The preparation of biomimetic nano-Al_2O_3 surface modification materials on gray cast iron surface

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Abstract

Through evolution over hundreds of millions of years, the natural biomaterials generally have superior microstructure and function to normal material. The surface layer of teeth is enamel, which is the hardest structure in the human body. Enamel as a kind of nanoceramic biomaterial; most of its physical and chemical characteristics are similar to normal ceramics. It is of high hardness and is particularly wear resistance. However, the gray cast iron is one of widely used materials. In the process of casting, surface blowholes and micro-pores, which can't be seen by the naked eye, are formed in castings because of the solidification shrinkage of alloy and separation of gas dissolving in liquid alloy, which results in the poor property of materials. Therefore, the gray cast iron and nano-Al_2O_3 were chosen as the substrate and reinforcement in this paper, respectively. A laser cladding method was used to prepare biomimetic nanoceramic surface modification composite materials. The surface property of gray cast iron was largely improved. The process and the factors influencing laser cladding were analysed. The microstructure of the surface modification layer can be divided into a cladding layer, bonding layer and substrate layer, and the formation mechanism of each different layer was researched.
Keywords: nano-Al_2O_3, biomimetic, surface modification, gray cast iron, microstructure.

WIT Transactions on Ecology and the Environment, Vol 87, © 2006 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/DN060131

1 Introduction

Tooth enamel is a kind of mineralized structure containing about 96% minerals, consisting mainly of calcium and phosphorus as calcium phosphate. As a kind of nanoceramic biomaterial, the surface of enamel has high hardness and wear resistance [1]. According to the special structure of teeth, a bio-inspired nano-Al_2O_3 surface modification material on gray cast iron was designed and prepared with a laser cladding method. Nano-Al_2O_3 was chosen as reinforcement in this paper. The process and the factors influencing laser cladding were analysed. The optimal technology parameters of laser cladding were obtained from this experiment. The solidification process and microstructure of the surface modification layer were researched.

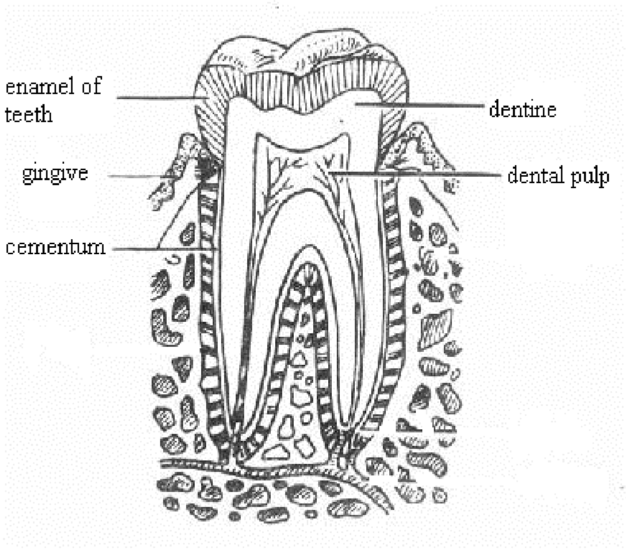

Figure 1: The microstructure of a tooth [2].

2 The preparation of biomimetic nano-Al_2O_3 surface modification layer

Laser cladding is a very quickly dynamic melting and solidifying course, whose cooling speed is quick (up to 10^6 °C/s). The microstructure was fine due to non-equilibrium solidification [3]. The reuniting of nanomaterials was effectively avoided. At the same time a small amount of nanomaterial formed a fine metallic bond between the cladding layer and the substrate, increases surface hardness and wear resistance.

2.1 The choice of modification materials

Nano-Al_2O_3 was chosen as modification material. The average granularity of nano-Al_2O_3 was 50nm ~ 180nm , with purity more than 99.99% and physics phase α- Al_2O_3. α- Al_2O_3 grain is stable, has a high hardness and has uniform dimensions.

