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Study on Microstructure and Properties of Slab Crystallizer by Laser Coaxial Cladding Strengthening

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Abstract. Adopted the compounding Ni-base alloy powder and properly mixed a few functional powders, the study on surface strengthening for slab crystallizer base material by substrate pre-heated and laser coaxial feeding cladding was investigated. The results indicate that the laser coaxial feeding cladding can effectively decrease cladding layer's pores and crackers compared with laser pre-laid cladding, the cladding layer structure is compact, uniform with typical rapid freezing character and the structure can be controlled by compounding alloy powders. The elements of substrate and cladding layer infiltrate and dilute to each other, the bonding interface is good with metallurgic and tight combination and the rate of dilution is very low. The erosion resistance and thermal fatigue of substrate are improved evidently by this treatment.

Introduction

Crystallizer is the key part for caster, which directly affects the surface quality of casting billet, working efficiency and working cost. The high efficient continuous casting technology asks for the important index as high strength, high wear resistance, high corrosion resistance and good thermal conductivity. Due to good thermal conductivity for the copper, crystallizers are made up of substrate as copper, but the copper is harm to most steels which leads to star-shaped cracks if the copper elements enter the billet during the smelting. To solve this problem, electrodeposition and plasma spraying have been used to enhance the surface capability. But the technology of electrodeposition and plasma spraying is difficult to control, the cost is high, the pollution is severe and the combination between coating layer and substrate is mechanical bonding, which limit its development space[1-3]. Moreover, laser cladding is a promising surface treatment for technological applications with an excellent metallurgical bonding, no pollution, high productivity and low cost compared with electrodeposition and plasma spraying.

Because of the character of copper as high thermal conductivity and reflectivity to laser beam, some scholars adapted the pre-laid powder and laser sintering to strengthen the surface. For example, Dehm pre-laid the Ni-based alloy and Co-based alloy on copper substrate then laser sintering[4]. Liu pre-deposited the Ni-based powder on the copper surface by plasma spraying, then remelted by steady plasma arc laser produced by a 5 kW transverse-flow CO2 laser[5]. Gao pre-brushed then clad to make ceramic coating layer[6]. The coated layers made by pre-laid powder then sintering exist many obvious pores and cracks which bring about stress concentration and reduce the quality of cladding layer.

Experimental

Experimental materials. The laser cladding is the typical process of rapid fusing and freezing, the temperature change is very large(10^4~10^6℃/s) in the cladding layers and bonding area, which is the main reason for fracture and crack of cladding layers because the large temperature change creates composition segregation and uneven for volume change among the substrate and powders with different physical characters.

Because Ni and Cu have the similar character as thermal expansion coefficient, melting point and wettability, the compounding powder were made up of Ni-base alloy (the elements of powder were shown in Table 1) and other powders as CuO to reduce the transgranular, MgO to thin and decrease cracks, Fe to improve the hardness and corrosion resistance for the formation of FeNi. The particle size of the powder was from -200-300 mesh. The substrate is slab crystallizer and the element content is: Cr, 0.5-1.5; Zr,0.08-0.3; Cu,97-99.

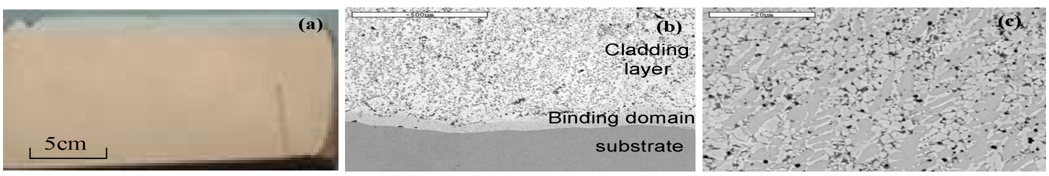
Table 1 Chemical composition of the Ni-based alloy (wt%)

Cr	W	Ti	Mo	B	Si	C	Ni
15-17	9-10	2-3	9-10	1.5-2	2-3	0.2-1.1	Bal

Experimental method. The powder was exsiccated in drying cabinet for 2 hours with the temperature of 100℃. The treatment to surface of slab crystallizer included degreasing and activating. Before laser cladding, the substrate was pre-heated to 600 ℃ by home-made heater, subsequently, the powder was clad on the crystallizer by coaxial powder feeding, then the crystallizer was cooled to room-temperature with heater in 1 hour. In this study, the parameters were as follows: laser power,1.8kw; scanning speed,4.0mm/s;laser beam diameter,2.5mm;the ration of overlap,32%; the thickness of each layer,0.6-0.7mm; three layers with cross cladding; powder feeding,15g/min; and the shielding gas, argon gas. The sample was cut as vertical to the scanning direction and parallel to the substrate surface separately, then the sections were polished and eroded by HF(10%)+HNO_3(90%).The microstructure and phase evolution of the cladding layers were characterized using metallographic microscope and scanning electron microscope(SEM).

