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Laser multi-layer cladding of Mg-based alloys①

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Abstract: By laser multi-layer cladding using a pulsed Nd-YAG irradiation the thickness of the cladding zone Mg-based alloys (ZM2 and ZM5) can reach about 1.0 mm. The microstructure of the substrate and the cladding zone was studied using optical microscope, scanning electron microscopy(SEM), X-ray diffractometry(XRD) and micro hardness analysis. It is observed that constituent of ZM5 alloy is δ+ $Mg_{17}Al_{12}$, that of ZM2 alloy is α+ MgZn+ Mg_9Ce. That of cladding layer ZM2 alloy(L-ZM2) is Mg+ Mg_2Zn_{11}+ MgCe; while that of the cladding layer ZM5 alloy(L-ZM5) is Mg+ $Mg_{32}(Al, Zn)_{49}$. The hardness of the cladding area can be increased to values above HV127. Very fine uniform microstructure and the produced new phases of nanometer/sub-micrometer order were obtained. Now, many repaired Mg-based alloy components have been passed by flying test in outside field.

Key words: laser multi-layer cladding; Mg-based alloys; microstructure; repairing
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1 INTRODUCTION

Mg-based alloys have wide application in airplane and automobile industry because of low density and high specific strength and specific modulus[1]. However, they have poor environmental performance and mechanical properties. The extreme position of Mg-based alloys in the electrochemical series coupled with the fact that, unlike aluminum, magnesium is unable to form protective self-healing passivity surface films in corrosive environments, which makes it vulnerable to galvanic attack. When coupled with a nobler metal, magnesium undergoes anodic dissolution and hence exhibits poor corrosion resistance. For example, a fro-supporting framework house of ZM2 alloy production used in one aero-engine is contacted with a locking washer of nobler metal($1Cr_{11}NiW_2Mo$), whereby to form many corrosion pits on its surface. The depth of the corrosion pits varies from nearly 0.1 mm to 1 mm. In addition, the great affinity of Mg to the oxygen makes porosity occur easily when die casting the Mg-based alloys parts. For example, one Mg-based finished accessories case of one module aero-engine was perforated under applied test pressure because of the porosity. In the past various methods including the laser cladding have been tried but there are also much problems as high melting oxide layer on the surface, the strong heat dissipation from the treating region, oxidation, porosity, cracking, ignition and insufficient depth etc reported by SI[2].

The bias of interest in lasers for materials processing stems from both their ability to produce extremely high power densities and applying them for the processed surface with precise spatial and temporal control[3]. Furthermore, laser, as a clean energy source, can be remotely located from the sample and does not require a critical environment during processing. With the help of powerful lasers, several processing techniques have been applied for the surface treatment of various metallic materials, for example surface melting, transformation hardening, cladding and surface alloying, laser-assisted chemical and physical vapor deposition and welding.

Early in 1990, Mazumder et al[4, 5] performed the experiment of the laser cladding of Mg-Al alloys. To reduce oxidation, the Mg laser cladding was carried out in a vacuum chamber in which the shielding argon pressure was above ambient pressure. Galun et al[6] reported that, by laser alloying with aluminum, copper, nickel and silicon, the hardness of several magnesium base alloys can be increased to values above HV250, but the alloying depth only varied from 700 μm to 1 200 μm. Kousomichalis et al[3] reported Mg-based alloy(AZ31B) was irradiated in air using a pulsed KrF excimer laser. Up to now, it is not reported that Mg-based alloy components used in aero-engine repaired by the laser treating techniques mentioned above. Complex construction and complicated corrosion morphology of the practical Mg alloy parts may be responsible for the reported techniques. In this paper laser multi-layer cladding has been developed and applied in repairing of Mg-based alloy elements used

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in aero-engine. The characterization of microstructure and the micro-hardness of laser multi-layer cladding zone are studied for two Mg-based alloys.

2 EXPERIMENTAL

2.1 Alloy preparation

Die cast plates (4 cm × 3 cm × 2 cm) of ZM2 and ZM5 alloys were used as the targets for laser multi-layer cladding. Their chemical compositions are listed in Table 1. These plates were polished with 600-grit SiC paper prior to laser multi-layer cladding. They were then washed with alcohol, air-dried and laser multi-layer clad dried.

