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Laser cladding of titanium alloy coating on titanium aluminide alloy substrate①

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Abstract: A new diffusion bonding technique combined with laser cladding process was developed to join TiAl alloy to itself and Ti-alloys. In order to enhance the weldability of TiAl alloys, Ti-alloy coatings were fabricated by laser cladding on the TiAl alloy. Ti powder and shaped Ti-alloy were respectively used as laser cladding materials. The materials characterization was carried out by OM, SEM, EDS and XRD analysis. The results show that the laser cladding process with shaped Ti-alloy remedy the problems present in the conventional process with powder, such as impurities, cracks and pores. The diffusion bonding of TiAl alloy with Ti-alloy coating to itself and Ti-alloy was carried out with a Gleeble 1500 thermal simulator. The sound bonds of TiAl/TiAl, TiAl/Ti were obtained at a lower temperature and with shorter time.

Key words: laser treatment; coating; diffusion bonding; titanium; titanium aluminide alloy

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1 INTRODUCTION

In the design and manufacture of aviation industry, different parts of the aircraft engine should meet the different requirements on operating temperature and service performance. The sound bond of dissimilar alloys is the key technique for developing novel equipments and improving their integral performance.

Low density and excellent high-temperature properties of TiAl alloys make them promising high-temperature structural materials. Successful joining of these materials will increase their utility in engineering[1, 2].

Some joining techniques such as laser welding, electron-beam welding, friction welding, braze welding and gas tungsten arc welding, were utilized to join TiAl alloys. But the brittleness of the material and the high residual stress limit the applications of these joining techniques[3-10]. Diffusion bonding avoids many of the above-mentioned problems and is attractive for TiAl alloys[2].

It was reported that defect-free diffusion bonds of TiAl sheets were achieved at 1 000 ℃ under pressure of 5, 10 and 20 MPa, held for 5-8 h[11]. And the diffusion bonding of the Ti-alloy Ti-6Al-4V to the TiAl IHI alloy 01A held at 900 ℃, 940 ℃, and 980 ℃ for 1 h under 200 MPa was also reported in Ref. [2].

Titanium alloys have more excellent weldability than TiAl alloys. Sound diffusion bonds of Ti-alloys can be achieved at 850-1 000 ℃ under pressure of 9.8-68.6 MPa, held for 5-10 min. Ti-alloys can dissolve oxides in diffusion bonding. Impurities, such as oxides, can be effectively avoided in the joining zone. So the weldability of TiAl alloy can be enhanced by fabricating Ti-alloy coating on TiAl alloy before diffusion bonding process. In this case, the joining of TiAl alloys(TiAl/TiAl) or the joining of TiAl alloy to Ti-alloy(TiAl/Ti) is essentially a joining process of Ti-alloy to Ti-alloy(Ti/Ti). The mechanical properties of the bonds such as plasticity, shock strength and fatigue resistance will be enhanced since Ti-alloys have good ductility as well as high strength.

The purpose of this work is to develop a new welding technique to obtain sound diffusion bonds of TiAl/TiAl and TiAl/Ti alloy at a lower temperature and with shorter holding time. Laser cladding of Ti-alloy coatings on TiAl alloy substrate is studied. Diffusion bonding of the TiAl alloy with a Ti-alloy coating surface is conducted.

2 EXPERIMENTAL

The TiAl alloy, Ti-46.5Al-2Cr-1.5Nb-1V(mole fraction, %), with a lamellar colony structure, was used as the substrate material of laser cladding. Two kinds of cladding materials were used respectively: (1) Ti powder. The average particle size of the powder was 70 μm and its purity was more than 98.0%. Ti powder is pre-placed on the substrate with a thickness of 3 mm before laser cladding. (2) Shaped Ti-6Al-2Zr-1Mo-1V alloy(mass fraction, %). The Ti

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alloy was machined into rectangular bars with a width of 2 mm and a thickness of 1.3 mm. This cladding material is called as shaped Ti-alloy in this paper. The cladding material was pre-placed on the substrate before laser cladding. Laser cladding of Ti-alloy coating on the TiAl substrate was carried out using a 5 kW continuous wave transverse flow CO_2 laser material processing systems with a laser power of 1.5-4 kW, a defocus distance of 32 mm and a laser scanning speed of 100-600 mm/min. The parameters were adjusted to obtain the optimum coating. Argon gas was blown into the melt pool to provide shielding during the laser cladding process.

