Rare Metal Materials and Engineering
Volume 47, Issue 3, March 2018
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com

ScienceDirect

Cite this article as: Rare Metal Materials and Engineering, 2018, 47(3): 0799-0802.

ARTICLE

Strength Stability of Aging Hardened Mg-10Y-1.5Sm Alloy

Zhang Qing, Chen Jun, Li Quanan

Collaborative Innovation Center of Nonferrous Metals, Henan Province, Henan University of Science and Technology; Luoyang 471023, China

Abstract: The tensile strength stability of aging hardened Mg-10Y-1.5Sm (mass fraction, %) alloy was investigated by microstructure analysis and tensile tests. The results show that the microstructure of Mg-10Y-1.5Sm alloy consists of α-Mg matrix and $Mg_{24}Y_5$ phase and the formation of Sm-containing phase is not observed. With the increase of temperature from 20 to 300 ^oC, the tensile strength exceeds 200 MPa and has no obvious change. It is insensitive to temperature and the variation range is less than 10 MPa. The strength stability is superior to that of heat resistant magnesium alloy WE54 developed most successfully. It is mainly attributed to the hardness stability of strengthening phase $Mg_{24}Y_5$ enhanced by dissolved Sm.

Key words: magnesium alloy; rare earth; tensile strength; strengthening phase

Mg-RE (rare earth elements) alloys are interesting materials since they have excellent mechanical properties at room and high temperature[1,2]. At present, those magnesium alloys whose applied temperature exceeds 200 ^oC are Mg-RE alloys[3,4]. Simultaneous addition of two or more kinds of rare earth elements belonging to different subgroups (Y subgroup, Ce subgroup) can produce solid solution strengthening and precipitation strengthening, and increase comprehensive mechanical properties of magnesium alloys[5]. Among Y subgroup (heavy) rare earth elements, Y has a high solid solubility of 12% (mass fraction) in Mg. Y is considered to be one of the most effective rare earth elements to improve mechanical properties of magnesium alloys at high temperatures [6, 7]. Among Ce subgroup (light) rare earth elements, Sm has a unique orthorhombic structure and the maximum solid solubility of 5.7% in Mg[8]. Therefore, Y and Sm are an interesting combination of heavy and light rare earth elements [9].

Heat resistant Mg-Y-Sm alloys have been attached more and more importance due to their better strength and creep resistance than commercial Mg-Y-RE (WE) alloys at high temperature [10-12]. However, their strength stability has few been investigated. In the present work, the strength stability of Mg-10Y-1.5Sm alloy is investigated.

1 Experiment

Metallic magnesium, Mg-25Y and Mg-25Sm (mass fraction, %) master alloys were used as raw materials. All the raw materials were baked before melting. The chemical composition of tested alloy was designed as Mg-10Y-1.5Sm (mass fraction, %). The alloy was melted in an induction furnace and cast in a preheated steel mold. Then, T6 treatment including solid solution (540 ^oC/6 h) and aging treatment (250 ^oC/2 h) was conducted for the cast alloy.

The tensile tests were carried out at a strain rate of 1 mm/min in AG-I 250 kN precision universal material testing machine at room temperature (20 ^oC) and elevated temperature (200, 250, 300 ^oC). The gauge section of tensile specimen is Φ6 mm×30 mm. The elevated temperature tensile tests were performed in air in an electric resistance furnace. The samples were held for about 5 min prior to the tensile test to reach a thermal equilibrium.

The phases were analyzed by D8 Advance X-ray diffraction meter (XRD) and MDI Jade 5.0 software. The microstructure was examined by Olympus optical microscope (OM) and JSM-5610LV scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS). The grain size was determined by a mean linear intercept method.