Laser multi-layer cladding was carried out with a JJ-D-400 pulsed Nd-YAG. The average incident power ranged between 0.3 and 0.5 kW and pulse time varied between 1 and 5 $m\cdot s^{-1}$. The beam scanned at velocities of 3 − 5 $mm\cdot s^{-1}$, adjacent scans being partially overlapped by 40% − 60%. A coaxial flow of high purity argon protected the surface of specimens during laser treatments. Cladding depths of 0.8 − 1.0 mm were typically produced. Evaporation was observed for all laser processing condition.

2.2 Microstructure observation

After the polishing and cleaning procedure, the cross-sections of the Mg-based alloys in the laser multi-layer cladding zone were observed using optical microscope and scanning electron microscope (SEM). The enchant was 90 mL distilled-water and 2 − 10g tartaric acid. The specimens were swabbed with enchant. After reaction of about 1s, the samples were rinsed with tap water, cleaned with ethyl alcohol and dried by hot air. XRD was also used to investigate the phase of constituentes of the cladding zone.

3 RESULTS AND DISCUSSION

3.1 Microstructure

As presented in specimen preparation above, the multi-layer cladding zone, which was a cave before laser irradiation, was building up through laser remelting of the same cast plates as the substrate alloy plate by plate, as shown in Fig. 1. Obviously, each of Mg-based alloy plates suffered from laser repeated irradition resulting in rapid melting and solidified microstructure. For the sake of description, the laser irradiated ZM2 or ZM5 alloy in multi-layer cladding is termed as L-ZM2 or L-ZM5 one in this paper. Overview of Fig. 1 pointed out that the whole multi-layer cladding zone was free of any defects such as crack, hole and porosity, etc. The tracks of multi-layer overlapping can cleanly be seen. Depth of the cladding zone reached above 1 mm. In the microstructure, the substrate is identified as A and the multi-layer cladding as B. The good fusion between the cladding and the substrate can be seen.

Fig. 2 shows the microstructures of the substrate and the cladding zone. In contrast to the cast microstructure (A), fine dendrite and homogeneous morphology can be seen in B. In addition, even fusing bonding interfaces between A and B formed without cracking in case of ZM2 and ZM5.

Detail observation shows obvious different

Table 1 Chemical compositions of alloys of ZM2 and ZM5 (%)

Specimen	Zn	Al	Zr	Re	Mn	Cu	Ni	Fe	Si	Impurity	Mg
ZM2	3.5 − 5.0	–	0.5 − 1.0	0.7 − 1.7	–	0.03	0.01	0.01	0.30		Bal.
ZM5	0.2 − 0.8	7.5 − 9.0	–	–	0.15 − 0.50	0.30	0.20	0.05	0.30	0.05	Bal.

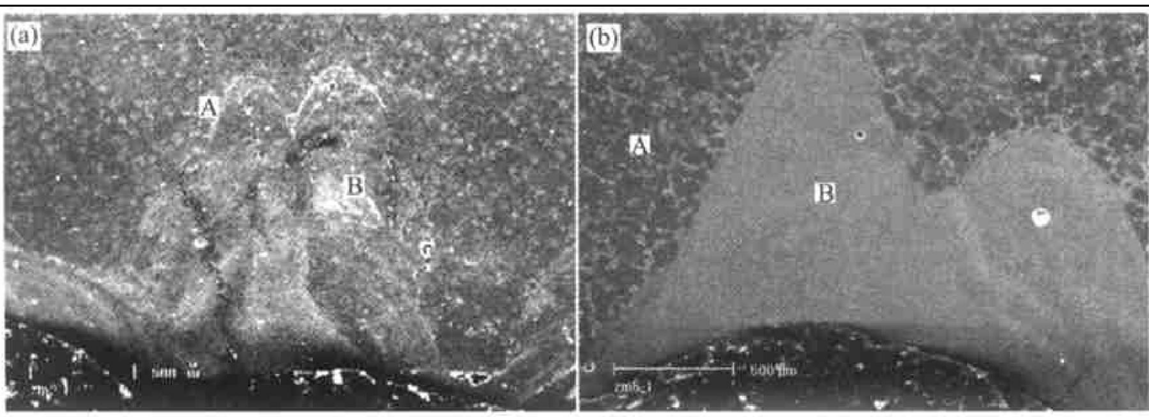

Fig. 1 Morphologies of laser multi-layer cladding zones (SEM)
(Region A is substrate and region B is cladding)
(a) —ZM2; (b) —ZM5

microstructures of ZM2 alloy from the ZM5 alloy, as shown in Fig. 3, which may be contributed to the reactive element rare earth and Zr in ZM2 alloy. Rare earth element plays a part in fining and restricting the secondary phase growth[6, 7]. It is possible the same reason as ZM2 alloy, the L-ZM2 alloy exhibited also a distinct feature of scanning electron image in contrast to L-ZM5 alloy. In Fig. 4(a), it can be seen the 10 – 100 nm particles which are dispersively distributed in the L-ZM2; while in Fig. 4 (b), there are many block phase of micrometer order.