Ti-6Al-2Zr-1Mo-1V and TiAl alloys with coating prepared using shaped Ti-alloy were selected as the bonding materials. All bonding surfaces were ground with SiC abrasive paper down to 1 200 grit. Diffusion bonding was carried out with a Gleeble 1500 thermal simulator under a vacuum of 10^{-1}-10^{-2} Pa. In this testing system, the bonding parameters were actually controlled under a computer.

Sections of the laser clad specimens and bonding specimens were prepared for metallographic analysis by standard metallographic techniques. The specimens were etched with Kroll's reagent(1-3 mL HF, 4-6 mL HNO_3 and 100 mL H_2O). The microstructure of specimens was characterized by OM and SEM. The phases in coatings were examined by X-ray diffractometer with EDS. The hardness along the coating depth direction was measured using a Vickers microhardness tester(with a load of 9.8 N and loading time of 30 s).

3 RESULTS AND DISCUSSION

3.1 Microstructure of coating

3.1.1 Results of laser cladding with Ti powder

Powder is conventionally selected as cladding material during the laser cladding process. The characters of small particle size and high specific surface area make the powder easily absorb H_2O, oxygen and hydrogen in the air. Especially, Ti is chemically active to react with nitrogen. So argon gas flow can't effectively protect the Ti powder in loosen condition from the intervention of active gases. A large amount of burning loss occurs during the laser cladding process using Ti powder as cladding material. The coating has many flaws such as rough coating surfaces, impurities, cracks and pores.

XRD and EDS analyses indicate that α Ti-based solid solution(α phase), β Ti-based solid solution(β phase), TiN and Al_2O_3 present in the coating prepared using Ti powder (Fig. 1). Fig. 2(a) is a SEM micrograph of the coating showing the presence of many impurities and non-uniform microstructures. The needle-like TiN presents in the form of network structure, which is caused by the segregation of

