Increased Thermal Conductivity of Mg-1Mn-2Zn-1Nd Alloy with Aging Time

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Abstract. The thermal conductivity of the Mg-1Mn-2Zn-1Nd alloy aged at 200°C for 12, 24 and 48 h was investigated for the applications of heat dissipation. The microstructures were examined by X-ray diffraction analysis, optical light and scanning electron microscopy. The thermal conductivity of the Mg alloy was measured at room temperature by laser flash method. The hardness was measured by with a load force of 29.4 N and dwell time of 30 s.The experimental results indicate that the hardness of Mg-1Mn-2Zn-1Nd alloy first increases and then decreases with the aging time. The thermal conductivity of the Mg alloy slowly increases with aging time and its maximum value exceeds the critical value (120 W/(m·k)) of wrought Mg alloys for the applicationsof heat dissipation.The aged Mg-1Mn-2Zn-1Nd alloy is expected to be a good candidate of heat dissipating alloys.

1. Introduction

The electronic devices have been developed in the direction of high performance, miniaturization and light weight, and thus higher requirement is needed for the heat dissipation performance of metal fins. To realize this goal, the metal fins should possess high thermal conductivity. Silver, gold, pure copper and aluminium (Al) have the best thermal conductivity among the metallic materials [1], however silver and gold are precious metals with very high price, and copper also has its own disadvantages: high cost, large weight and poor corrosion resistance. So the currently-used most heat sinks are made from the light Al alloys. Recently, magnesium (Mg) alloys have attracted increasing attention and many Mg alloys have been developed as potential thermal materials [2-13] because Mg has better thermal conductivity (156 W/(m·K)) which is only lower than that of pure Al (237 W/(m·K)) among the commercially-used metallic materials [1] and Mg has relatively lower density and higher specific heat conductivity. However, the as-cast Mg alloys usually exhibit both poor thermal and mechanical properties or better thermal property but poor strength [2-4], and the wrought Mg alloys usually have higher strength but lower thermal conductivity [12, 13], which prevents their extensive applications of heat dissipation because the heat dissipation materials used for 3C products, shell of automobile engines and LED radiators demand both higher mechanical and thermal properties [14]. It seems that the Mg alloys have difficulty inthe applicationsof heat dissipation. Fortunately, the recent studies have indicated that the aging treatment can improve thermal performanceof Mg alloys [14-18] and therefore the aged Mg alloys are expected to have a good

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combination of both mechanical and thermal performance. Previous studies showed that the cast Mg-Zn-Mn alloy exhibits good heat performance of 125 W/(m·K) [10] and the extruded Mg-1Mn-2Zn-1Nd alloy exhibited the best strength among the Mg-1Mn-2Zn-xNd alloys [19]. Thus the Mg-1Mn-2Zn-1Nd alloy (mass%) is expected to offer a good combination of both strength and thermal performance, and the influence of aging treatment on the thermal property of wrought Mg-1Mn-2Zn-1Nd alloy was studied in this study to check its potential applications of heat dissipation.

2. Experimental

The Mg-1Mn-2Zn-1Nd alloy (mass%) was melted using pure Mg (99.99%), Zinc (99.99 mass%), Mg-10Mn (99.98 mass%), and Mg-25Nd (99.97 mass%) mother alloys. Pure metals were first put into a graphite crucible, and the mother alloys were then added at 780°C. After melting at 750~780°C for 0.5 h, the melting cast was finished with a steel mould at 730°C. The heat treatment of homogenization for the cast ingot was performed at 400°C for 24 h. The cylinder with the diameter of 46 mm was hot-extruded to ϕ12 mm at 350°C. The chemical compositions of the Mg alloy were respectively 1.23 mass% of Mn, 2.31 mass% of Zn, 0.81 mass% of Nd and the balance of Mg, which were checked by X-ray fluorescence spectrometric method. The samples, which were cut from the hot-extruded bar at cross section, were aged at 200°C for 12, 24 and 48 h with water cooling. The Vickers hardness of the studied alloy was measured by a load force of 29.4 N for 30 s, and five hardness tests were made for each specimen. The microstructure of the Mg alloy was examined by light optical microscopy (LM), scanning electron microscopy (SEM) operated at 20 kV and X-ray diffraction analysis (XRD) using a copper Kα radiation in the range $2\theta = 15\sim 85°$ with 40 kV and 40 mA at the scanning speed of 1°/min after the samples were ground with SiC emery papers of up to 3000 grit and polished with 0.5 μm diamond powder. The etching solution was composed of 5 ml nitric acid and 100 ml distilled water.

