Effects of Y_2O_3 upon mechanical properties of laser coating

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Roles of Y_2O_3 in mechanical properties of the bioceramic coating by the laser cladding were reported in this paper. The bonding strength of interface between the laser coatings with/without Y_2O_3 and substrate Ti-6Al-4V (TC4), bending strength, compressive strength, tensile strength, and hardness in these coatings were contrastively tested, and the ceramic-metal interface was observed by scanning electronic microscopy (SEM). These results indicated that the rare earth was the important factor which influenced the mechanical properties of the coating. Y_2O_3 was adequately dispersed in the melting pool of the laser coating, crystal grain got smaller after the melted coating was cooled, the impurity existing in crystal interface was reduced by chemical reactions, and so the strength was evidently improved. On the other hand, the rare earth could also obviously increase the hole numbers in the coating and decrease the compressive strength. So the effects of the rare earth on the laser coating were intricate and all-purpose.

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The biomedical materials, due to their mechanical properties such as bending strength, compressive strength, tensile strength, hardness and so forth, are prerequisite to substitutions for the biological organs or tissues, in particular, for the hardness tissue which need endure or transfer the loading. Laser cladding calcium phosphate (Ca-P) coating on alloy Ti-6Al-4V (TC4) is a promising bioceramic material[1−3], which is potentially used in orthopedic and dental implants, due to it nice biocompatibility and bioactivity[4]. Therefore Ca-P coating/TC4 composite prepared by laser cladding is requested to have excellent mechanical properties with biological characteristics to meet the clinical demands.

Rare-earth yttrium (Y) has multifunctional applications in the biomedicine field and materials engineering[5]. It was likely to improve biocompatibility of the laser cladding Ca-P coating[6]. However, mechanism of Y, which affects the strength and the hardness of coating, was still not clear, though the preparation, microstructure, and properties were investigated a lot[7,8]. In this paper, effects of Y_2O_3 on mechanical properties of laser coating on alloy TC4 are discussed by the strength and microhardness experiments.

Two group experiments of the bonding strength, of which were with and without 1% Y_2O_3 respectively, were carefully tested on the 10 T machine, according to GB5210-85, as shown in Fig. 1, and each group had three samples with ϕ18 mm as Table 1. Top and end layers of the samples firstly were worn to flat and cleared out, then agglutinated with the pull-loll sticks by the polyvinyl alcohol. The test methods of the compressive strength is the same as the mentioned above, two groups were on WE-5 machine. Each sample dimension is listed in Table 2. Two same groups testing the bending strength for the laser coating were on the WE-30 machine, on which distance between two points of supporter was 15.90 mm. Stretch rate δ, fracture shrinkage rate Ψ, and tensile strength σ_b of three samples only with 1% Y_2O_3 in the experiment were tested by FSY-CX01 type of electrical material machine, as shown in Table 3.

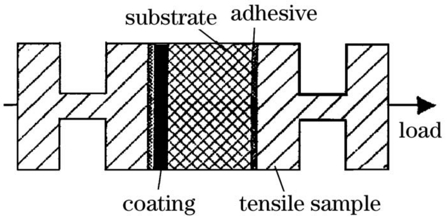

Fig. 1. Schema of bonding strength testing.

Two same groups in the experiment of the microhardness from the coating to alloy were tested on HV-!000 type of microhardness machine with 100-g loads ,15-s load time, and distance from two tested site in sample is 0.05 mm.

The experiment of the bonding strength, showed that Y_2O_3 is able to evidently improve the bonding strength of the interface between the laser coating and alloy TC4 as shown in Fig. 2. The average strength with 1% Y is

Table 1. Dimensions of Bending Samples

No.	1	2	3	4	5	6
Breadth (mm)	7.26	7.14	7.12	7.36	7.26	7.26
Height (mm)	5.40	5.38	5.34	5.44	5.28	5.26

Table 2. Dimensions of Bonding Samples

No.	1	2	3	4	5	6
Breadth (mm)	7.30	7.30	7.35	7.40	7.30	7.35
Height (mm)	3.40	3.30	2.65	3.25	3.25	3.25

Table 3. Dimensions of Tensile Samples

No.	1	2	3
L_0 (mm)	131.60	131.70	131.50
B_0 (mm)	7.80	7.76	7.76
H_0 (mm)	5.34	5.24	5.32

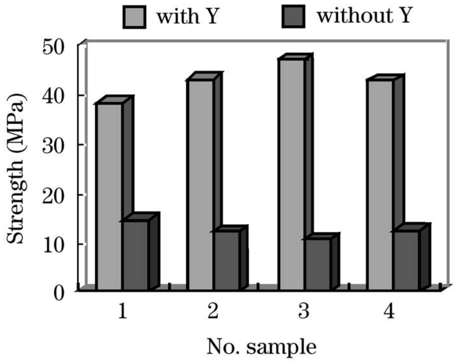

Fig. 2. Comparsion of the bonding strengths.

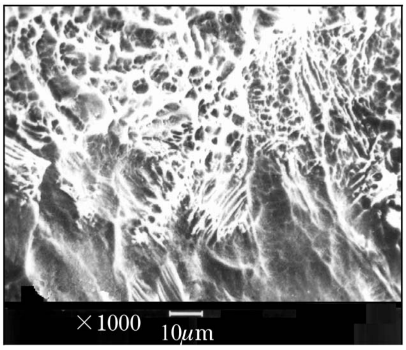

Fig. 3. SEM micrograph of the interface.

close to 42.96 MPa, much bigger than 38 MPa acquired by plasma-spray technology[9], and 12.74 MPa without 1% Y. Lee *et al.*[10] found that the adhesive bond of HA/TC4 composite to *in vivo* tissues was enhanced by time duration, but the interfacial strength between the material and tissue was less than 42.96 MPa. These data illuminated that laser interface with Y could satisfy the bonding strength.

