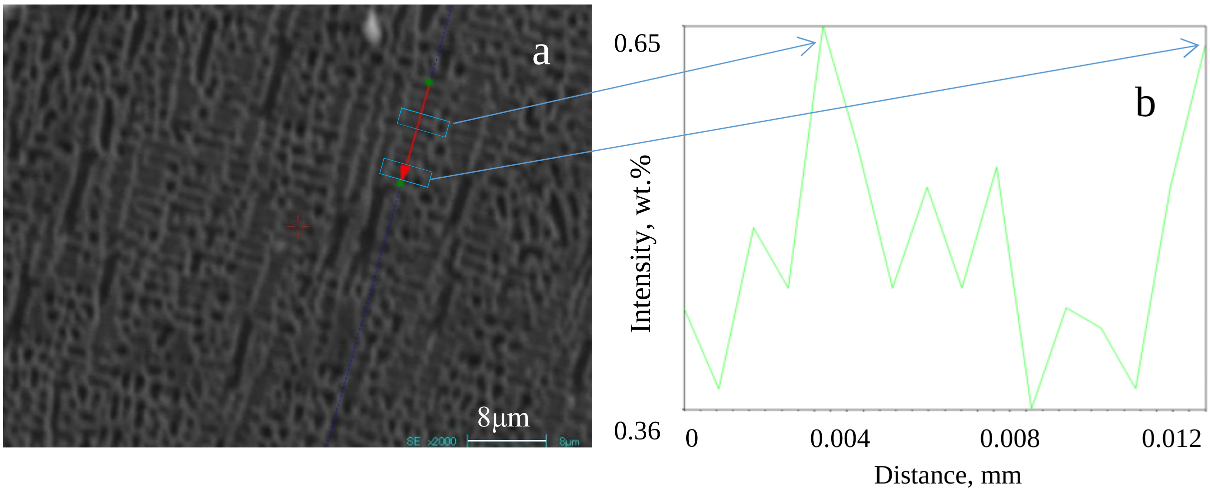

Figure 3. EPMA of La atoms distribution : (a) scan trace location and (b) La content.

In figure 3, the EPMA line scan results proved the La is more likely stay inter-dendrite. Then the drag of grain size increase in molten pool solidification is thus possible. And the top surface dendrites are in fact smaller than that in middle and bottom part, seen in figure 2.

