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Formation mechanism of laser-clad gradient thermal barrier coatings①

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Abstract: The stratified gradient thermal barrier coatings (TBCs) were obtained by laser cladding of ZrO_2 and NiCoCrAlY mixture powder. The coatings were four-layer structure: cellular dendritic ZrO_2, dense ZrO_2, Ni-based alloy bonding coating and substrate. The formation of the stratified TBCs was attributed to the insolubility of ZrO_2 in the Ni-based alloy and the lower density of ZrO_2 than that of Ni-based alloy when both of them were in melted condition. The formation of two-layered ZrO_2 was related to the presence of Al in the Ni-based alloy, i) Al could be preoxidized into Al_2O_3 that could be segregated in the grain boundaries of ZrO_2 during solidification process; ii) Al could be partially preoxidized into Al_2O_3, then Al and Al_2O_3 could be segregated simultaneously at the grain boundaries of ZrO_2 during solidification process. Two formation processes were presented.

Key words: laser cladding; thermal barrier coatings; formation mechanisms **Document code: A**

1 INTRODUCTION

The ZrO_2 ceramics was selected as the material of thermal barrier coatings (TBCs) for its high melting point and high expansion coefficient[1]. The method to produce TBCs was usually plasma spraying technique. The porosity in the coating and the poor adherence between coating and substrate were the major problems in the plasma-sprayed coatings[2]. Laser was used to improve the properties of plasma-sprayed TBCs but the poor bonding of coating and substrate was not solved thoroughly[3~6]. Therefore, laser cladding of ZrO_2 and alloy powder was employed[7~9]. In the previous work, the authors successfully cladded gradient TBCs in which no cracking could be observed[10]. In the present study, the formation mechanisms were evaluated.

2 EXPERIMENTAL

The materials used in preparation were Ni825 superalloy, ZrO_2(partially stabilized with 8% Y_2O_3) ceramics, and NiCoCrAlY. The nominal compositions of these materials are listed in Table 1.

The ZrO_2 (volume fraction, 60%) and NiCoCrAlY (volume fraction, 40%) mixture powder were preplaced with binder on Ni825 superalloy and kept at 150 ℃ in air for 6h. A 5kW CW CO_2 laser was used under the conditions of 1~ 1.5kW power, 15~ 25 mm/s scanning speed of laser beam with 3mm diameter. Argon was blown to shroud the melted pool from the outside atmosphere.

The obtained specimen was cut through laser track, polished and examined by scanning electron microscopy (SEM) with energy dispersive analysis of X-ray (EDAX).

Table 1 Composition of raw materials (mass fraction, %)

Material	Ni	Co	Cr	Al	Y	Fe	C
Ni825	41.1	—	21.21	0.12	—	Bal	0.019
NiCoCrAlY	49	22	21	7.5	0.5	—	—

Material	Si	Mn	Mo	Ti	S	Cu
Ni825	0.42	0.55	2.73	0.88	0.0054	2.04
NiCoCrAlY	—	—	—	—	—	—

3 RESULTS

The cross section of laser-clad coating is shown in Fig. 1. It can be seen that there are four layers in the obtained coatings: upper cellular dendritic ZrO_2 and dense ZrO_2, Ni-based alloy bonding coating and substrate. The elemental maps of ZrO_2 and bonding coating are shown in Fig. 2. It is shown that Al was in the cellular ZrO_2 coating. EDAX was conducted on the cellular ZrO_2 and the results are given in Table 2. It can be seen that Al was mostly presented at the grain boundaries of ZrO_2.

4 DISCUSSION

From the previous work, it could be understood that a stratified coating could be obtained by laser cladding of ZrO_2 and alloy mixture powder. Nevertheless, in this work a four-layered structure coating was obtained. From the elemental map it is thought that such coating was mainly related to the presence of Al. Therefore, a possible formation process to explain this phenomenon was proposed.

