Applied Surface Science 256 (2009) 1609–1613

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Composition design and laser cladding of Ni–Zr–Al alloy coating on the magnesium surface

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ARTICLE INFO

Article history:
Received 17 April 2009
Received in revised form 8 September 2009
Accepted 9 September 2009
Available online 19 September 2009

Keywords:
Composition design
Laser cladding
Ni-based alloy
Magnesium alloy

ABSTRACT

The cluster line criterion was used for optimized design of a Ni–Zr–Al alloy used as coating on the AZ91HP magnesium alloy by laser cladding. Results show that the coating mainly consists of an amorphous, two ternary intermetallic phases with $Ni_{10}Zr_7$ and $Ni_{21}Zr_8$ type structures resulting in high hardness, good wear resistance and corrosion resistance. The interface between the clad layer and the substrate has good metallurgical bond.

1. Introduction

Magnesium alloys are important engineering materials in the 21-century due to their low density, excellent machine-ability, high specific strength and stiffness [1–3]. However, the Mg alloys also have some undesirable properties, such as the low hardness, poor resistance to corrosion and wear, which limit their applications. Therefore, it is important to improve the mechanical and the chemical properties of the Mg alloys in order to expend their applications.

Previous research has demonstrated that laser cladding is an effective way to improve the surface properties of Mg alloys. However, there are still some limitations in the choice and design of cladding material systems due to the low melting points and the low thermal conductivities of Mg alloys. Light alloy cladding materials (such as Al- and Mg-based alloys) exhibit good physicochemical compatibility with a Mg alloy substrate. To some extent, it can improve the corrosion resistance of the substrate, but the mechanical properties of the clad layers are relatively lower [4–9]. One way to improve the mechanical properties of the light alloy cladding materials is to introduce some hard particles into them forming hard particle reinforced composite. But the problem is this process introduces cracking and porosity that is not easy to be avoided, especially for cladding of large surfaces [10–12]. Another way is to use Co-, Ni- and Fe-based alloys with good integrated properties as the cladding materials to replace the light alloys. However, the large difference in the melting points between a transition metal alloy based cladding material and a Mg alloy substrate makes it difficult for laser cladding as the substrate overheating and the clad layer over-diluting could easily happen. Although a two-step method has been used to solve the problem of physicochemical compatibility between the cladding material and the Mg alloy substrate [13,14], it is not practical because of its complicated process and high cost. Therefore, the key to the technology lies in how to design the cladding materials with good compatibility, and high mechanical and chemical properties.

In the present study, the cluster line criterion was applied to design a Ni–Zr–Al alloy. Then the alloy coating with an optimized composition was prepared by laser cladding on the AZ91HP Mg alloy, which has potential applications in the areas of aircraft, aerospace vehicle and engine [15]. Systematical study on microstructure and properties of the system was then performed.

2. Design of Ni–Zr–Al alloy

The cluster line criterion refers to a specific composition line linking a specific binary cluster composition to the third element, which reflects the structure relationship between the optimized ternary alloy and the basic binary cluster. It can be regarded as a growth pathway from a binary cluster to a ternary phase. Therefore, if the structural information of the basic binary cluster is known, the composition of the ternary phase can be designed using the cluster line criterion [16].

In the present study, a Ni–Zr–Al alloy was designed using the cluster line criterion. Firstly, the icosahedron Ni_9Zr_4 was selected as a Ni–Zr binary cluster based on topological packing, chemical

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2009.09.029

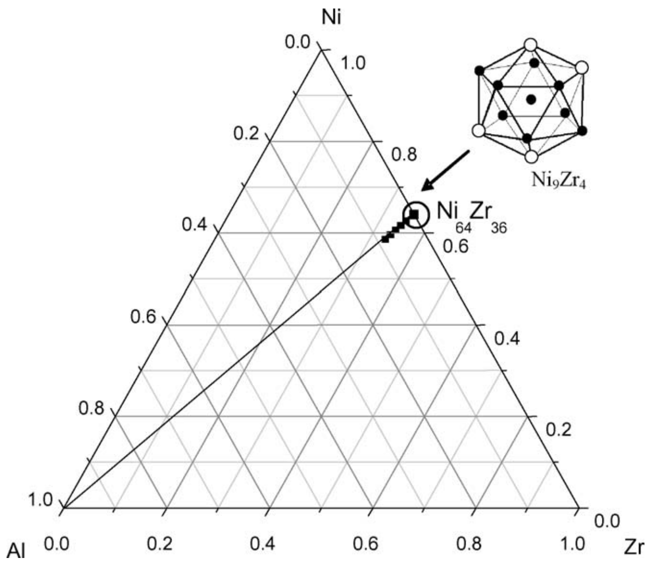

Fig. 1. Composition chart of the Ni–Zr–Al system.

Table 1
compositions of Ni–Zr–Al alloy (at.%).

Sample No. Element	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Ni	63.04	62.08	61.12	60.16	59.20	58.24
Zr	35.46	34.92	34.38	33.84	33.30	32.76
Al	1.50	3.00	4.50	6.00	7.50	9.00

short-range order, and kinetic rules. Then the cluster line was constructed by linking the special cluster to the third element Al in the composition chart of Ni–Zr–Al system (Fig. 1). Along the specific composition line, a series of $(Ni_{0.64}Zr_{0.36})_{100-x}Al_x$ alloy ingots with diameters of 3 mm were prepared by copper mould suction casting in an argon atmosphere. The compositions of the alloys are shown in Table 1.

