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Laser cladding of Ni-based hardfacing alloy replacing Stellite06

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Abstract: For the disadvantages of Co element, such as rarity, high price and nuclear pollution, the Co-based materials will be eliminated in the valves which are used in the third and fourth-generation nuclear plants. In this paper, the composition of a Co-free Ni-based alloy was designed. With laser cladding technology, the Ni-based coatings were obtained. Microstructure of the coatings was characterized by optical microscopy (OM) and scanning electron microscopy (SEM). The phases in the surface layer were identified by X-ray diffraction (XRD) and energy-dispersive spectrometer (EDS). And the wear resistance of the coatings were tested and compared with Co-based alloy. The results showed that the coatings were mainly made of dendrite phases and interdendritic constituents. The dendrites were characterized of primary dendrites M_7C_3 and $M_{23}(CB)_6$ and some Ni_3Al round particles uniformly dispersed in the γ-Ni matrix. There were a bit of Ni_3B and Ni_3Si phases in the coatings. The wear volume loss of Ni-based alloy was close to of Co-based alloy.

Introduction

Nuclear valve is the important nuclear equipment and its sealing surface whose quality affects the valves' service life directly is the most crucial working face. The valves' life can be obviously lengthened by using hardfacing materials with good properties. The Co-based alloy has long been thought as No.1 hardfacing materials which are suitable for high temperature and high pressure valves. But the element Co is rare and expensive. The worst is, in radiation environment Co can be easily activated to be isotope Co_{60} which can cause nuclear pollution for its long radioactive half-life [1]. As a result, the Co-based materials will be eliminated in the valves of third and fourth-generation nuclear plants. So it becomes necessary and urgent to design new Co-free hardfacing alloys to replace Stellite alloys.

In our previous study, the efforts of fabricating wear resistant composite coatings on valve seats with Ni-Cr-W-C powders were made and the results showed that Ni-Cr-W-C alloy was a promising material for hardfacing valves [2-5]. On the other side, for the excellent performances of intermetallic compound Ni_3Al, such as high-temperature strength, high-temperature oxidation resistance and strong effects on age hardening[6], as a further step in obtaining high performance anti-wear composite coatings on nuclear valves, Al element was added in the previous Ni-Cr-W-C powders. Through the adjustment of Ni-based alloy composition and laser cladding parameters, the coatings were got with good structure and properties.

Experimental Procedures

Specimen. In this work, stainless steels 1Cr18Ni9Ti 50mm × 30mm × 10mm were used as the substrate. The composition of Ni-based alloy powders mainly contained Ni, Cr, Al, W, Mo, Si, B and C. Chemical composition of substrate and Ni-based powders was listed in Table1.

The powders mixed with the adhesive cellulose acetate were spread on the surface of substrate and dried in an even at 120℃ for 1h. The process parameters for laser cladding were: laser power 4KW, beam diameter 3.0mm and beam traverse speed 6.0mm/s. Argon gas was used to protect the surface from oxidation.

Table 1 Chemical compositions of 1Cr18Ni9Ti and Ni-based alloy (wt %)

Alloy	Amount (%)								
	C	Cr	Ni	Mo	Fe	Si	W	Al	Y_2O_3
1Cr18Ni9Ti	≤0.12	17.0～19.0	8.0～11.0	-	余	≤1.0	-	-	-
Ni-based	1.0～1.2	24.0～28.0	Bal.	4.0～6.0	-	2.4～2.8	4.0～5.0	6.0～10.0	1.0～5.0

Microstructure of the coatings was characterized by optical microscopy (OM) and scanning electron microscopy (SEM). The phases present in the surface layer were identified by X-ray diffraction (XRD) and energy-dispersive spectrometer (EDS).