The specimens with ϕ 10 × 3 mm were machined from the aged alloy bar and the thermal diffusivity was gauged at room temperature by laser flash method. The averaged density of the samples measured by Archimedes method was 1.826 g/cm^3, which was higher than the calculated density (1.814 g/cm^3).The Neumann–Kopp Rule was employed to determine the specific heat capacities of the designed alloy according to the Refs.[20,21]. The thermal conductivity was obtained using the following equation [2]:

$$\lambda = \alpha \times \rho \times C_p \tag{1}$$

Where α is the thermal diffusivity (m^2/s), ρ is the density (g/cm^3) and C_p is the specific heat capacity (J/(g·K)) under constant pressure. The experimental results were the averages based on at least 3 samples.

3. Results and discussion

3.1. Microstructural characterization

Figure 1. presents the XRD results of the Mg-1Mn-2Zn-1Nd alloy aged at 200°C for 12, 24 and 48 h, respectively. It is noticed that both the extruded and aged samples exhibit both α phase and Mg_7Zn_3, which indicates that no new precipitate appears during the aging treatment. However, the obvious texture of extruded sample disappears after aging treatment because the strongest peaks of the aged alloy are (101) that is the same to that of powder Mg (JCPCS card 35-0821). More peaks of Mg_7Zn_3 have been detected after the aging treatment, which is possibly due to the increased amount of Mg_7Zn_3 duringthe aging treatment.

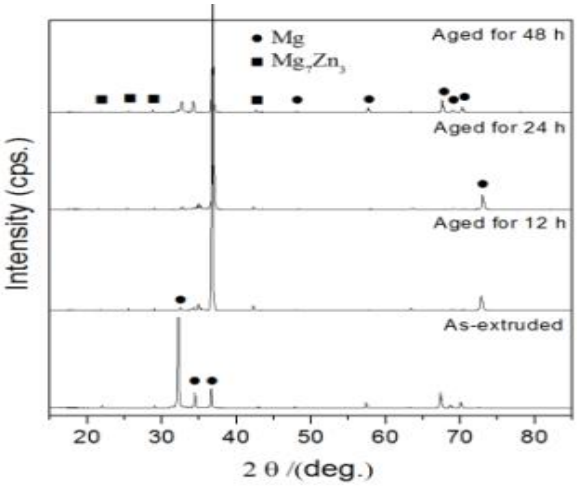

Figure 1. XRD patterns of the Mg alloy.

Figure 2. presents the microstructures of transverse sections of the Mg alloy. It can be noticed that both the extruded and aged Mg alloy exhibits very fine microstructure. Some unrecrystallized structure indicated by the arrows exists in the as-extruded sample (Figure 2(a)) while the aged samples are composed of the similar equiaxed microstructure, which suggests that the re-crystallization has fully completed after the aging treatment. The Mg_7Zn_3 is not observed because of limited resolution of LM and the SEM microstructure proves that Mg_7Zn_3 forms near the grain boundaries of the wroughtMg-1Mn-2Zn-1Nd alloy (Figure 3.). The grain sizes of aged alloy slightly grow with the aging time, especially for the aging time of 48 h.