Received date: March 15, 2017
Foundation item: National Natural Science Foundation of China (NSFC-Henan Joint Fund of Personnel Training, U1404501)
Corresponding author: Zhang Qing, Ph. D., Associate Professor, School of Materials Science and Engineering, Henan University of Science and Technology, Luoyang 471023, P. R. China, Tel: 0086-379-64231269, E-mail: foxzq@126.com

2 Results and Discussion

2.1 Mechanical properties

The mechanical properties of aging hardened Mg-10Y-1.5Sm alloy are given in Table 1. At room temperature, the mechanical properties are not very ideal. The tensile strength is only 205 MPa, and the elongation is less than 3%. However, at elevated temperature, the mechanical properties do not decrease. The tensile strength exceeds 200 MPa at 200~300 ºC. With the increase of temperature, the tensile strength remains unchanged (200, 300 ºC) or increases slightly (250 ºC). It can be drawn that the tensile strength is not sensitive to temperature. On the other hand, the elongation increases slowly with the increase of temperature, from 3.0% at 200 ºC to 3.3% at 300 ºC. As a whole, the mechanical properties at 200~300 ºC are close to or a little higher than those at room temperature. Considering the tensile strength and elongation, the maximum applied temperature of the alloy is up to 300 ºC.

Among Mg-Y-RE (WE) alloys, WE54 (Mg-5.1%Y-3.3% RE(Nd)-0.5%Zr) alloy is one of the heat resistant magnesium alloys developed most successfully. It has good strength properties at room and high temperature. Its tensile strength is 280 MPa at room temperature, 240 MPa at 200 ºC, 230 MPa at 250 ºC and 180 MPa at 300 ºC. Its heat resistant temperature is up to 300 ºC [13, 14]. Fig.1 shows the tensile strength of Mg-10Y-1.5Sm and WE54 alloys. It can be seen that the strength of Mg-10Y-1.5Sm alloy is lower than that of WE54 alloy from room temperature to 250 ºC. However, the strength of Mg-10Y-1.5Sm alloy is higher at 300 ºC. As a result, the tensile strength of Mg-10Y-1.5Sm alloy is stable. It has no obvious change and the variation range is less than 10 MPa from room temperature to 300 ºC. Its strength stability is superior to that of heat resistant magnesium alloy WE54.

Table 1 Mechanical properties of Mg-10Y-1.5Sm alloy

Temperature/ºC	20	200	250	300
Tensile strength/MPa	205	203	213	204
Elongation/%	2.8	3.0	3.1	3.3

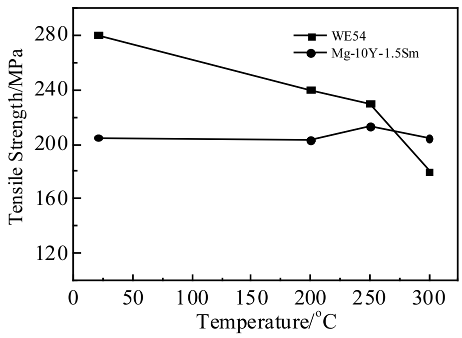

Fig.1 Tensile strength of Mg-10Y-1.5Sm and WE54 alloys with different temperatures

2.2 Microstructure

Fig.2 shows the microstructure of Mg-10Y-1.5Sm alloy. It can be seen that the microstructure of the as-cast alloy consists of white matrix and black second phases. According to the relative phase diagrams, they should be α-Mg matrix and eutectic compounds, respectively. The eutectic compounds are distributed in the grains and at the boundaries. They have granular and rod-like morphologies (in Fig.2a). After aging treatment, the microstructure of the alloy has two outstanding features: (1) the grains are uniform and their average size is about 60 μm; (2) the second phases are particles and they distribute uniformly and dispersedly in the alloy (see Fig.2b).

At different temperatures, the main strengthening mechanism is different for magnesium alloys. At room temperature, grain refinement is the main strengthening mechanism for magnesium alloys. However, the grain size of aging hardened Mg-10Y-1.5Sm alloy is not very small. At high temperature, dispersion strengthening of second phase is the main strengthening mechanisms for magnesium alloys. The uniform and dispersive distribution of particle phase can enhance the dispersion strengthening effect. As a result, the microstructure of aging hardened alloy is a little harmful to the mechanical properties at room temperature, while it is very helpful to the mechanical properties of the alloy at high temperature.