Wear test specimens were machined as presented in Fig.1. Wear test surfaces were polished to a roughness value Ra less than 0.8μm and the hardfacing thickness of specimens was about 1.0-1.5mm.The wear resistance tests were carried out on a ball-on-disc type high temperature sliding friction machine supplied by Lanzhou Institute of Chemical Physics CAS. The tests were performed in air at temperature 360℃ which was higher than maximum operating temperature of nuclear power plant valves. The angular sliding speed was 200r/min and the movement orbit radius was 5mm. At the first 5 minutes the temperature rose from ambient temperature to 360℃ and then it kept at 360℃ for 2 hours. After the tests, the abrasive surfaces of specimens were measured in profiler. The wear volume loss of Ni-based alloy was measured and compared with Stellite06's.

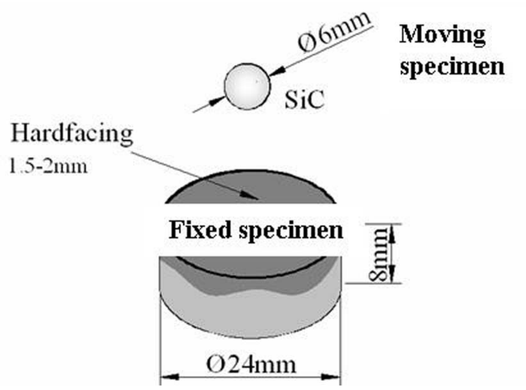

Fig.1. Geometry of wear test specimens

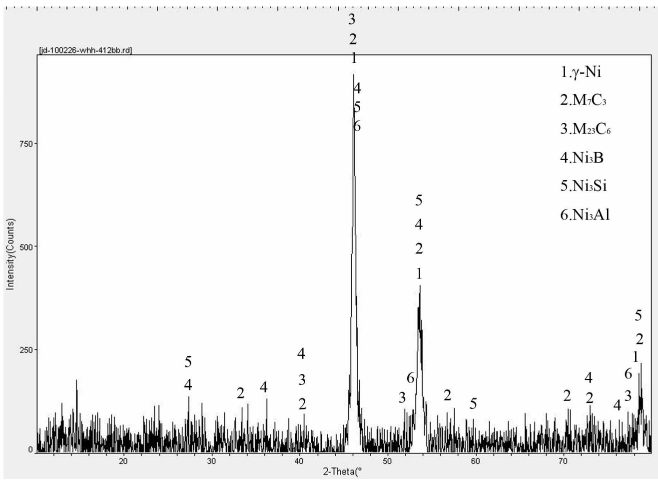

Fig.2. XRD spectrum of Ni-based alloy

Results and Analysis

Microstructure and Micro-hardness. Different phases formed in the cladded layers were identified through X-ray diffraction and EDS analysis. XRD spectrum of Fig.2 showed presence of γ-Austenite, M_{23}（CB）$_6$ (M means Cr, W, Mo, Ni, Si), M_7C_3, Ni_3Al and a bit of Ni_3B, Ni_3Si phases in the layers.

Fig.3 (a) was the typical microstructure of Ni-based alloy coatings (SEM), which could be seen more clearly in Fig.3 (b) with higher magnification. The microstructure featureed primarily dendrite phases and interdendritic constituents.

Due to the low solubility of C in Ni-based solid solution and the high melting point of carbides[6], M_7C_3 and $M_{23}(CB)_6$ phases were precipitated first from the molten pool. In general, M_7C_3 phases were precipitated from C-rich zone directly. But $M_{23}C_6$ phases were thought to form in two ways: formed via peritectic reaction between liquid and M_7C_3; precipitated directly from liquid phase [7]. In the similar way, there some Ni_3Al phases (also called γ') were formed. Along with the decrease of temperature of molten pool and the reduce of C in liquid phase, So most of Cr, W, Mo, Si could only be super-saturated in residual molten pool and eutectic reaction happened to form the stable γ-Ni solid solution, which was the ductile, heat and corrosion-resistant matrix and a bit of hard phases such as Ni_3Si and Ni_3B. The element of B usually segregated on grain boundary and made positive effects on grain boundary strengthening.