3.2 XRD analyses

XRD of cladding are shown in Fig. 5. From Fig. 5 (a), it is identified that the microstructure of the ZM2 alloy consisted of α+ MgZn + Mg_9Ce, while that of the ZM5 of δ+ $Mg_{17}Al_{12}$(Fig. 5(c); L-ZM5 of δ and $Mg_{32}(Al, Zn)_{49}$ (Fig. 5(d), while the L-ZM2 of Mg + Mg_2Zn_{11}+ MgCe(Fig. 5(b)). The reason that the different phases formed in ZM5 and in L-ZM5 alloys or in ZM2 and in L-ZM2 alloys can be due to pulse laser inherent rapid solidification rate resulting in synthesizing non-equilibrium alloy and creating a fine dispersion of intermetallic phases[8–11]. As it is shown in Fig. 4 that the nanometer particles and the sub-micrometer block phase were formed because of laser irradiation super rapid melting and solidification process promote the formation of either anamorphic phase or non-equilibrium crystalline phases[12].

Observation on surface of the multi-layer cladding zone showed the surface is darked, but no formation of magnesium oxide or nitride is detected by X-ray diffraction. The fact indicated that the dark film is very thin. It was possible that large volume of argon and strong evaporation/ionigation of Mg elements inhibited oxygen and/or nitrogen penetrating into the alloy inside.

3.3 Micro-hardness analysis

Table 2 shows the micro-hardness of the four alloys. From this table, it can be observed that the micro-hardness of the laser multi-layer cladding zone is higher than that of the non-laser-cladding alloy zone. The reasons can be attributed to the fine dispersive intermetallic phases formed in laser multi-layer cladding zone and to the feather-like obtained far from equilibrium conditions, usually lead to stronger and harder alloys.

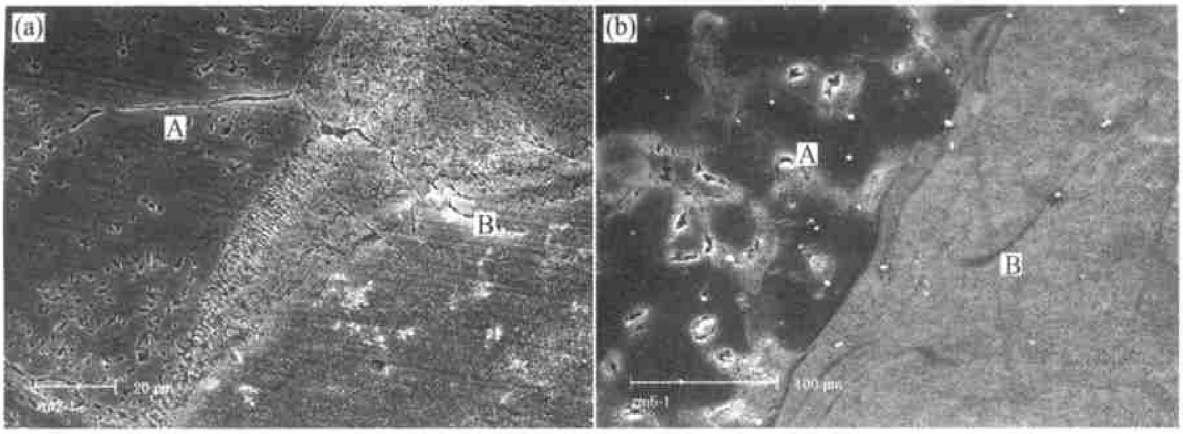

Fig. 2 Microstructures of substrate(A) and layer cladding zone(B) at interface region
(a) —ZM2; (b) —ZM5

