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Laser induced TiC particle reinforced composite layer on Ti6Al4V and their microstructural characteristics①

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Abstract: An in-situ synthesized TiC particle reinforced composite layer on Ti6Al4V were fabricated by laser induced reaction of the pre-placed mixed powders of Ti and Cr_3C_2. The microstructure of the composite layer was strongly related to the composition of original powders and also the laser processing parameters. Under certain processing parameters, the matrix of the composite layer was transferred from dual $\alpha+\beta$ to single phase β with increasing Cr_3C_2 content in the original powder mixture. The TiC particles were fine and uniformly dispersed in the matrix. Furthermore, the fine TiC particles show excellent compatibility with the matrix, thus offering good wear performance.

Key words: metallic composite; TiC particles; in-situ forming; coating **Document code: A**

1 INTRODUCTION

Metal-ceramic composite coatings have widely been built up by means of thermal spray or laser techniques on traditional engineering materials for improving their performances related to corrosion and wear etc[1~5]. However, metal-ceramic or cermet composites are multi-phase system consisting of continuous matrix and dispersed reinforcer phase or phases. Therefore, the characteristics of the reinforcer phases, such as their size, shape and distribution and especially the characteristics of the interface bonding between the reinforcer phase and the matrix may exert great influence on the performance of the composite itself[6,7]. It was reported that a uniformly distributed dispersion of smaller fine reinforcer phase will certainly give rise to better mechanical performance of the composites and a clean interface between the reinforcer phase and the matrix may also be beneficial to the mechanical properties of the composite. Generally speaking, the in-situ preparation of composite may be promising in terms of producing fine disperses, bringing clean boundaries of reinforcer phase/matrix etc[8,9]. The present study is attended to in-situ produce a carbide reinforced Ti-base composite on the surface of Ti-alloy through melt and reaction induced by laser irradiation. The microstructural characters of the formed composite coatings were examined in detail and their formation mechanism was also discussed.

Laser cladding techniques have been used to build up metallic base coatings on surface of traditional metals to improve their wear resistance[1~5]. Cermet composites are multi-phase system, consisting of continuous matrix and dispersed reinforcer phase. Therefore, characteristics of the reinforcer phases, such as size, morphology and dispersion, and characteristics of the bonding interface between the reinforcer phase and matrix have great effects on properties of the composite. It has been reported that the smaller the size and the more uniformly dispersive the reinforcer phases, the higher the composite mechanical properties. And clean interface can improve the mechanical properties. So, in-situ metal matrix composites are promising because they have small size of reinforcer phases and clean interface between the reinforcer phases and the matrix, also the reinforcer phases are inherently bonded to the matrix and have high stability to the matrix in terms of thermal dynamics. In this work in-situ particle reinforced cermet composite was fabricated on the surface of titanium alloy from carbides of β-Ti stabilizer via laser cladding processing. At the same time, an effective method for improving properties of titanium alloys and developing new composites was proposed.

2 EXPERIMENTAL

2.1 Sample preparation

Cr_3C_2 (commercial product obtained from the Zhuzhou Hard Alloy Co.) and Ti (commercial pure metallic powder) powders with a size of 60~ 70 μm were mechanically mixed. Then, the mixed powder was pre-placed on the surface of Ti6Al4V alloy, which had been ground and cleaned before use. The

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alloy was put into a vacuum chamber, which was firstly evacuated and then refilled with pure argon gas. JJ-D-400 Nd: YAG pulsed laser was employed for the laser processing. The optimal processing parameters were as follows: energy for one laser pulse is 50 J, frequency is 4 Hz, focal length 200 mm, laser spot size 2 mm in diameter and scanning velocity 1.1 mm/s.

2.2 Post analysis

Philips XL400-FEG scanning electron microscope, Link OPAL back scattered electron diffractometer (Oxford Instrument Pte. Ltd., England), D/max-ra X-ray diffractometer, IBAS20 type image analyzer and EM420 transmission electron microscope were employed respectively to examine the microstructure and composition of the laser induced composite coatings.