Results and Discussion

Morphology of cladding layer. Figure 1 is the picture of cross section and microscope of cladding layers. The morphology of cladding layer was smooth, uniform and continuous, and there was no deficiency such as cracks and pores. The cladding layer consists of dendrites and equiaxed grains, which is the typical character of rapid freezing.



(a)cross section; (b) structure state of cladding layer and substrate; (c)Structure of cladding layer

Fig.1 Morphology and microstructure of cladding layer

X-ray diffraction to the cladding layer was made and the result is shown as Fig.2. The phase composes of γ phase solid melts(Ni-Cr) and other compounds such as Fe3C, Ni31Si12, Cr15.58 Fe7.42C6 existing in eutectics among dendrites. The crystal orientation peaks of others solid melts and compounds are stationary except that Cr1.12Ni2.88 is obvious, which show that the internal crystal orientation and gains are relatively fine and the orientation is nearly consistent.

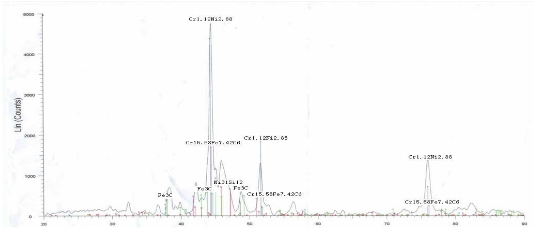


Fig. 2 X-ray diffraction pattern of sample in the inner of cladding layer

Microstructure and invasive character of bonding interface. The microstructure indicates that the cladding layer and substrate combine tightly and there is a bright transitional zone between them, which is bonding zone that the elements of cladding layer and substrate diffuse to each other. The bonding interface is uneven as serrate which shows that the surface of substrate has been presented phase transition by laser heat but the affected zone is very small. The structure between cladding layer and substrate exists gradient change and there are no cracks and pores, as shown in Fig.3.

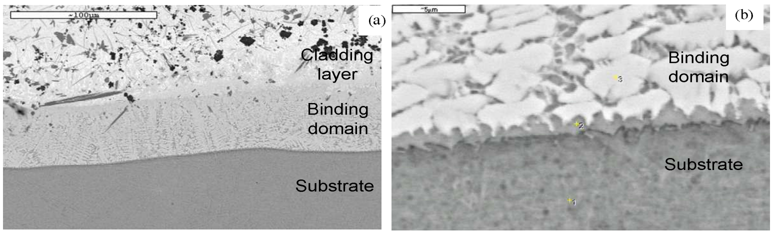


Fig.3 SEM of the bonding domain between cladding layer and substrate

X-ray diffraction to the bonding interface between cladding layer and substrate was made and the result is shown in Fig.4. The phase composes of γ phase Cu, γ phase Ni-Cr and other compounds such as Fe3C, Ni31Si12. The crystal orientation peaks of γ phase Cu and γ phase Ni-Cr are significant which illustrates that the grains are bigger and crystal orientation is unorderly. The microstructure is non-directional freezing structure strengthening the combination.

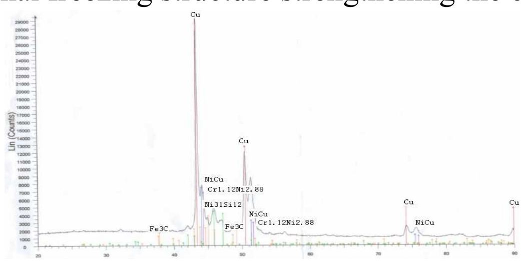


Fig.4 X-ray diffraction pattern of the bonding interface

Figure 5 showed the EDS and the thickness distribution of each element in the bonding interface along the growth direction of cladding layer. There were the elements of powder in the substrate and element copper in the bottom of cladding layer. The bonding interface comprised of elements such as Cu, Ni, W and Cr. Furthermore, the content of each element changed with gradient, the distance of Cu existing in cladding layer is 50μm and Ni existing in substrate is 30μm. These indicated that the substrate and the cladding layer were diluted by each other and the elements infiltrated to each other. The bonding interface with metallurgic and tight combination was obtained.