Fig.3 shows the XRD pattern of aging hardened Mg-10Y-1.5Sm alloy. It can be seen that there are only Mg matrix

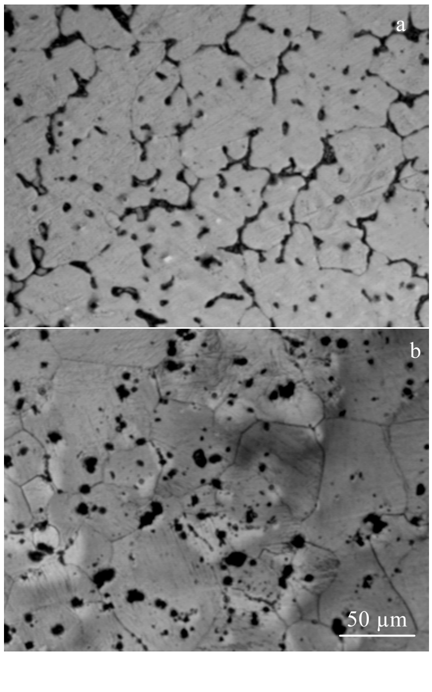

Fig.2 Microstructures of as-cast (a) and aged (b) Mg-10Y-1.5Sm alloy

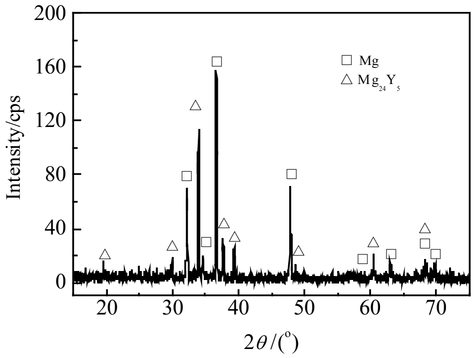

Fig.3 XRD pattern of Mg-10Y-1.5Sm alloy

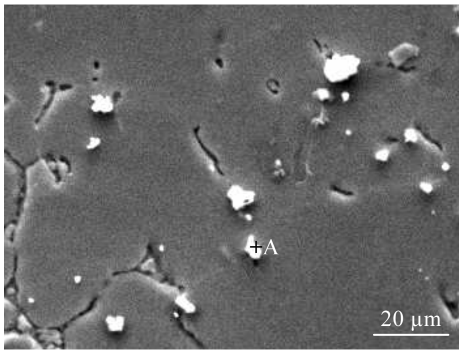

Fig.4 SEM image of Mg-10Y-1.5Sm alloy

and $Mg_{24}Y_5$ phases and no Sm-containing phases are formed in the alloy. There are two possible reasons: (1) Sm dissolves in Mg matrix and $Mg_{24}Y_5$ phases due to its low content (1.5%) and high solid solubility (5.7% at 540 ºC, and 0.4% at 200 ºC[15]). The lattice constant of $Mg_{24}Y_5$ phase (bcc structure) in the alloy is measured to be a=1.1278 nm and larger than usual value (a=1.1260 nm), which may be explained by the solubility of Sm in $Mg_{24}Y_5$ phase; (2) Sm-containing phase is not detected by XRD due to its small amount.

2.3 Strengthening phase

Fig.4 and Fig.5 show SEM image of the microstructure and EDS analysis of aging hardened Mg-10Y-1.5Sm alloy, respectively. It can be seen that particle A consists of three elements Mg, Y and Sm, but the content of Sm is very low. Considering the XRD pattern in Fig.3, only Mg matrix and $Mg_{24}Y_5$ phases are observed in the alloy and no Sm-containing phases are formed. It can be drawn that the particle should be $Mg_{24}Y_5$ phase. And the existence of Sm in the particle can be explained to be the dissolving of part Sm in $Mg_{24}Y_5$ phase. With the solubility of Sm, the compact density and lattice distortion of $Mg_{24}Y_5$ phase is increased. Therefore, the stability of strengthening phase $Mg_{24}Y_5$ is enhanced with the dissolving of Sm.