3 RESULTS AND DISCUSSION

3.1 Design of coating

Table 1 lists the critical contents of the stabilizers needed for totally transforming an alloy into β-state for some binary Ti-alloys by quenching[10]. It is believed that an appropriate combination of a matrix with high toughness and dispersed particles with high hardness may result in excellent wear resistance of the composite. In order to obtain a composite consisting of β-phase matrix with fine dispersed TiC particle, some of the carbides of β-stabilized elements may be used as raw materials. In terms of the difference of their free energy of formation with titanium carbide, which may facilitate the reaction between the selected carbide with titanium during the processing, most of the carbides of the stabilizers listed in Table 1 are suitable candidates. Among them chromium carbide Cr_3C_2 was employed for the study. The morphology of the Cr_3C_2 powder particles is shown in Fig. 1. From Fig. 1 one can see that the particles show round shape with clear growth step of the crystalline Cr_3C_2 on their surface.

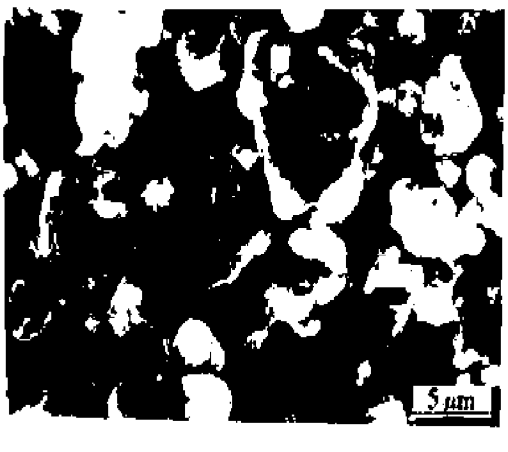

Fig. 1 Morphology of Cr_3C_2 particles

Table 1 Critical concentration of various stabilizers required to retain 100% β-phase for Ti alloys by quenching

β-stabilizer	Data from US		Data from USSR	
	w %	x %	w %	x %
Mn	6.5	5.6	5.3	5.0
Fe	3.5	3.0	5.1	4.7
Cr	6.3	5.8	9.0	8.4
Co	7.0	5.8	6.0	4.9
W	22.5	6.7	26.8	8.7
Ni	9.0	7.5	7.2	5.9
Mo	10.0	5.3	11.0	5.8
V	15.0	14.2	19.4	18.4

3.2 Microstructure of composite coating

With the optimal laser processing parameters, two powder mixtures with 5% (mass fraction) and 10% (mass fraction) Cr_3C_2 respectively were used to make composite coating on Ti6Al4V alloy surface. The microstructures of the two coatings are shown in Fig. 2. One may observe from Fig. 2 that the hard reinforcing particles disperse very uniformly in the matrix and the particles size ranges from 0.5 μm to 2 μm. The results of image analysis shows that the volume fractions of the formed TiC particles in the composite layer were about 15% and 38% respectively for those two kinds of samples shown in Fig. 2. Fig. 3 shows an electron back scattered pattern from a particle in the coating of the sample 90Ti-10Cr_3C_2(a) and it is solved and identified as TiC(b). Furthermore the matrix around the particles is identified as β-Ti phase. Fig. 4 shows an X-ray diffraction pattern taken from the surface of those two composites, it again proves the formation of TiC fine particles in β-Ti matrix through the desired process.

From thermal dynamic point of view, during the laser induced melting the following in-situ reaction may occur:

$$Ti + Cr_3C_2 \rightarrow TiC + Cr \quad (1)$$

then, the released Cr may solve in the Ti around as follows:

$$Cr + Ti \rightarrow \beta\text{-}Ti \quad (2)$$

Thus a composite consists of fine dispersed TiC particles and β-Ti matrix was finally formed on the top surface of the Ti6Al4V alloy. However, if the chromium carbide content in the original mixture was not high enough to provide Cr to fulfill the later process, the matrix of the composite should be dual phase α+ β. The present study results confirm that 10% of Cr_3C_2 was enough to convert the matrix of the composite into single beta-state through the above two steps. It is noted that an EDAX analysis result by TEM study shows that the average Cr content in the matrix obtained by the process using the original powder with 10% Cr_3C_2 was only around 4.4%,

