Effect of V on the microstructure and mechanical property of Al-Mg-Si alloy by adding Al_3V phase

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Abstract: The effect of V microalloying on the microstructure and mechanical properties of Al-Mg-Si wrought aluminum alloy by adding the Al-4V (wt.%) master alloy containing the single type of Al_3V phases was studied by optical microscope, scanning electron microscope and energy spectrum analysis. The results showed that adding V into the Al-1.6Mg-1.2Si (wt.%) alloy by means of Al_3V phases significantly refined the as-cast alloy structure and reduced the grain size by 3.30%. During homogenization heat treatment, dispersed spherical V-containing phase precipitated from the matrix and strongly inhibited the recrystallization grain growth during the T6 heat treatment. The mechanical properties of T6 alloy was improved significantly when the minor V was added by means of Al_3V phases, with the tensile strength (UTS) and yield strength (YS) increased by 1.21% and 2.42% respectively while elongation (EL) increased significantly by 130%.

1. Introduction

It is well known that Al-Mg-Si alloy, as a medium-strength heat-treatable strengthened aluminum alloy, has good melt-casting properties and deformation processing properties [1]. However, in practical application, to further enhance the properties of Al-Mg-Si alloys, micro-alloying is usually used by adding trace elements such as V, Mn, Cr and Zr into the alloy to form diffusion-reinforced phase [2, 3].

In 6xxx series aluminum alloys, Yi Meng [4] et al. added V elements to Al-1.6Mg-1.2Si-1.1Cu-0.16Cr-0.03Ti alloy by Al-4V (wt. %) master alloy containing the single type Al_3V phases, and the results showed that the introduction of V promoted the formation of fine equiaxed as-cast microstructures, and the formation of the complex Al(VCrTi)Si phase significantly inhibited the dynamic recrystallization nucleation and grain growth during the hot extrusion, resulting in improving the mechanical properties. Elhadari et al. [5] found that the Al_3Zr and $Al_3(Zr, V)$ phases formed in the alloy when Zr and V were added to Al-7Si-1Cu-0.5Mg (wt.%) alloys were effective in improving the yield strength and fatigue life of the alloy. In addition, Daniele Casari et al [6] found that adding 0.1 wt. % V to A356 cast aluminum alloy promoted the precipitation of Mg_2Si strengthening phase in T6 heat treatment, and the strength resistance and yield strength were significantly increased. Therefore, the strengthening effect of V on the aluminum alloy is expected.

However, in actual production, V is usually added to Al-Mg-Si alloy with other trace elements such as Ti, Zr and Cr simultaneously, which will produce very complex V-containing phases in the alloy after heat treatment. As a result, the effect of V element on the microstructures and properties of Al-Mg-Si alloy cannot be accurately distinguished. In this experiment, the Al-1.6Mg-1.2Si-0.15V (wt. %) alloy was prepared by using the Al-4V (wt. %) master alloy containing the single type of Al_3V phases. The effects of V elements on the microstructure and mechanical properties of Al-1.6Mg-1.2Si (wt. %) alloys were investigated.

2. Materials and experimental methods

2.1 Experimental materials

Al-1.6Mg-1.2Si-0.15V (wt. %) wrought aluminum alloys were prepared from Al-4V (wt. %) master alloys and Al-1.6Mg-1.2Si (wt. %) alloys. The Al-4V (wt. %) master alloy was melted at 1100°C and cooled in a water-cooled copper mold, resulting in the single type of Al_3V phases present in the ingot. The alloy melting was heated in a graphite crucible resistance furnace and casted into the 40 mm × 40 mm × 110 mm ingot in a stainless- steel mold.