Y_2O_3 microparticles were convected and diffused in the melting coating pool by laser beam, distributed largely in the lower layer (24 wt.-%), and partly in the surface layer of the high-temperature coating (8.793 wt.-%). Y microparticles became relatively bigger, congregated in the lower layer, closed to melting interface, interacted with Ca and Y, produced the new phase[11] and formed a chemical-metallurgical bonding[12] as shown in Fig. 3. These analysis revealed that Y_2O_3 could promote the chemical reaction in the interface and improve the bonding strength.

Figures 4 and 5 show that effects of Y_2O_3 on the bending and compressing strengths were opposite, because the bending strength of the laser coating with Y was obviously enhanced, while the compressive strength reduced a little. The bending strength is the confluence reflection of the tensile and compressive strengths, therefore it is safe to say that the tensile strengths in Table 4 are bigger than those without Y. At the same time, these data indicated that the mechanism of the Y_2O_3 in the laser coating was intricate and omnifarious.

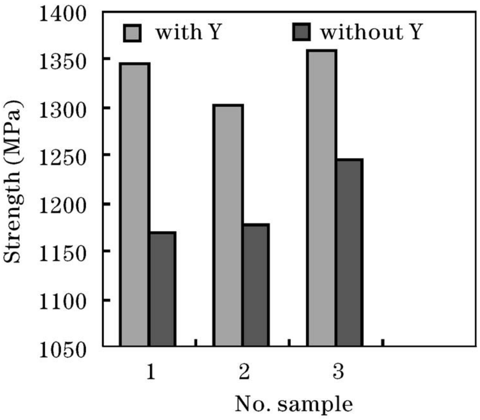

Fig. 4. Comparasion of the bending strengths.

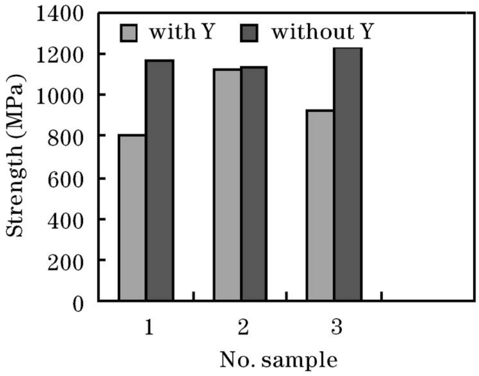

Fig. 5. Comparasion of the compressive strengths.

Table 4. Results of Tensile Test

No.	1	2	3	Average
δ (%)	0.97	1.31	1.26	1.18
ψ (%)	5.73	6.42	7.09	6.41
$P_{\rm b}$ (kN)	37	36	34	—
$\sigma_{\rm b}$ (MPa)	886	866	827	860

Effects of Y_2O_3 on the strength of laser coating mainly resulted from two basic factors. Y_2O_3 grains in the melting coating (temperature up to 2481 K[12]) by the high-energy laser were cooled under the natural condition. The number of the crystal grains got larger and dimensions of these grains were adequately dispersed, and Y_2O_3 microparitcles became nucleus, from which the coating crystal grains would grow up when coating grains changed smaller[7,12]. The lager number of the smaller grains made important contributions to the bending strength. On the other hand, Y_2O_3 aggrandized the hole rate in laser coating from 9.1% without Y to 15.1% with Y. The increased quantities of hole were bound to reduce the compressing strength. Effcets of Y_2O_3 on the tensile, compressive and bending strengths were comprehensive behaviors which resulted from two basic factors analyzed above.

Of the results from the Fig. 6, the microhardness of the laser cladding coating and interface with Y was a bit advanced, which further illustrated that the bonding interface between coating and alloy TC4 was strengthened by Y, and the distributing microhardness was gradually reduced under a gradient condition. These information implied that there existed gradient grain changes in

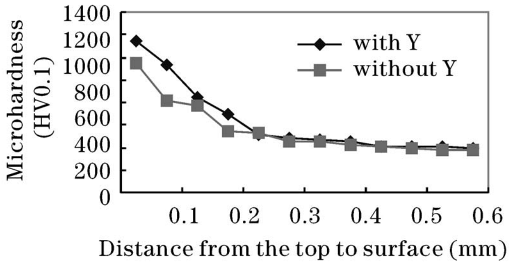

Fig. 6. Microhardness curves from coating to substrate.

changes in the coating, which was clearly illuminated by our studies[3,6,12].

Y in the laser melting coating and interface could react with other elements, such as calcium, phosphorus, oxygen, and so on[12], especially with the impurity elements, which reduced the impurity existing in crystal interface among ceramic phases, and between ceramic and alloy phases, elevated the bonding energy of the coating grains and interfaces, heightened the resistance of crack in the coating and interfaces[13,14], and so improved the mircohardness.

The research and analysis presented that Y_2O_3 microparticles were convected and diffused in the melting pool of coating by laser cladding, distributed largely in the lower layers; the chemical reaction in the interface was further promoted; the bonding of the coating and alloy TC4 was strengthened. The tensile and bending strengths were enhanced, while the compressive strength was weakened a bit; Y in the the laser melting coating and interface reacted with the impurity elements in crystal interface, reduced the impurity in the coating and interface, elevated the bonding energy, and heightened the extending resistance of crack.

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