2.4 Strength stability

The strength of magnesium alloy at high temperature depends on thermal stability of strengthening phase at grain boundaries. Considering the microhardness of phases in magnesium alloy (in Table 2)[16], the thermal stability of $Mg_{24}Y_5$ phase in Mg-Y alloy is much higher than that of $Mg_{17}Al_{12}$ phase in Mg-Al alloy and MgZn phase in Mg-Zn alloy. The thermal stability of strengthening phase determines the heat resistant temperature of the alloy and its position in heat resistant magnesium alloys. Judged from that the hardness drop of strengthening phase is less than 20%, the heat resistant temperature of Mg-Al alloy and Mg-Zn alloy does not exceed 200 ºC. They are consistent with the existing research results. The hardness (HV) of

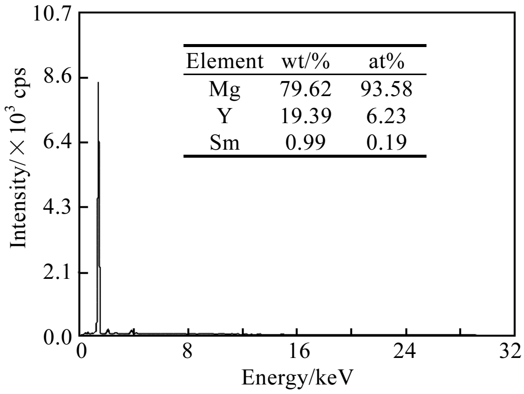

Fig.5 EDS analysis of particle A in Fig.4

Table 2 Microhardness of some phases in magnesium alloy (MPa)

Phase	20 ºC	200 ºC	250 ºC	300 ºC
$Mg_{24}Y_5$	2180	2010	1960	1730
$Mg_{17}Al_{12}$	1830	1580	1250	840
MgZn	1560	1310	910	470

$Mg_{24}Y_5$ decreases slowly with the increase of temperature, from 2180 MPa at 20 ºC to 1730 MPa at 300 ºC, and the drop is a little more than 20%. So Mg-Y alloys (such as WE54) have good heat resistance and their maximum applied temperature is up to 300 ºC.

In order to find out the reason for strength stability of aging hardened Mg-10Y-1.5Sm alloy, the relationship between tensile strength of Mg-10Y-1.5Sm alloy and microhardness of $Mg_{24}Y_5$ phase is plotted and fitted linearly (in Fig.6). The tensile strength of Mg-10Y-1.5Sm alloy is stable and insensitive to the change of temperature. It keeps a linear relationship with the microhardness of $Mg_{24}Y_5$ phase. So the tensile strength stability is mainly attributed to the hardness stability of strengthening phase $Mg_{24}Y_5$. Of course, Sm also plays an important role in the alloy. The dissolved Sm enhances the thermal stability and there by

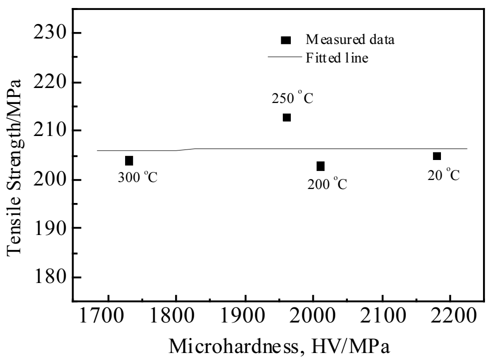

Fig.6 Relationship between tensile strength of Mg-10Y-1.5Sm alloy and microhardness of $Mg_{24}Y_5$ phase

the dispersion strengthening effect of $Mg_{24}Y_5$ phase in the alloy. Therefore, $Mg_{24}Y_5$ phase still keeps high hardness at high temperature and acts as a bar to dislocation movement and boundary sliding and improves the strength properties of the alloy at high temperature.