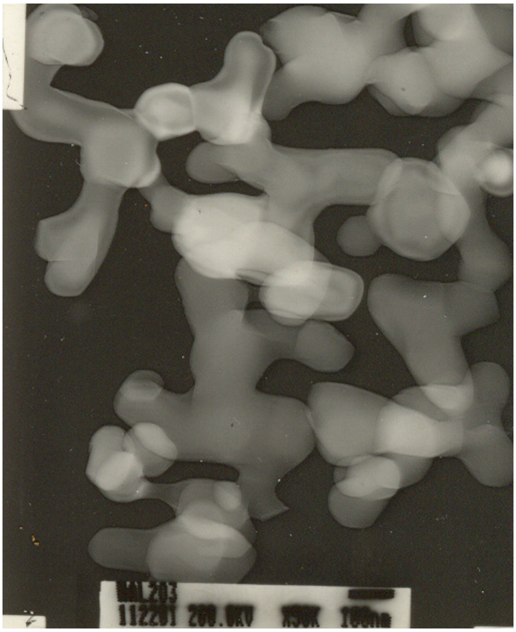

Figure 2: Nanoalumima microstructure (SEM).

2.2 Optimization of technology parameters

A 5 kW CGJ-93 type crosscurrent CO_2 laser machining equipment developed by Changchun University of Science and Technology was used. The colophony alcohol solution was chosen as a binder. The coating material was coated on gray cast iron surface and then scanned by laser.

The laser equipment usually has two kinds of facula including gauss facula and rectangle facula with broadband. The energy density of the broadband rectangle facula is uniform and fit for laser cladding. The dimension of the sample is $500\times50\times150mm^3$, and the dimension of facula is $15\times2mm^2$. The range of power is 2.0 ~ 3.0kw and the scanning speed is 90 ~ 120 mm/min. The power and scanning speed were chosen as technology parameters. The result of our experiment indicated that the optimal technology parameters were to use a 3.0 kW laser and scanning speed of 90mm/min.

3 Analyses on the course of laser cladding

Laser cladding is a dynamic melting and solidifying course, and non-equilibrium state. With the laser beam scanning continually the melting and solidifying of metal occurred in the melting pool at the same time. In the fore of the melting pool, alloy powder enters the melting pool and melts quickly, governed by self-diffusion, surface tension due to temperature gradient on surface and gravity, diffusing in very short time. In the back of the melting pool, as the laser beam moved away a great deal of heat was transferred quickly by substrate and liquid metal suddenly cooled and solidified. In the process of laser cladding, molten metal solidifies very quickly, and the nucleation rate increases greatly. Thus the microstructure of the cladding layer was fined [4,5], which was a key element improving cladding layer property.

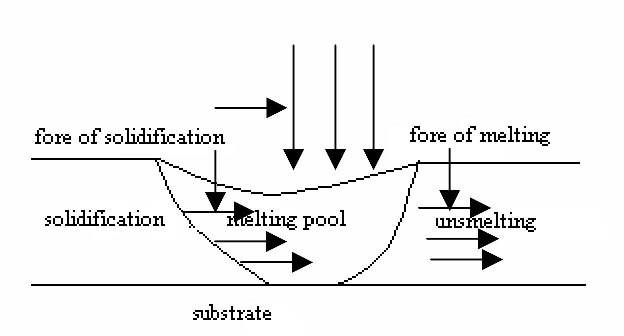

Figure 3: The course of laser cladding.

4 The microstructure of cladding layer

The gray cast iron used contained 3.4 wt%C was hypoeutectic. The sample of laser cladding had three different layers including a cladding layer, bonding layer and substrate layer. Fig.4.1-4.4 showed the three layers of the microstructure.

a) Fig.4.1 shows the microstructure of the cladding layer. The non-equilibrium solidifying microstructure was formed under the condition of fast solidification. In the solidification process, the nucleation rate increased greatly and the grain growth was prevented due to the large temperature gradient in melting pool. The microstructure was fine and dense and C didn't diffuse and existed as carbide in the cladding layer so that the gray cast iron transformed into white cast iron in which a ledeburite phase exists. The martensite phase was formed in the cladding layer due to the fast cooling speed.