The melting point of ZrO_2 is nearly 2700 ℃ and

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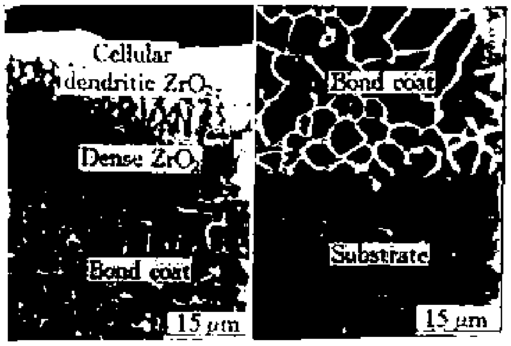

Fig. 1 Cross section of laser-clad coatings

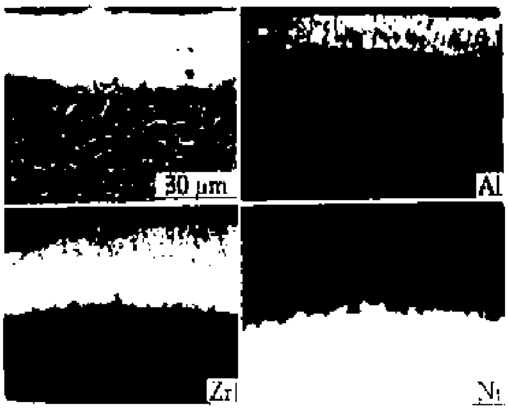

Fig. 2 Elemental maps of coatings

Table 2 Results of EDAX (mass fraction, %)

Microstructure	O	Al	Y	Zr
Cellular	5.429	0.598	12.994	80.979
Grain boundary	7.495	7.409	11.207	73.621

the melting point of NiCoCrAlY only approximately 1 000 ℃. The absorption efficiency of ZrO_2 to laser beam energy is nearly 90%, whereas that of the Ni-based alloy is only 10% or less. So it is thought that both of them were almost melted at the same time during laser cladding. When both ZrO_2 and Ni-based alloy were in the melted condition, due to the lower density of ZrO_2(ρ= 5.9 g/cm^3) than that of Ni-based alloy (ρ= 7.8 g/cm^3) and their insolubility, the ZrO_2 melted pool was on the Ni-based alloy pool.

For the lower NiCoCrAlY alloy melted pool, solidification started from the interface between bonding coating and substrate, while for the upper ZrO_2 melted pool from the interface between ZrO_2 and bonding coating. Thus, stratified coating was formed. However, due to the presence of Al, the two-layered ZrO_2 was formed in the ZrO_2 pool. The formation mechanism was interpreted by the following two aspects.

1) The mixture powder was subjected to preheat treatment so that the Al in the NiCoCrAlY could be oxidized into Al_2O_3. According to ZrO_2-Al_2O_3 phase diagram, the Al_2O_3 and ZrO_2 could be soluble under melting condition, but insoluble in solid state. During the solidification, the ZrO_2 solidified at first due to its high melting point and high amount and formed dense ZrO_2 coating. At last Al_2O_3 and ZrO_2 could solidify simultaneously and then the cellular dendritic ZrO_2 coating was formed.

2) The Al in NiCoCrAlY alloy had not been all oxidized into Al_2O_3, because of its lower density than that of ZrO_2. There were two layers in the ZrO_2 melt pool: the outer layer ZrO_2+ Al+ Al_2O_3, the inner layer ZrO_2+ Al_2O_3. The inner layer solidified firstly and formed dense ZrO_2 coating. During the solidification, ZrO_2 solidified and put the Al_2O_3 to the upper layer for their insoluble in solid state. The cellular dendritic ZrO_2 was formed when Al and Al_2O_3 segregated at the grain boundaries during the final solidification period.

5 CONCLUSIONS

The four-layered structure coating consisting of cellular dendritic ZrO_2, dense ZrO_2, Ni-based alloy bonding coating and substrate was obtained by laser cladding. The formation of such coatings was related to the existence of Al or Al_2O_3.

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