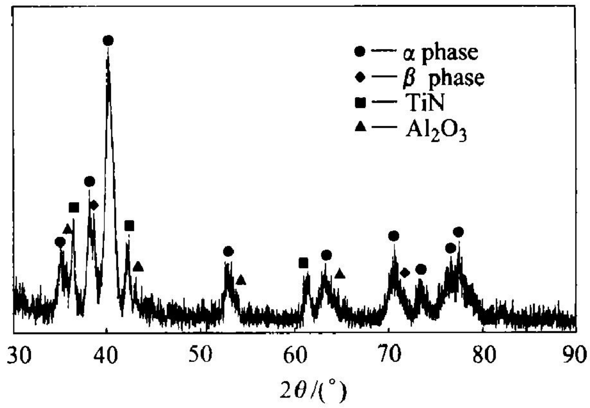

Fig. 1 XRD pattern of laser clad coating prepared with Ti powder

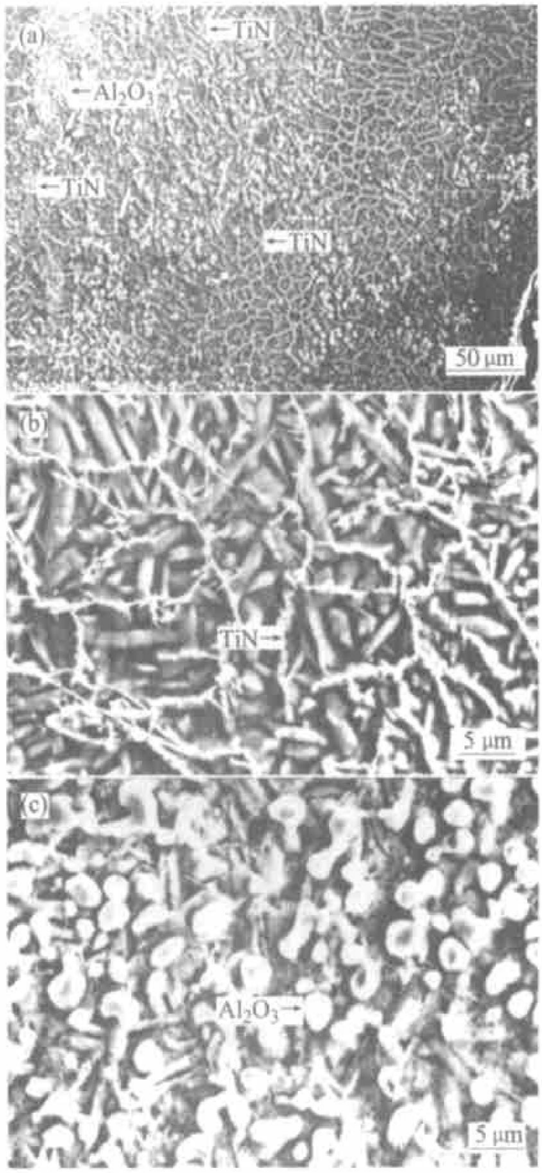

Fig. 2 SEM micrographs of typical microstructure of laser clad coating prepared with Ti powder

TiN along the cellular grain boundary of prior-β phase. The prior-β phase was decomposed to woven rod-like α and minor retained β during cooling (Fig. 2 (b)). Dendritic TiN phase and spheric Al_2O_3 phase are also found in the coating (Fig. 2(a) and (c)). The presence of Al is caused by the dilution of the TiAl substrate in the laser cladding process.

This Ti-alloy coating with a rough surface and many brittle impurities is not available for diffusion bonding. And the conventional laser cladding process must be improved to avoid the strong reaction between cladding material and gas at high temperature.

3.1.2 Results of laser cladding with shaped Ti-alloy

In order to avoid the influence of the strong reaction between Ti powder and gas, the shaped Ti-alloy was selected as cladding material instead. Thus a very small surface area was exposed to air in the laser cladding process. Crack- and pore-free coatings were obtained by this new method with a laser power of 2 kW and a laser scanning speed of 300 mm/min. XRD patterns (Fig. 3(a), (b)) indicate that the coating consists of α phase and α'' Ti-based solid solution (α'' phase). Since many diffraction peaks of α are approaching to those of α'', a low-speed scanning of X-ray was conducted with double diffraction angles varying from 51° to 56°, indicating both α and α'' present in the coating (Fig. 3(b)). Fig. 4 shows the different zones of the laser clad specimen, that is, coating, heat affected zone (HAZ) and TiAl substrate. The coating is metallurgically bonded to the substrate. The coating microstructure is homogeneous and pure. Fig. 5 shows the grain pattern of α and needle-like α'' in the coating.