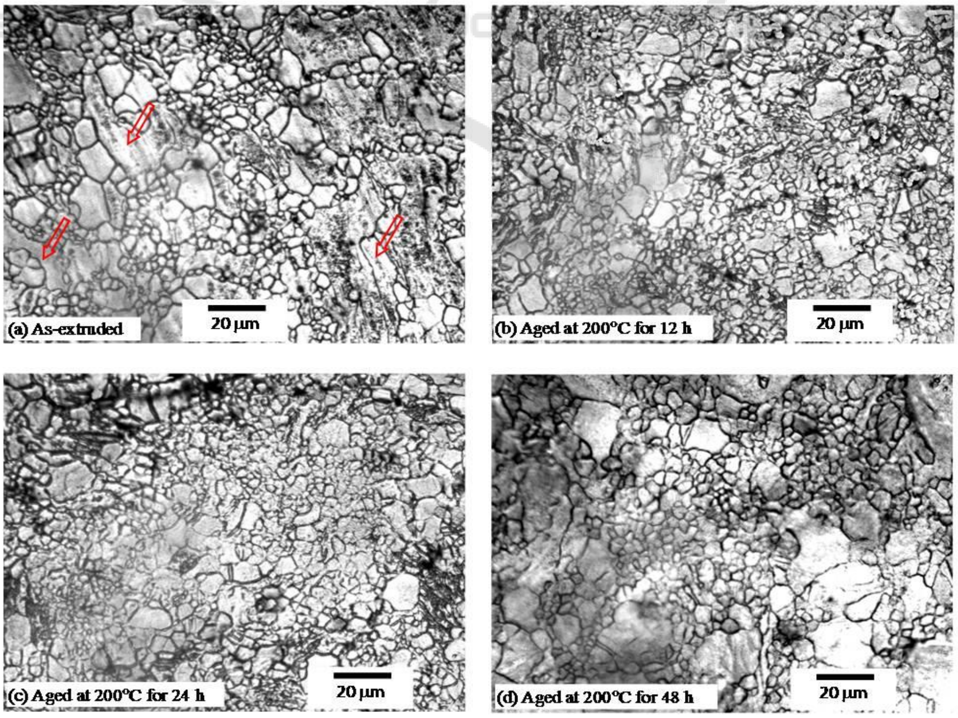

Figure 2. Microstructures of transverse sections of the Mg alloy.

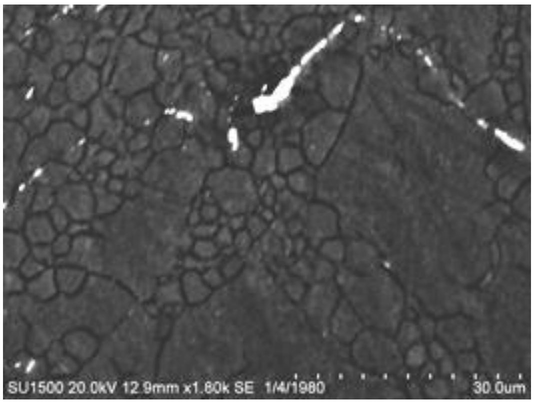

Figure 3. SEM microstructure of the extruded Mg alloy.

3.2. Vickers hardness of the Mg alloy with aging time

Figure 4. depicts the average Vickers hardness of the Mg-1Mn-2Zn-1Nd alloy aged 200°C for 12, 24 and 48 h, which first increases and then decreases with the aging time. The slight increase of hardness for the aged alloy is associated with the formation of new grains from the unrecrystallized structure and increased amount of Mg_7Zn_3 during the aging treatment, and the slow reduction of hardness with the aging time is due to the growth of grain sizes (Figure 2.).