3 Conclusions

1) With the increase of temperature from 20 to 300 °C, the tensile strength of aging hardened Mg-10Y-1.5Sm alloy is more than 200 MPa and has no obvious change. It is stable and insensitive to temperature and the variation range is less than 10 MPa.

2) The strength stability of Mg-10Y-1.5Sm alloy is superior to that of heat resistant magnesium alloy WE54 developed most successfully. The reason is mainly the hardness stability of strengthening phase $Mg_{24}Y_5$ enhanced by dissolved Sm.

References

1 Mayumi S, Hiroyuki S, Kouich M *et al*. *Materials Science and Engineering A*[J], 2001, 319-321: 751
2 Mayumi S, Tsuyoshi K, Junichi K *et al*. *Materials Science and Engineering A*[J], 2004, 387-389: 706
3 Yao Sujuan, Yi Danqing, Li Wangxing *et al*. *Light Metals*[J], 2007(9): 55 (in Chinese)
4 Wu Yujuan, Ding Wenjiang, Peng Liming *et al*. *Materials China*[J], 2011, 30(2): 1 (in Chinese)
5 Rokhlin L L, Dobatkina T V, Nikitina N I. *Materials Science Forum*[J], 2003, 419-422: 291
6 Zhang Jinghuai, Tang Dingxiang, Zhang Hongjie *et al*. *Chinese Journal of Rare Metals*[J], 2008, 32(5): 659 (in Chinese)
7 Deng Yonghe. *Chinese Rare Earths*[J], 2009, 30(1): 76 (in Chinese)
8 Zhang Qing, Li Quanan, Chen Jun *et al*. *Advances in Engineering Research*[J], 2015, 9: 83
9 Ding Wenjiang. *Magnesium Alloy Science and Technology*[M]. Beijing: Science Press, 2007: 115 (in Chinese)
10 Li Daquan, Wang Qudong, Ding Wenjiang. *Materials Science and Engineering A*[J], 2007, 448: 165
11 Wang Qudong, Li Daquan, Suéry M *et al*. *Materials Science and Engineering A*[J], 2009, 516: 189
12 Zhang Qing, Li Quanan, Chen Jun *et al*. *Journal of the Chinese Society of Rare Earths*[J], 2015, 33(6): 718 (in Chinese)
13 Zhang Xinming, Peng Zhuokai, Chen Jianmei *et al*. *The Chinese Journal of Nonferrous Metals*[J], 2004, 14(9): 1443 (in Chinese)
14 Yan Yunqi, Zhang Tingjie, Deng Ju *et al*. *Rare Metal Materials and Engineering*[J], 2004, 33(6): 561 (in Chinese)
15 Li K J, Li Q A, Jing X T *et al*. *Scripta Materialia*[J], 2009, 60(12): 1101
16 Chen Zhenhua. *Heat Resistant Magnesium Alloy*[M]. Beijing: Chemical Industry Press, 2007: 206 (in Chinese)

时效硬化 Mg-10Y-1.5Sm 合金的强度稳定性

张 清，陈 君，李全安

(河南科技大学 有色金属共性技术河南省协同创新中心，河南 洛阳 471023)

摘 要：采用组织分析和拉伸试验，研究了时效硬化Mg-10Y-1.5Sm (质量分数，%)合金抗拉强度的稳定性。结果表明，Mg-10Y-1.5Sm合金的显微组织由α-Mg基体和$Mg_{24}Y_5$相组成，没有发现含Sm相的生成。随着温度从20 ℃升高到300 ℃，合金的抗拉强度均高于200 MPa，没有明显变化。合金强度对温度不敏感，变化幅度低于10 MPa。其抗拉强度稳定性优于发展最为成功的商用耐热镁合金WE54，原因可主要归结于因Sm固溶而增强的强化相$Mg_{24}Y_5$硬度的稳定性。

关键词：镁合金；稀土；抗拉强度；强化相

作者简介：张 清，男，1974 年生，博士，副教授，河南科技大学材料科学与工程学院，河南 洛阳 471023，电话：0379-64231269，E-mail: foxzq@126.com