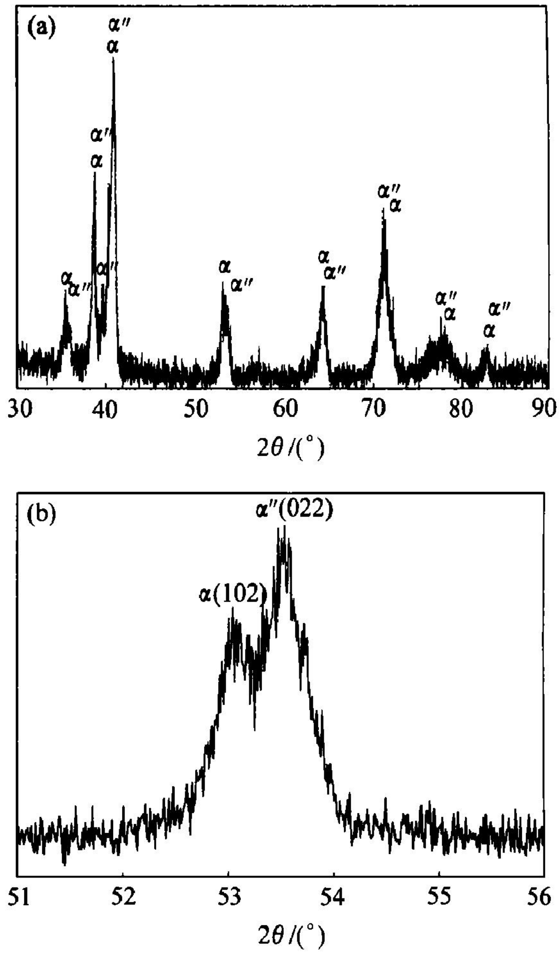

Fig. 3 XRD patterns of laser clad coating prepared with shaped Ti-alloy

Fig. 4 Typical OM microstructures of laser clad coating prepared with shaped Ti-alloy on TiAl alloy

A —Celluar structure; *B* —Planar crystal; *C* —Heat-affected zone; *D* — Substrate

3.2 Microhardness of coatings

Fig. 6 shows the microhardness profiles of the laser clad Ti alloy coatings on TiAl alloy. The microhardness profile of the coating prepared with Ti powder is not regular because the microstructure of this coating is not homogenous. As many phases with high hardness present in the coating, the hardness of the coating is much higher than that of the TiAl substrate. The average thickness of the coating is no more than 0.5 mm.

On the contrary, the hardness of the coating prepared with shaped Ti-alloy is approaching to that of the substrate. Because of the homogeneity of microstructure, the microhardness profile of the coating is flatter. The average thickness of the coating is about 1 mm. No thermal stress cracking is detected in the coating after repeated water quenching from 900 ℃, indicating the sound bond between the coating and the substrate.