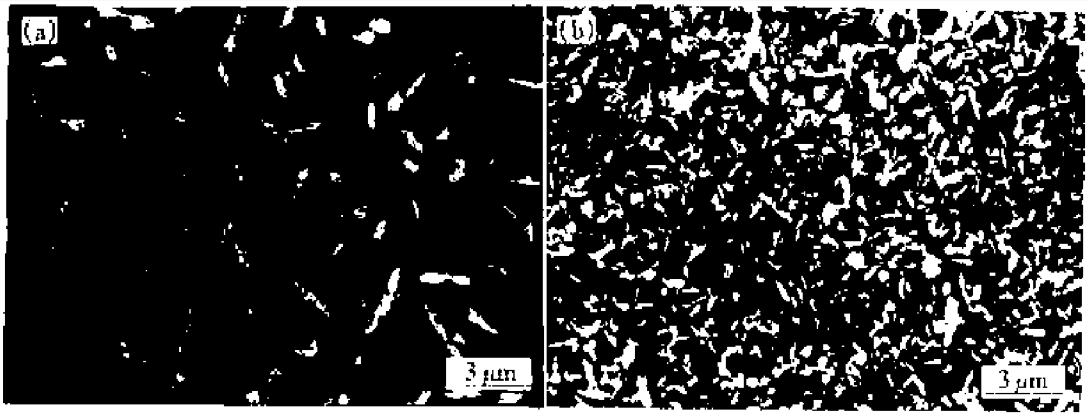

Fig. 2 Scanning electron micrographs of composite layer formed respectively with (a) 5% Cr_3C_2 and (b) 10% Cr_3C_2

Fig. 3 Electron back scattered pattern of a particle in composite layer (a) and selected area electron diffraction pattern proving it as TiC (b)

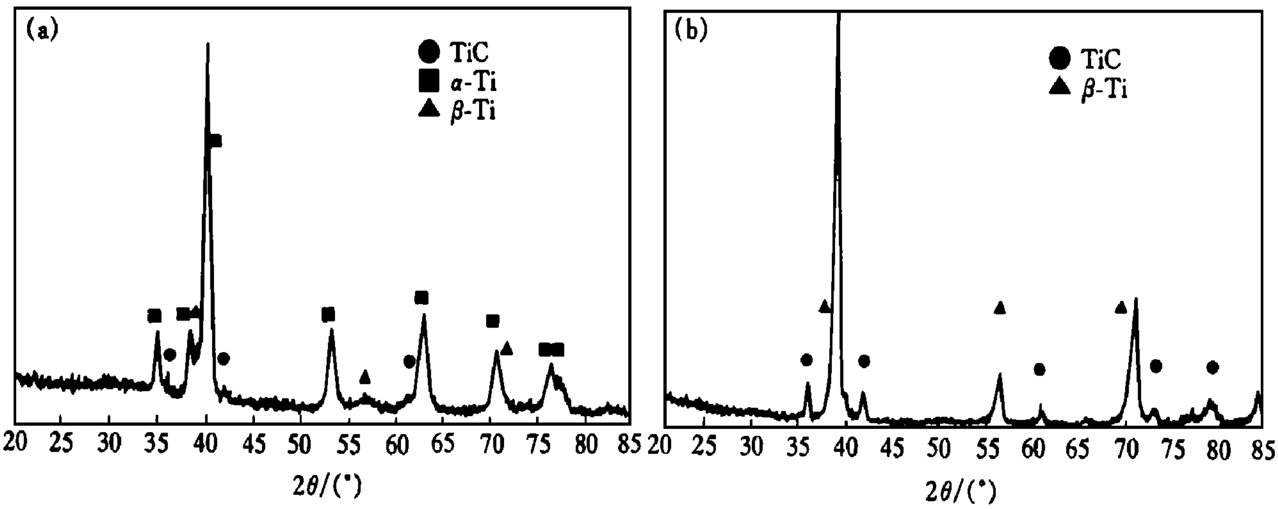

Fig. 4 X-ray diffraction patterns of composite layers formed with (a) 5% Cr_2C_2 and (b) 10% Cr_3C_2 respectively

which is obviously lower than the values listed in Table 1. From this fact one may understand that the laser induced rapid melting-solidifying non-equilibrated process may play a role in enlargement of the beta-phase regime. Fig. 5 shows a TEM bright field image of the interface of TiC/β-Ti and the corresponding selected zone electron diffraction patterns of both TiC and β-Ti. It may be seen that the interface between the two phases is sharp and clear, thus the bonding between the two may be metallurgical.