b) Fig.4.2 shows the microstructure of the interface bonding layer that was affected by temperature gradient. The temperature near the cladding layer exceeded autenitic temperature due to the influence of surface laser energy. In the process of fast cooling, in addition to a small amount of residual autenitic, most of the autenitic had transferred martensite. A good metallurgy bonding between the cladding layer and substrate was formed as shown in Fig.4.2.

c) The substrate was gray cast iron, whose microstructure was pearlite + ferrite + flaky graphite as shown in Fig 4.3. The microstructure didn't change and still kept a typical gray cast iron microstructure because the layer was far from the surface, only transferred heat and its temperature wasn't high.

It can be found that the microstructure of the cladding layer was dense and uniform (as shown in Fig.4.4), but the microstructure of the substrate was loose. The bonding layer between the cladding layer and the substrate produced a good metallic bonding.

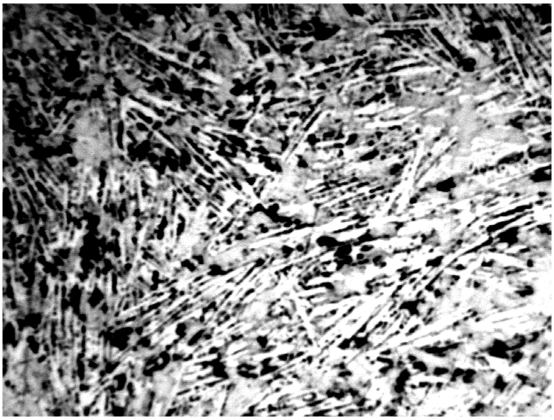

Figure 4.1: Cladding layer micro-metallographic structure ×250.

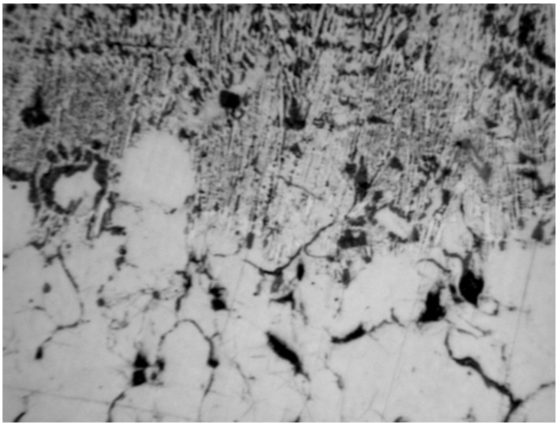

Figure 4.2: Bonding layer micro-metallographic structure ×250.

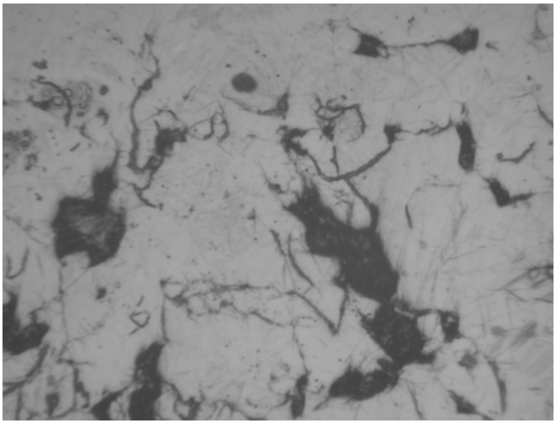

Figure 4.3: Substrate micro-metallographic structure ×250.