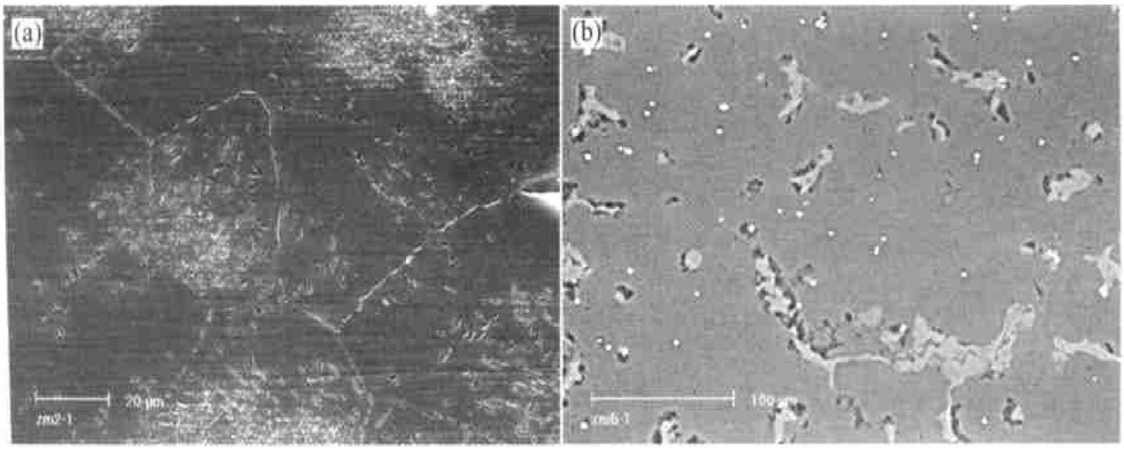

Fig. 3 Secondary electron images of ZM2 and ZM5 alloy
(a) —ZM2; (b) —ZM5

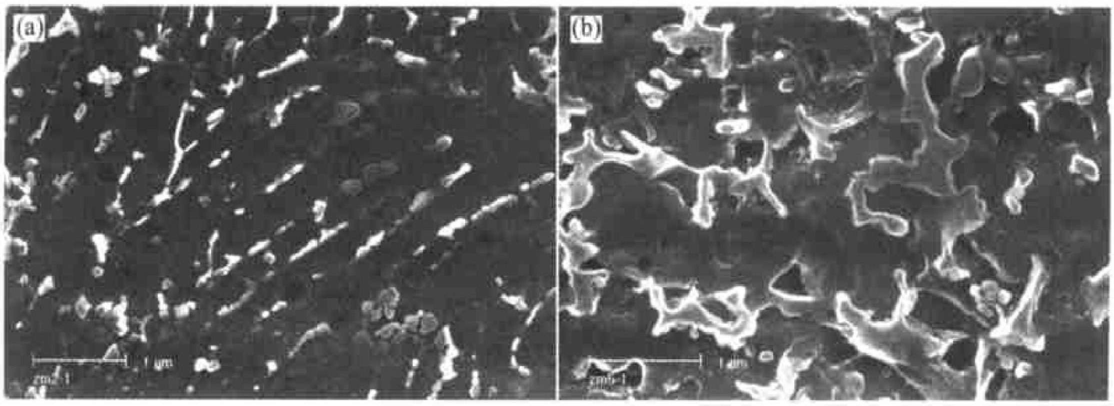

Fig. 4 Secondary electron images of L-ZM2 and L-ZM5 alloys in multi-layer cladding zone
(a) —L-ZM2; (b) —L-ZM5