EDS analysis, as shown in Fig.3(b), revealed the matrix to be γ-Ni, which also contained Cr, W, Mo, Al and Si， dendrites and some blocks to be carbides, some round grains to be γ' and the phases between the dendrites and inter-dendrites with network distribution to be Ni_3B. As the structure of Ni_3Si was very fine, EDS analysis was unable to distinguish the individual phases.

For the large amount and high hardness of carbides, they played a vital role in strengthening the coating. γ' phase owned the face-centered cubic long-range order structure and its lattice parameters were close to matrix. It contained many other elements such as W, Mo, Ni and etc and made strong age hardening effects.

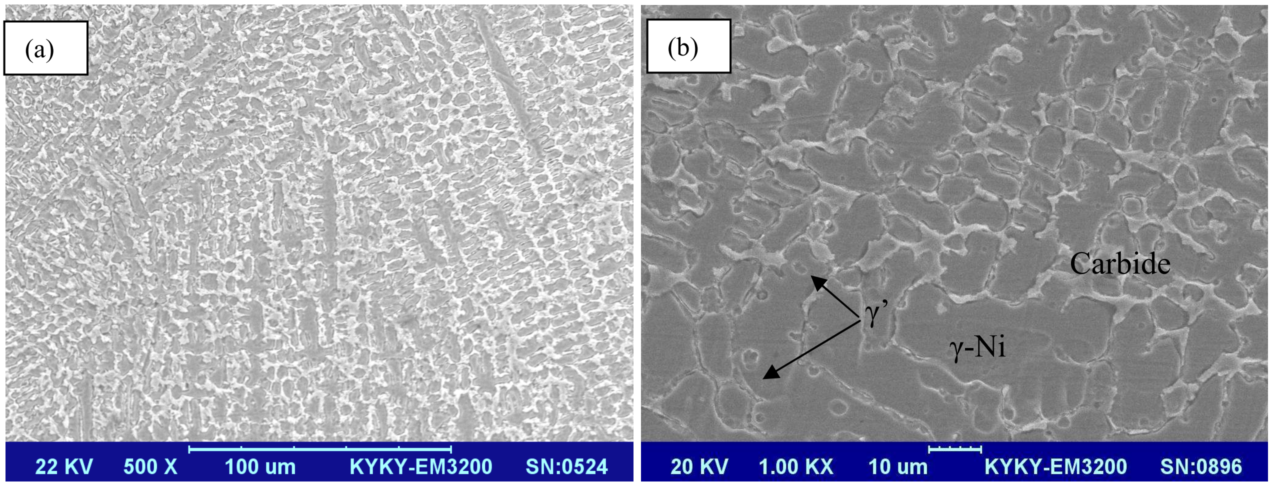

Fig.3 SEM typical microstructure (a) and its magnified image (b) of Ni-based alloy laser cladding