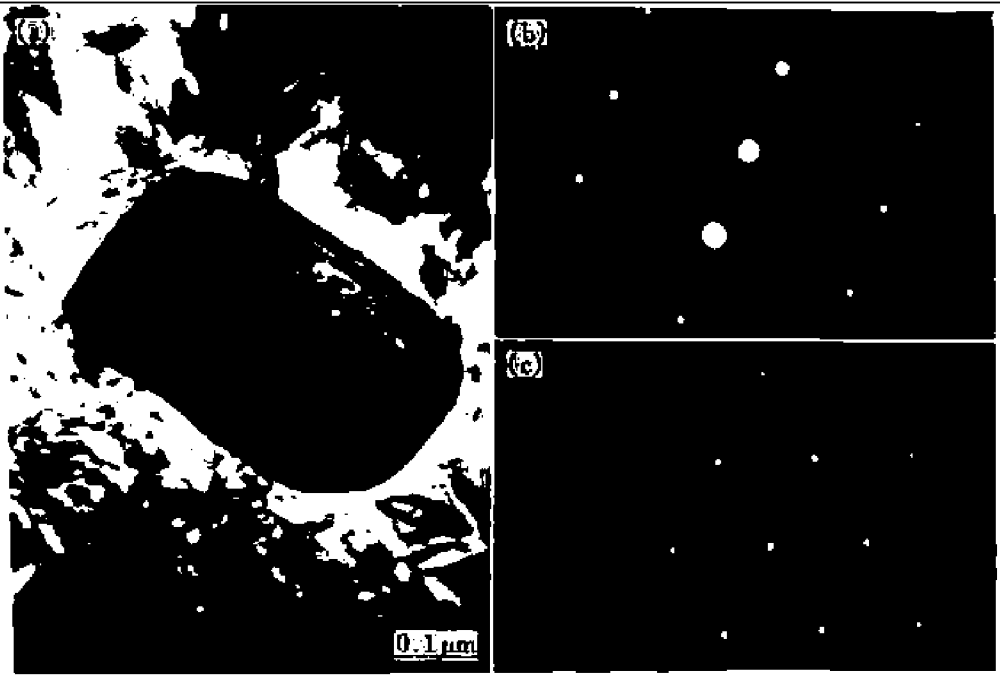

Fig. 5 TEM analysis results of TiC/ β-Ti composite

(a) —Bright field image of a particle; (b) —Diffraction pattern of TiC; (c) —Diffraction pattern of β-Ti

4 CONCLUSIONS

1) TiC/ β-Ti composite coatings were successfully built up on the surface of Ti6Al4V alloy from Cr_3C_2 and Ti powder mixture through laser induced melt-reaction processes. The in-situ formed TiC particles were uniformly dispersed in the matrix, which ensures the uniform microstructure of the composite coating.

2) As a beta-phase stabilizer, the released Cr from Cr_3C_2 may be solved into the alpha-Ti based surface layer, thus converting it into beta-state during the laser processing.

3) The interface between the in-situ formed TiC particles and the matrix is sharp and clear. The laser induced composite coated to the substrate shows a good integrity between the in-situ formed TiC particles and the Ti_6Al_4V matrix.

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REFERENCES

[1] Abboud J H and West F D R. Journal of Material Science Letters, 1991, 10: 1149~ 1152.

[2] HU C, XIN H, *et al*. Acta Mater, 1997, 45(10): 4311 ~ 4320.

[3] ZHANG Song, KANG Yu-ping, SONG Huan, *et al*. Chinese Journal of Lasers, 1996, 5B(4): 379~ 384.

[4] Fouilland-Panila L, Ettaqi S, Benayoun S, *et al*. Surf Coat Technol, 1996, 88: 204~ 211.

[5] ZENG Xiao-yan, TAO Zeng-yi, ZHU Bei-di, *et al*. Surf Coat Technol, 1996, 79: 209~ 217.

[6] YU L G, DAI J Y, XING Z P, *et al*. J Mater Res, 1997, 12(7): 1790~ 1795.

[7] ZHANG Song, WANG Mao-cai, WU Wei-tao, *et al*. Tribology, 1999, 19(1): 18~ 22.

[8] LIU Jin-shui, XIAO Han-ning, SHU Zhen, *et al*. Chinese Journal of Nonferrous Metals, (in Chinese), 1998, 8A(2): 259~ 263.

[9] LI Bang-sheng, OUYANG Jia-hu, GUO Jing-jie, *et al*. Chinese Journal of Materials Research, (in Chinese), 1998, 12A(2): 154~ 158.

[10] IEC 825-1, Safety of Laser Products-Part 1: Equipment classification, requirements, and user's guide, International Electrotechnical Commission, Geneva, 1993. Available from ANSI in New York and from International Electrotechnical Committee, 3 Rue de Varembe, CH-1121, Geneva 20, Switzerland.

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