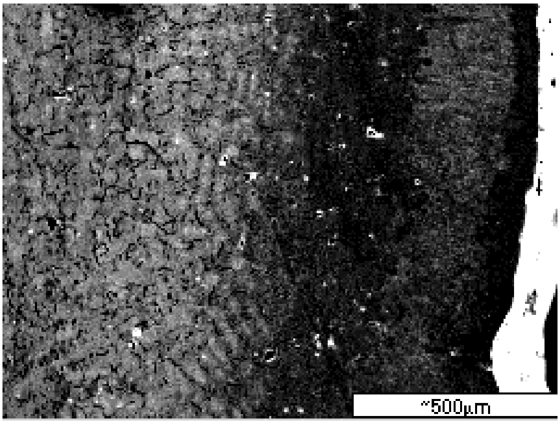

Figure 4.4: Interfacial microstructure (SEM).

Fig.5 showed the element component of cladding layer. The result proved that nano-Al_2O_3 diffused into the cladding layer under laser beam scanning. Fig.6 showed the element component of the substrate and the component of substrate is still gray cast iron.

The technology parameters in the process of laser cladding have important effects on the microstructure of the cladding layer. When the output wavelength of the laser was determined, the main parameters affected the process of laser cladding included laser power P, dimension of facula D and scanning speed v [7]. The facula was a fixed value in this experiment, so the main parameters were laser power P and scanning speed v. When P was too high and v was too low, the energy absorbed by the cladding layer was increased, and the temperature was high. The substrate was melted, the dilution ratio was increased, which resulted in burning loss of the coating materials. On the other hand, when P was too low and v was increased, the energy absorbed by the cladding materials was reduced. Therefore, the temperature was lower, the substrate didn't melt, and the cladding layer was easy to break off. A good metallic bonding was not formed in the interface, and the surface was very rough. The influence of the scanning speed on the cooling speed was important. The cooling speed was increased if the scanning speed was increased. Therefore, the grains of the cladding layer were fine. Increasing the scanning speed was essential for producing a good metallic bond between the cladding layer and the substrate.

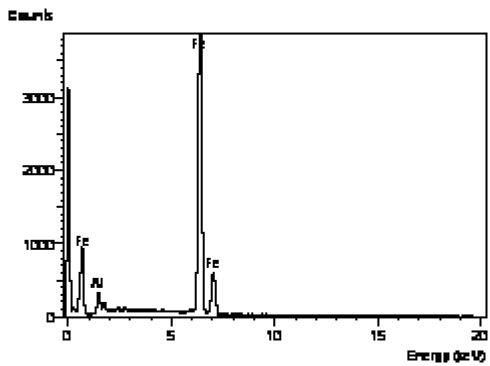

Figure 5: Energy spectrum curve of the cladding layer.

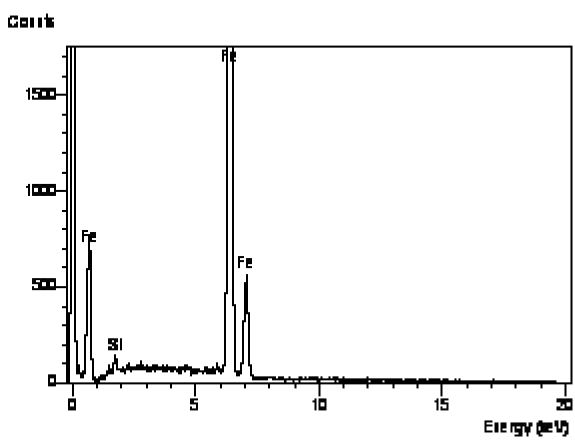

Figure 6: Energy spectrum curve of the substrate

5 Conclusion

1. The gray cast iron was used as a substrate, and nano-Al_2O_3 was chosen as reinforcement. A laser cladding method was used to prepare biomimetic nanoceramic surface modification composite materials.

2. The course of laser cladding was analysed. The microstructure can be divided into a cladding layer, a bonding layer and a substrate layer. The forming factors of different layers were researched.

3. The influence of technology parameters on the microstructure of the laser cladding layer was researched.

Acknowledgements

The authors are grateful for the financial support provided by Trans-Century Training Program Foundation for the Talents by Chinese Ministry of Education (2003) and the Foundation for Distinguished Young Scholars of Jilin Province (Grant No. 20040104)

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