Phase identification of these alloys was carried out by means of X-ray diffraction (XRD) using the Cu Kα radiation. As shown in Fig. 2, all the alloys consist of two ternary intermetallic phases with $Ni_{10}Zr_7$ and $Ni_{21}Zr_8$ type structures, and the content of phase with

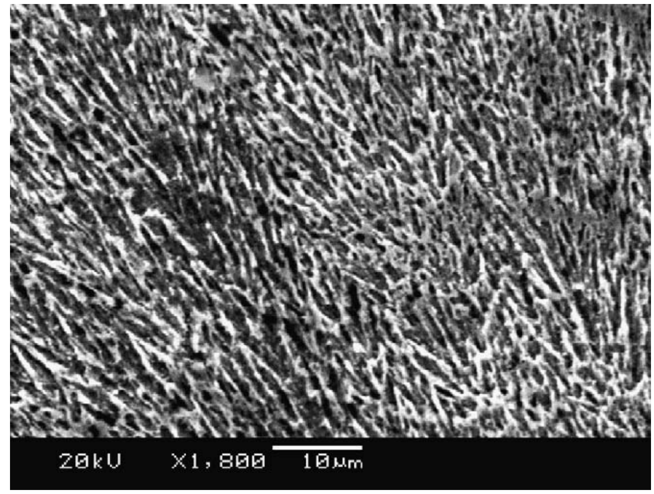

Fig. 3. SEM micrograph of the $Ni_{60.16}Zr_{33.84}Al_{6.0}$ alloy.

$Ni_{10}Zr_7$ type structure gradually decreases with the increase of Al content. Further, SEM analysis reveals that the microstructures of the alloys are featured with dendritic eutectic, growing along the directions perpendicular to lateral surfaces of the samples. A typical SEM morphology of the alloys is shown in Fig. 3. When the Al content is less than 6 at.%, with the increase of the Al content, the dendrite becomes shorter and slender. However, when Al content is more than 6 at.%, the dendrite re-coarsens resulting the densities of the alloys decrease. At the same time, the precipitation with $Ni_{21}Zr_8$ type structure is formed in the eutectic matrix.

Vickers hardness of the alloys were measured with a Vickers micro-hardness tester under a load of 0.981 N. Test data were taken from twenty different points of the cross-section of each alloy. With the increase of the Al content (less than 6 at.%), the hardness values of the alloys increase due to the refinement of the eutectic. When the Al content is more than 6 at.%, the hardness values of the alloys decrease due to the eutectic coarsening and the low density of the alloys despite of the presence of the precipitation with $Ni_{21}Zr_8$ (Fig. 4). Further analysis of the corrosion behaviors of the alloys show that the corrosion rates of the alloys slightly vary with the Al content in a 3.5 wt.% NaCl solution for 60 h of corrosion. All alloys exhibit good corrosion resistance in sea water (Fig. 5).

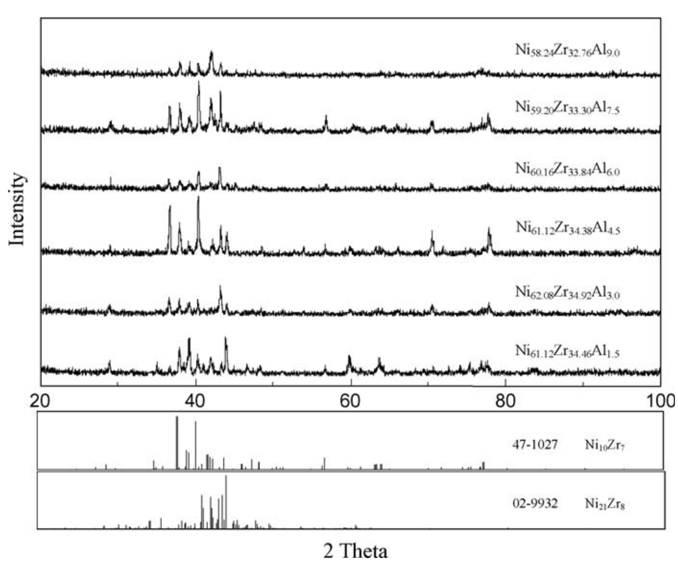

Fig. 2. X-ray diffraction patterns of the $(Ni_{0.64}Zr_{0.36})_{100-x}Al_x$ alloys.

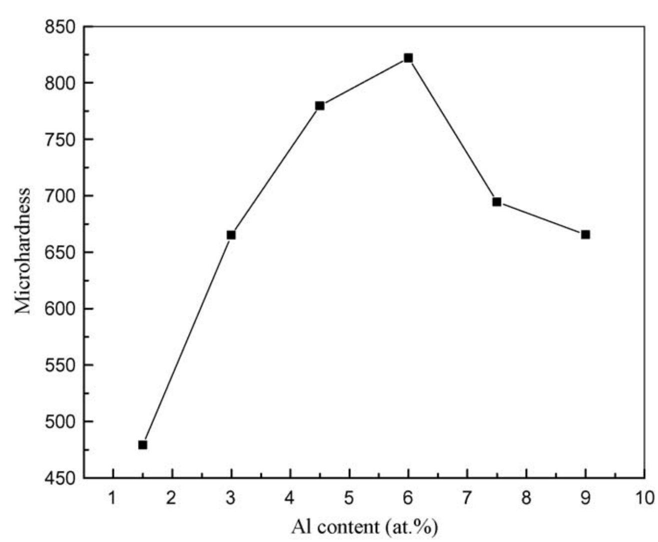

Fig. 4. Influence of Al content on the hardness of the Ni–Zr–Al alloys.