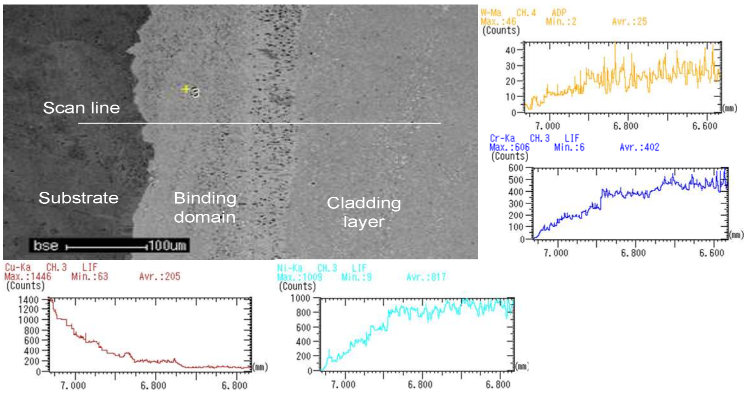


Fig.5 Element thickness distributions in bonding interface

Erosion resistance. The erosion resistance test of sample was conducted by putting them in $CuSO_4$ etching solution for 24h, 48h and 72h, the results are shown in Fig.6. Both of the cladding layer and substrate appeared less yellow rust spots and the lost weight is 1.4mg, 1.8mg and 2.1mg by precise electronic analytical balance, which explained that the cladding layer has good erosion resistance.

(a) Corrosion for 24 hours (b) Corrosion for 48 hours (c) Corrosion for 72 hours

Fig.6 Corrosion results in $CuSO_4$ solution of the samples

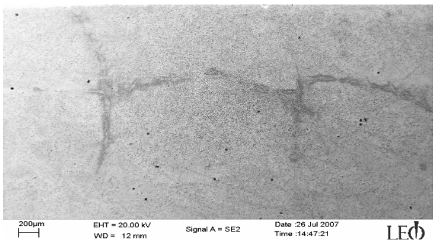
Thermal fatigue. The thermal fatigue detection of sample was made. The sample was cut by linear cutting along the direction vertical to laser scanning. The test process is as followings: heating the sample to 700℃ by 20s, keep the temperature for 90s then put them in the water at room temperature, repeat the process for 40, 80 and 120 times..

After 40 times cycle, the bonding interface did not show any cracks and the same with the cladding layer. There are less microcracks along dendrite boundary direction by scanning electron microscope, shown in Fig.7(a). After 80 times, the bonding interface has obvious interface cracks and the cladding layer has many microcracks, the interface crack occupies about 20~30%, shown in Fig.7(b).

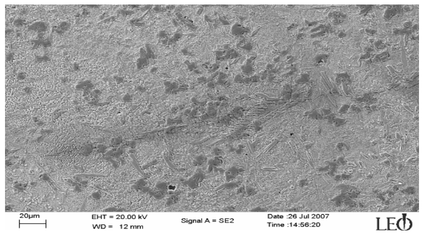
(a) SEM micrograph of sample after 40 times (b) SEM micrograph of sample after 80 times

Fig.7 SEM micrograph of sample for thermal fatigue

After 120 times, the bonding interface appeared large area interface cracks while the cladding layer did not exfoliate from the substrate. The interface cracks account for 60~75% of whole interface zone and the cladding layer existed obvious horizontal-vertical cracks. The reason for the horizontal-vertical cracks is that there is difference of thermal expansion coefficient between cladding layer materials and substrate, the bonding interface is metallurgic combination and internal stress did not release along the interface zone, which lead to the cracks in the cladding layer, shown as Fig.8. Observed at more amplification, most cracks are transgranular and appeared around the big grains because internal stress was accumulated by more times thermal fatigue formed tensile stress that released to grains or around the big grains while the fine grains have good bonding force.



(a) SEM micrograph of sample after 120 times



(b) Microcrack result of sample after 120 times

Fig.8 SEM micrograph of sample after 120 times thermal fatigue

Conclusions

(1) Adapted substrate preheated and coaxial power feeding, the slab crystallizer was strengthened by laser cladding, the interface between substrate and cladding layer is metallurgic combination and the elements in interface is gradient transition, which efficiently decrease the pores and crack compared with pre-laid powers.

(2) Through cladding compounding Ni-base alloy powder and properly mixed a few functional powders on the crystallizer, the composition of cladding layer is easily controlled and the morphology of cladding layer was smooth, uniform and continuous. There was no deficiency, the erosion resistance and thermal fatigue are improved obviously, which was able to provide strong protection to the crystallizer.

(3) Because of the character of rapid fusing and freezing for laser cladding, not only the substrate and cladding layer implement metallurgic and tight combination, but also the dilution between them is small, which keeps them have functional properties to each other.

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