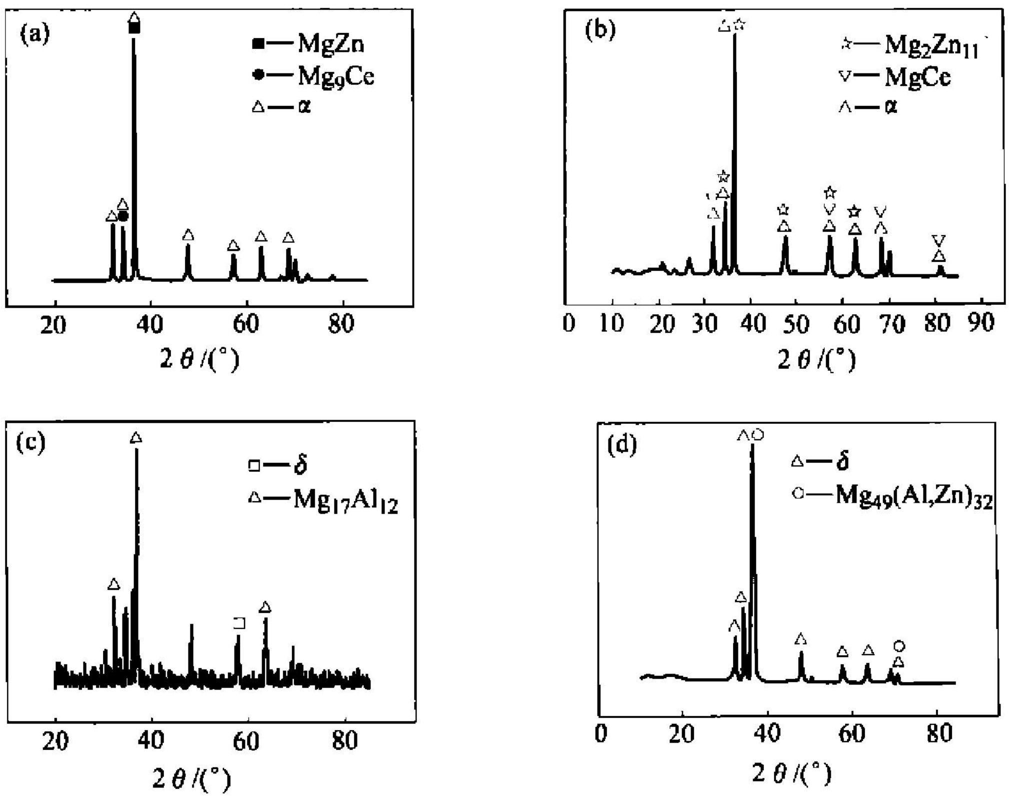

Fig. 5 XRD paterns for ZM2, ZM5, L-ZM2, L-ZM5 alloys
(a) —ZM2; (b) —L-ZM2; (c) —ZM5; (d) —L-ZM5

Table 2 Micro-hardness of four alloys

Alloy	Hardness(Hv)		Alloy	Hardness(Hv)	
ZM2	86	86	L-ZM2	127	132
ZM5	95	88	L-ZM5	140	144

4 CONCLUSIONS

Laser multi-layer cladding of Mg-based alloy on the same Mg-based substrate has been performed for two kinds of Mg-based alloys with rare earth or without rare earth. A perfect multi-layer cladding zone was obtained by the use of Nd-YAG laser with the help of argon shadow, the Mg-based alloys formed by pulse laser irradiation have higher microhardness, very fine uniform microstructure and the produced new phases of nanometer/sub-micrometere order.

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REFERENCES

[1] HU Qian-wu, YANG Tai-ping, LI Zhi-yuan, et al. Study on laser cladding of copper alloy on Mg-based matrix composite [J]. Applied Laser, 2001, 21(8): 247 - 250. (in Chinese)

[2] SI Chong-yao. Welding Handbook[M]. Beijing: Mechanical

Industry Press, 1982. (in Chinese)

[3] Koutsomichalis A, Saettas L, Badekas H. Laser treatment of magnesium[J]. J Mater Sci, 1994, 29(22): 6543−6547.

[4] Wang A A, Sircar S, Mazumder J. Laser loading of Mg-Al alloys[J]. J Mater Sci, 1993, 28(19): 5113−5122.

[5] Subramanian R, Sircar S, Mazumder J. Laser cladding of Zirconium on Magnesium for improved corrosion properties [J]. Mater Sci, 1991. 26: 951−956.

[6] LIN Zhao-qi. Materials Science of Nonferrous Metal[M]. Shenyang: Northeastern University Press, 1986. (in Chinese)

[7] Galun R, Weisheit A, Mordike B L. Laser surface alloying of magnesium base alloys[J]. Journal of Laser Applications, 1996, 8(6): 299−305.

[8] Bamberger M. Review structural refinement of cast magnesium alloys[J]. Materials Sciences and Technology, 2001, 17(1): 15−24.

[9] Polmear I J. Overview magnesium alloys and applications [J]. Materials Sciences and Technology, 1994, 10(1): 1−16.

[10] Froes F H. Rapid solidification of lightweight metal alloys [J]. Materials Science and Engineering A, 1989, A117: 19−32.

[11] Das S K, Chang C F. Rapidly Solidified Crystalline Alloys [M]. The Metallurgical Society, Narrendate, PA, 1985. 137.

[12] Dubé D, Fised M, Couture A, et al. Characterization and performance of laser melted AZ91D and AM60B[J]. Materials Science and Engineering A, 2001, A299: 38−45.

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