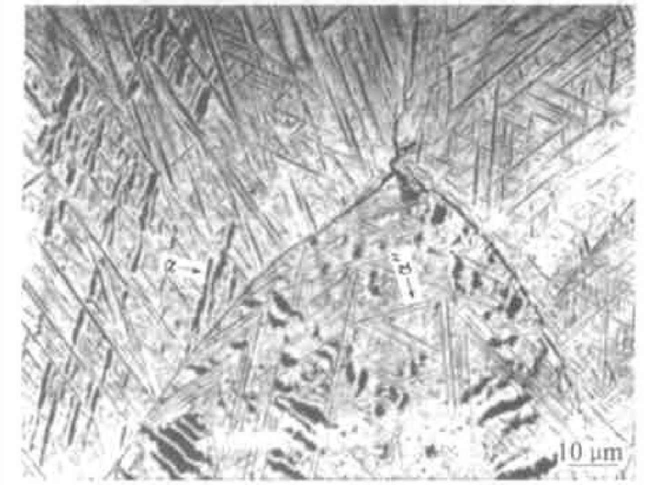

Fig. 5 Typical SEM microstructure in zone *A* of Fig. 4

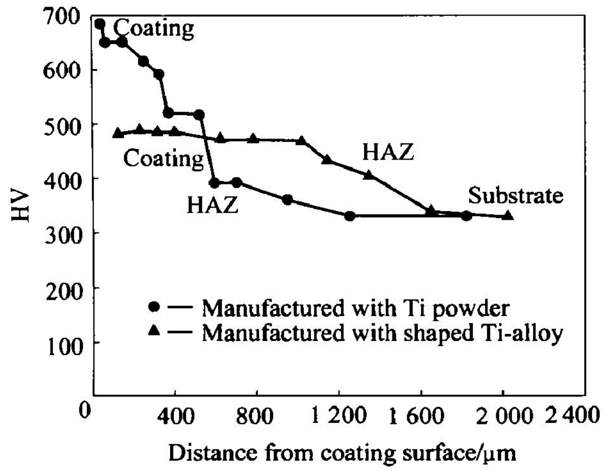

Fig. 6 Microhardness profiles of laser clad Ti-alloy coatings on TiAl alloy

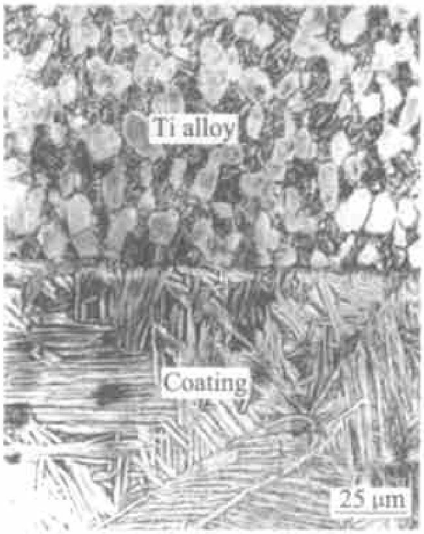

Fig. 7 OM microstructure of bond of TiAl(Ti)/Ti

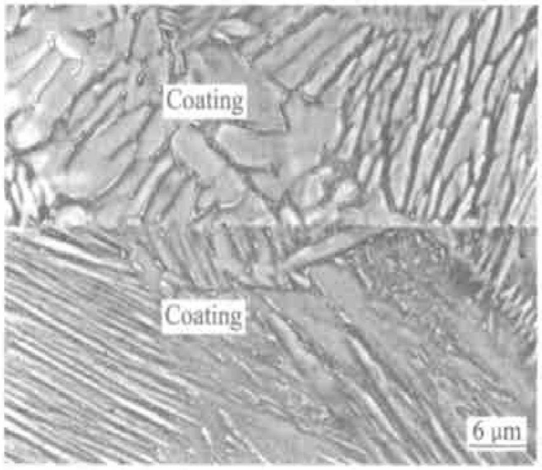

Fig. 8 SEM microstructure of bond of TiAl(Ti)/(Ti)TiAl

3.3 Diffusion bonding of TiAl alloy with Ti-alloy coating

The results above show that the laser clad coatings prepared with shaped Ti-alloy are qualified for the surface materials of TiAl alloys in their diffusion bonding. The diffusion bonding of the TiAl alloy with a laser clad Ti-alloy surface to Ti-6Al-2Zr-1Mo-1V alloy(TiAl(Ti)/Ti) was carried out at 800 ℃ under 100 MPa for 10 min, and the diffusion bonding of the TiAl alloy with a Ti-alloy surface to itself(TiAl(Ti)/(Ti)TiAl) was carried out at 800 ℃ under 200 MPa for 10 min. Microscopy was employed to investigate the quality of the bonds. Neither porosity nor cracks can be detected before the bonding specimens are electrolytically polished and chemically etched, indicating sound bonds have been achieved. Figs. 7 and 8 respectively show the above-mentioned bonds, that is, TiAl(Ti)/Ti and TiAl(Ti)/(Ti)TiAl.

4 CONCLUSIONS

1) Because of the strong reaction between Ti powder and gas, it is difficult to prepare sound Ti-alloy coatings using Ti powder. The coating prepared with Ti powder contains α, β, TiN and Al_2O_3 and its surface is rough. Pores and cracks are difficult to avoid. The hardness of the coating is not homogenous and is much higher than that of the TiAl substrate.

2) Shaped alloy was firstly used as cladding material. By this method, the problems of burning loss, pores and impurities can be remedied, and sound Ti-alloy coating was obtained.

3) Microstructure and hardness of the coating prepared with shaped Ti-alloy are homogenous. The coating is a Ti-alloy consisting of α and α'' phases.

4) The laser clad Ti-alloy surface is beneficial to enhancing the weldability of TiAl alloys. Sound diffusion bonds of TiAl alloy to itself and Ti-alloy can be achieved at a lower temperature and with very short time.

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