2.2 Experimental method

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The ingots were homogenized at 540°C for 24h, and then cut into 25 × 100 × 10mm samples by wire cutting. The samples were rolled to 1.6mm at room temperature with a total deformation of 84%. After cold rolling, the alloys were solid solution at 550°C for 2h and water quenched, and then aged at 170°C for 24h immediately (T6 heat treated). The chemical composition of the alloy was examined using an EXPEC 6500 inductively coupled plasma emission spectrometer (ICP). The microstructures of the alloys in the as-cast and homogenized states were finely polished with 0.02μm alumina polishing solution after mechanical polishing of the metallographic sample (anodic coating solution: 38ml H_2SO_4+43ml H_3PO_4+19ml H_2O), and the image observation was performed with a polarizing lens LEICA DM4 P microscope and the scanning electron microscope (SEM) equipped with a DX-4 energy spectrum analyzer JSM-IT300 scanning electron microscope. The tensile specimens were cut by wire-cutting and polishing with 800# water-grit sandpaper after cold-rolling, the specific dimension is shown in Figure 1. The tensile strength (UTS), yield strength (YS, 0.2% strain) and elongation (EL) of the T6-alloys were obtained by using UTM5105 electronic universal tensile machine with the tensile rate of 2 mm/min.

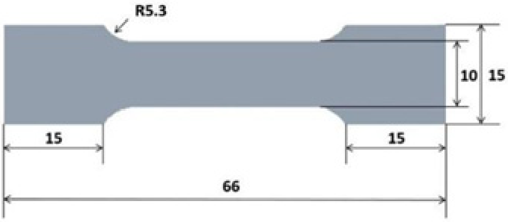
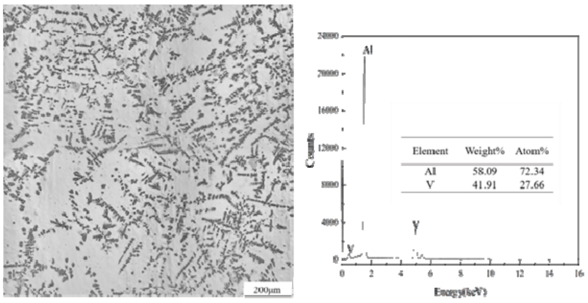


Fig 1 Dimensions of tensile specimens (mm).

3. Results

3.1 Al-4V (wt. %) master alloy with single type Al_3V phase

Figure 2 shows the Al-4V (wt. %) master alloy microstructures and EDS analysis results. As shown in Fig. 2a, Al-4V (wt. %) master alloy contains a single petal-like type phases which can be identified as Al_3V phase based on the EDS results shown in Fig. 2b. The area proportion of Al_3V phase in Fig. 2a reached 16.00%, and the Al_3V phase illustrate the similar size and uniform distribution.



Element	Weight%	Atom%
Al	58.09	72.34
V	41.91	27.66

Fig. 2 Micrographs of Al-4V (wt. %) master alloy and EDS analysis results
(a) Al-4V (wt. %) master alloy containing single type Al_3V phase;
(b) Results of EDS analysis of Al_3V phase in fig (a).

3.2 Microstructures of Al-1.6Mg-1.2Si(-0.15V) alloys

Table 1 shows the chemical composition of Al-1.6Mg-1.2Si(-0.15V) alloys tested by ICP chemical elemental analysis, the results indicating that the alloy melting process is appropriate and V has been successfully added into the alloy. Figure 3 show as-cast microstructures of V-free alloy and V-added alloy. From Fig. 3, it can be seen that the as-cast alloys are composed of coarse α-Al dendrites showing equiaxed shape (Fig. 3a). After adding trace amount V with the single type Al_3V phase (Fig. 3b), the grain size of as-cast alloy is reduced from 360.4μm to 348.0μm, indicating that the V addition could refine the as-cast Al-1.6Mg-1.2Si (wt. %) alloy significantly.

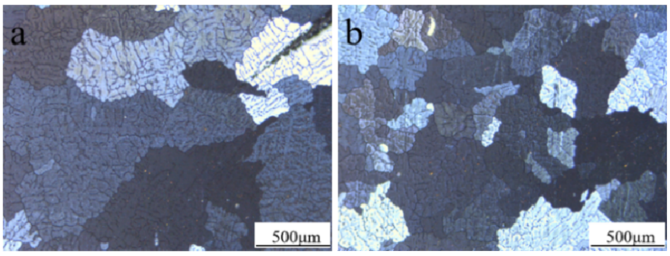


Fig. 3 As-cast microstructures of alloys observed under polarised light
(a) V-free alloy; (b) V-added alloy.

Table 1 Chemical composition of the alloys (wt. %).