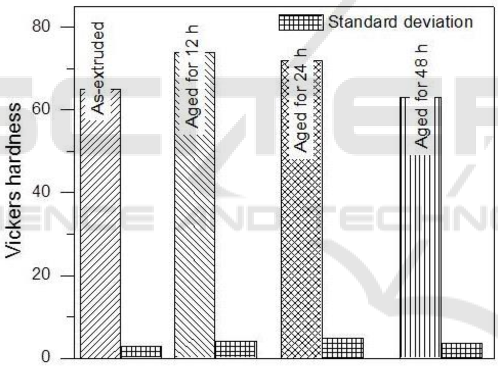

Figure 4. Vickers hardness of the Mg alloy

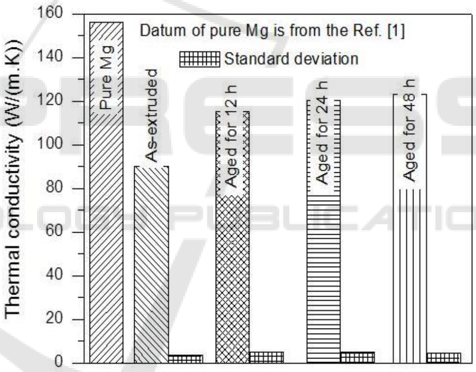

Figure 5. Thermal conductivity of the Mg alloy.

3.3. Thermal conductivity of the Mg alloy with aging time

Figure 5. shows that the thermal conductivity of the Mg-1Mn-2Zn-1Nd alloy aged at 200°C for 12, 24 and 48 h, which was calculated from the thermal diffusivity data using Eq.(1), slowly increases with the aging time and it exceeds 120 W/(m·K) when it is aged at 200°C for 24 and 48 h. This change trend is in agreement with the previous studies [15-18]. The thermal conductivity of the alloys is composed of electronic thermal conductivity and lattice thermal conductivity where the electrons and phonons are the main heat carrier of the alloys [7]. The lattice defects including vacancies, dislocations and crystal boundaries, are also the scattering centres of phonons and electrons that stop the free flow of electrons and accordingly reduce the thermal conductivity of the alloys [12, 14]. The coarser crystalline size leads to better thermal performance of the Mg alloys [11, 12]. The influence of extrusion texture on the thermal conductivity of ZM51 was investigated [10] and the texture including dislocation decreases the thermal conductivity of the alloy [10, 12, 13]. Combining with the above microstructures, it is considered that the disappearance of void, dislocation, texture and growth of grain sizes of aged alloy during the aging treatment are mainly

responsible for the enhanced thermal conductivity of the alloy with the aging treatment as shown in Figure 5.

Usually, the ageing treatment leads to the reduction of solute atoms in the α–Mg matrix and the subsequent formation of element particles or intermetallic compounds, which would definitely affect the thermal conductivity of the alloys. However, no new precipitate except Mg_7Zn_3 and α–Mg has been detected by XRD analysis, which is associated with the limited concentration of alloying elements, Mn, Zn and Nd. Therefore,the changes of defects and grain boundaries of the Mg alloy during the aging treatment are mainly responsible for the slight increase of thermal conductivity with the aging time. If new phase precipitates from the Mg alloy, the variation of thermal conductivity would be abrupt.

According to Figures 4 and 5, it can be observed that the Mg alloy aged at 200°C for 24 h has good combination of both mechanical and thermal properties. The thermal performance of heat dissipation materials is an essential thermophysical property. The higher thermal conductivity of metal fins leads to better cooling effect [22], which can prevent the electric (al) equipment from overheating and prolong the service life. Huawei Technology Co., Ltd., a globe leading manufacturer of information and technology, demanded that the cast and wrought Mg alloys at least should possess the thermal conductivity of 100 and 120 W/(m·K), respectively[23]. Therefore the Mg-1Mn-2Zn-1Nd alloy aged at 200°C for 24 and 48 h meets this requirement forthe wrought Mg alloys and is expected to be a good candidate of heat dissipating alloys.

4. Conclusions

The thermal conductivity of the Mg-1Mn-2Zn-1Nd alloy aged at 200°C for the different aging time was studied at room temperature by laser flash method. The experimental results indicate that the thermal conductivity of the Mg-1Mn-2Zn-1Nd alloy slowly increases with the aging time and exceeds the required critical value (120 W/(m·K)) of wrought Mg alloys, thus the aged Mg-1Mn-2Zn-1Nd alloy is expected to be a good candidate for the application of heat dissipation.

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