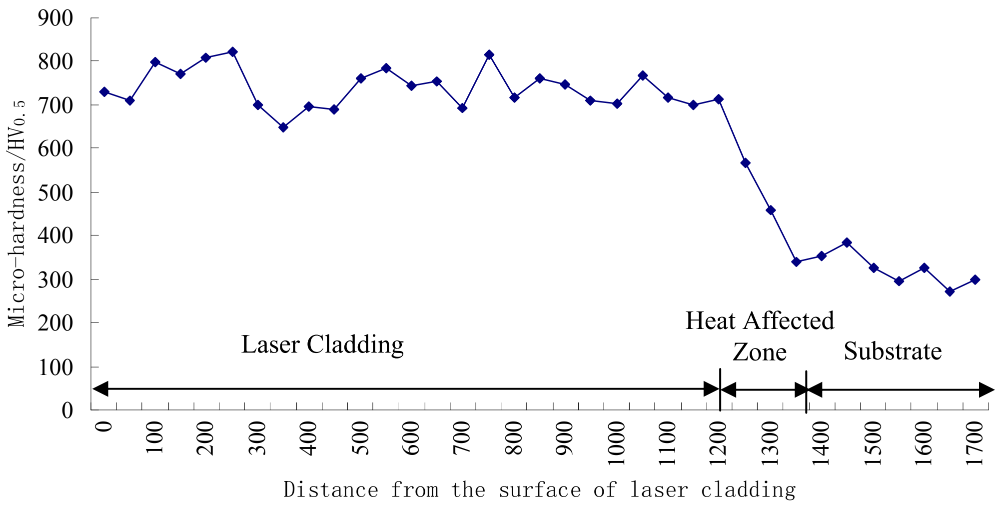

Fig.4. Distribution of micro-hardness

Fig.4 showed the hardness distribution of laser cladding from surface to substrate. The hardness distribution may be divided into three regions: the top cladding layer, the heat affected zone and the substrate. The average micro-hardness of the alloy layer was about $730HV_{0.5}$. Owing to solution strengthen, second phase strengthening and grain boundary strengthening, the micro-hardness of the coatings was more than twice of stainless steel substrate ($270\ HV_{0.5}$-$300HV_{0.5}$).

Wear Performance. Fig.5 showed the profiles of wear traces of Ni-based alloy and Stellite06 coatings and the wear volume loss was $21.4mm^3$, $20.3mm^3$, respectively. The wear resistance of Ni-based alloy was very close to Stellite06 under the present wear test conditions. So it is possible for this kind of Ni-based alloy to replace Stellite 06 alloy in the nuclear valves which generally suffer from wear.

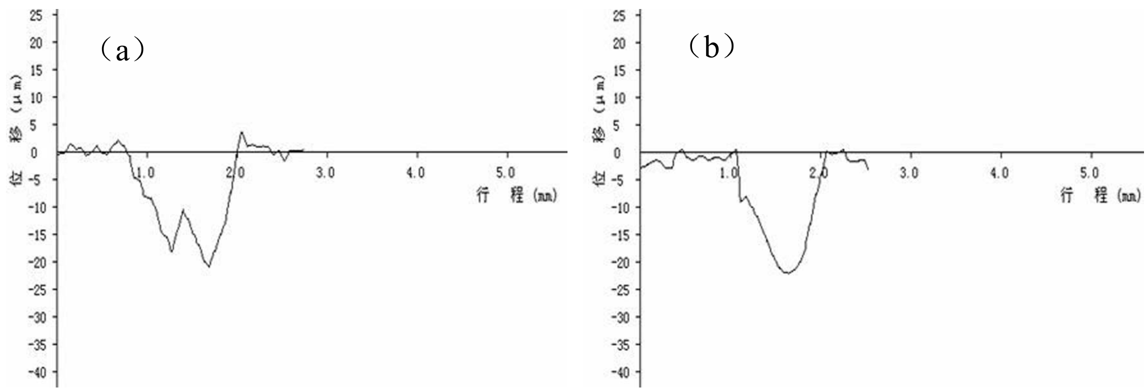

Fig.5 Profile of wear trace of Ni-based alloy (a) and Stellite06 (b)

Summary

From the above, the following conclusions can be drawn:

(a) A Co-free Ni-based alloy was designed. Combined with laser cladding technology, the defect-free coatings were obtained with compact-grain structure, and mainly consisted of dendrite phases and interdendritic constituents.

(b) Microstructure of Ni-based alloy coatings was characterized of primary dendrites M_7C_3 and $M_{23}(CB)_6$ carbides reinforcement as well as some Ni_3Al round particles uniformly dispersed in the γ-Ni matrix. And there were a bit of Ni_3B and Ni_3Si phases in the coating.

(c) The wear volume loss of both materials was 21.4mm^3 (Ni-based alloy) and 20.3mm^3(Stellite06), respectively. It is possible for this kind of Ni-based alloy to replace Stellite 06 alloy in the nuclear valves which generally suffer from wear.

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