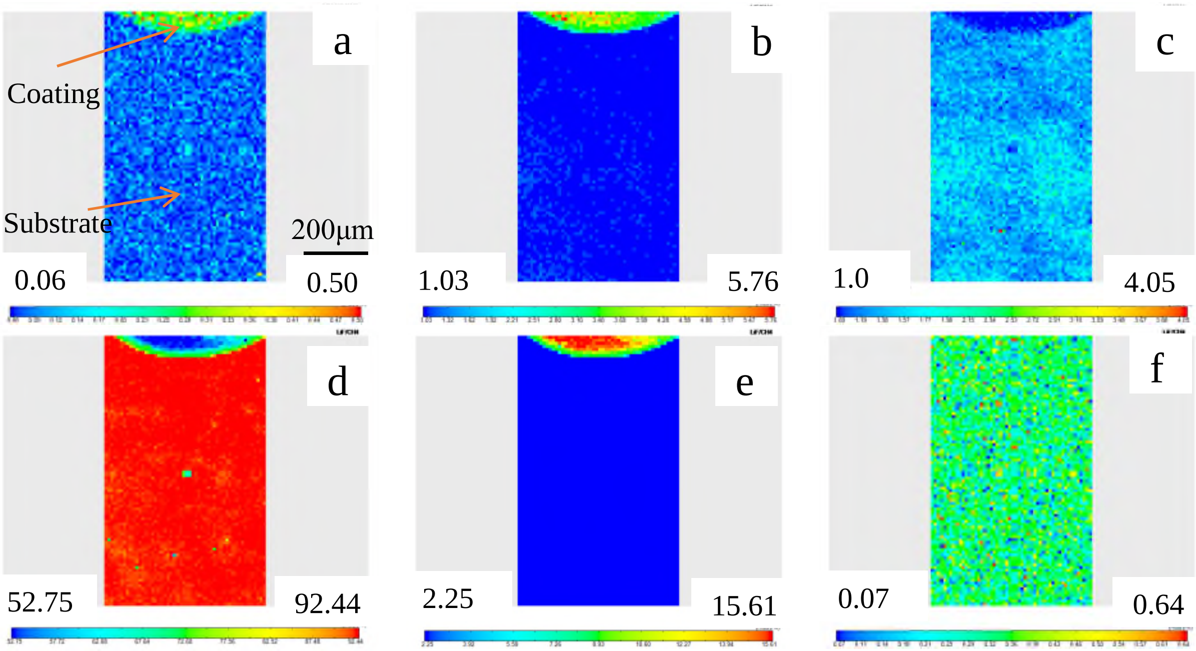

Figure 4. EPMA of different elements distribution:
(a) B, (b) Cr, (c) Mo, (d) Fe, (e) Ni and (f) La. (in wt.%).

From figure 4 (f), a conclusion can be reached that the lanthanum almost evenly distributed in the heat affected zone of substrate and the content density has no obvious differ with that in laser layer zone. This phenomena justified the homogeneously dispersion strengthen of RE to gear steel 17CrMoNi6.

3.3. *Wear test*

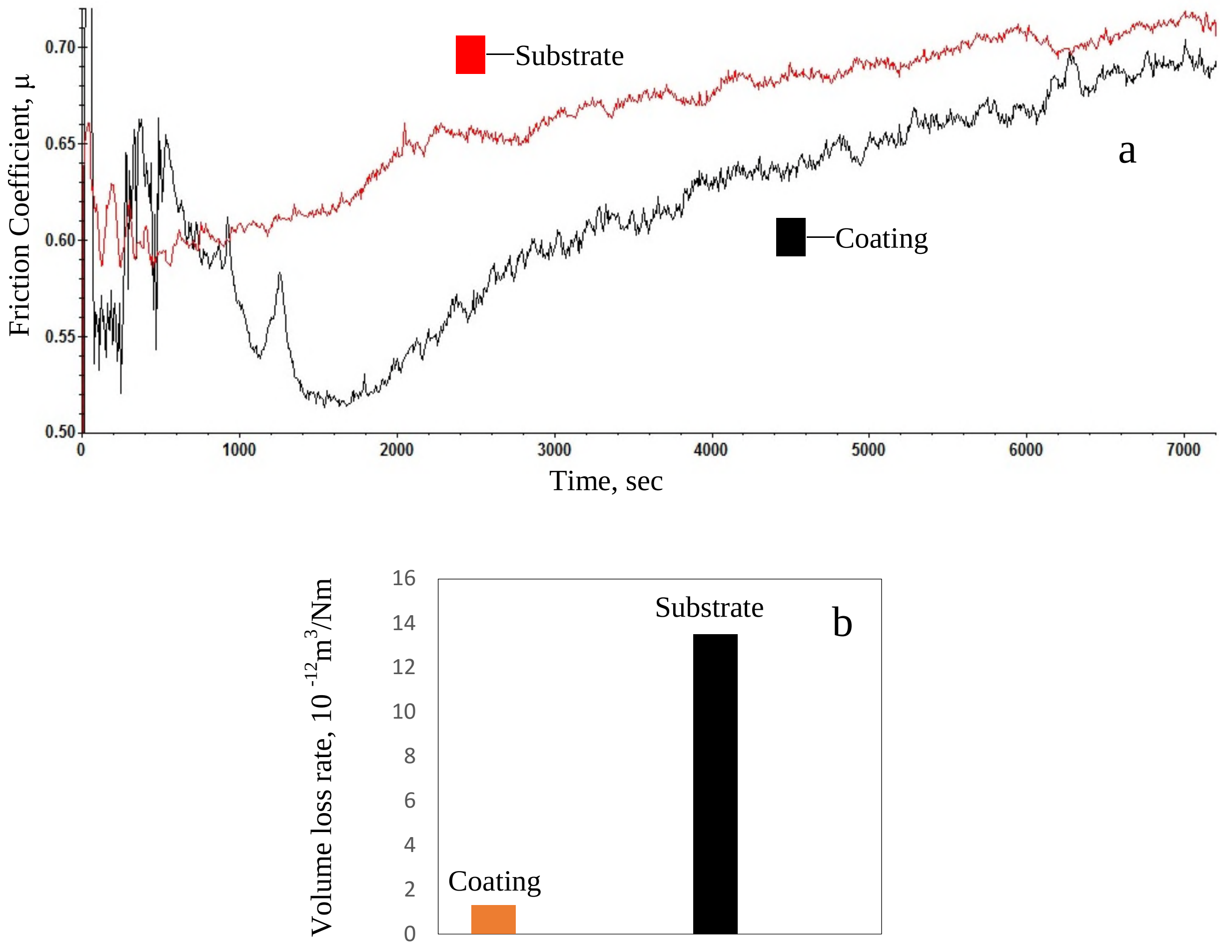

Figure 5. Wear resistance of composite coating: (a) COF and (b) wear volume loss rate.

The COF of composite coating keep below the COF of base steel 17CrMoNi6 in figure 5 (a). As shown in figure 5 (b) the wear volume loss rate average value of 3 tested parallel specimens were 1.3 and 13.5 for composite coating and substrate gear steel 17CrMoNi6, respectively.

4. Conclusions

- The RE element La can be traced evenly dispersed in laser clad layer and deep in the base gear steel 17CrMoNi6.
- The La element mainly segregated in inter-dendrite space and effectively controlled grain size growth.
- Even the overlapped region has both flat and neat top surface and tiny, homogeneous microstructure and dendrites. The laser clad wear-resistance layer has no crack no pore and metallurgically bond with base metal 17CrMoNi6 gear steel.

5. References

[1] Paul C P et al. 2013 *J. Opt. Laser Tech.* **50** 155.
[2] Ocelik V et al. 2015 *J. Surf. Coat. Tech.* **197** 303.

[3] Desale, G R, Paul C P and Gandh B K et al. 2009 *J. Wear* **266** 975.
[4] St Georges L 2007 *J. Wear* **263** 562
[5] Amado J M, Tobar M J and Alvarez J C et al. 2009 *J. Appl. Surf. Sci.* **255** 5553.
[6] Amado J M, Montero J and Tobar M J et al. 2012 *J. Phys. Proc.* **39** 362.
[7] Sharma S P, Dwivedi D K and Jain P K 2009 *J. Wear* **267** 853.
[8] Farahmand P et al. 2014 *J. Ceram. Int.* **40** 15421.
[9] Zhang S H et al. 2008 *J. Mater. Chem. Phys.* **112** 668.
[10] Zhou X W and Shen Y F 2014 *J. Surf. Coat. Tech.* **249** 6.
[11] Sen R J, Das S and Das K et al. 2011 *J. Surf. Coat. Tech.* **205** 3847.
[12] Cai B et al. 2013 *J. Trans. Nonferr. Met. Soc. China* **23** 2002.
[13] Zhang K M et al. 2015 *J. Trans. Nonferr. Met. Soc. China* **22** 1817.
[14] Li X L, He S M and Zhou X T et al. 2014 *J. Mater. Charact.* **95** 171.
[15] Xiao C B and Han Y F 2001 *J. Mater. Sci.* **36** 1027.
[16] Song S H, Sun H J and Wang M 2015 *J. Acta. J. Rare Earth.* **33** 1204.
[17] Serres N, Hlawka F and Costil S et al. 2011 *J. Wear* **270** 640.

Acknowledgments

This work was financially supported by the National Natural Science Foundation of China (51075328, 51675424) and Fundamental Research Funds for the Central Universities (3102015BJ (II) MYZ28).