Alloy	Si	Mg	V	Fe	Al
Al-1.6Mg-1.2Si (wt. %)	1.19	1.29	-	0.0073	Bal
Al-1.6Mg-1.2Si-0.15V (wt. %)	1.24	1.11	0.16	0.0076	Bal

Figure 4 show microstructures of the Al-1.6Mg-1.2Si-0.15V alloy after homogenization heat treatment. Table 2 shows the EDS results of phases shown in Figure 4b. As shown in Fig. 4a, there is still a larger size 5-7 μm primary Mg_2Si phase and some intermetallic distributed in the matrix after the homogenization heat treatment. Due to the presence of Fe with a very trace amount in the Al-1.6Mg-1.2Si-

0.15V alloy (Table 1), besides the spherical V-containing phases, the rod-like β-AlFeSi phase (b-2 phase in Fig. 4b) is also present in the Al-1.6Mg-1.2Si-0.15V alloy. Meanwhile, trace amount of V is solidly dissolved to the β-AlFeSi phase as shown in Fig.4b and Table 2.

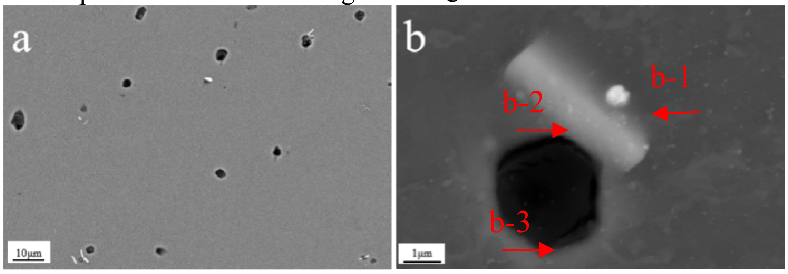


Fig. 4 Microstructures of Al-1.6Mg-1.2Si-0.15V alloy after homogenization heat treatment.

Table 2 The EDS results of the phases in Fig. 4b.

	Elemental mass percent (wt. %)					
Phase	Al	Fe	Mg	Si	V	Phase Type
b-1	55.71	5.37	2.18	21.05	15.68	V-containing phase
b-2	64.62	12.19	11.45	11.22	0.53	β-AlFeSi
b-3	61.69	-	23.69	14.62	-	Mg_2Si

3.3 Microstructures of Al-1.6Mg-1.2Si(-0.15V) alloys after cold-rolling

Figure 5 shows the microscopic structure of the alloys after cold rolling. As shown in Fig. 5, after the alloy was cold deformed V-free alloy and V-added alloy have similar microstructures, the original equiaxed crystals were elongated in the rolling direction (RD), the grain aspect ratio was increased, and a more obvious directionality appeared, showing streamlined characteristics.

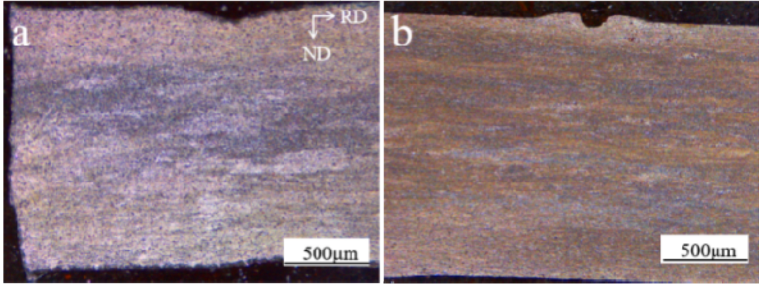


Fig. 5 Micrographs of alloy transverse direction by polarised light after cold-rolling:
(a) V-free alloy; (b) V-added alloy.

3.4 Micrographs and mechanical properties of T6-alloys

Figure 6 shows the microscopic structure of the alloys after the T6 heat treated state. As shown in Fig. 6a, the grain size of the alloys was 118.38μm (V-free) and 82.70μm (V-added) respectively, indicating that the introduction of V with the single type of Al_3V phase into the alloy will significantly inhibit the recrystallization grain growth during the T6 heat treatment. Figure 7 shows the mechanical properties of the alloy V-free and alloy V-added after T6 heat treatment. Comparing to the V-free alloy, the UTS, YS and EL of the V-added alloy increased from 342.92 MPa to 348.33 MPa, 316.13 MPa to 323.80 MPa, and 12.8% to 29.45%, up 1.21% and 2.42% and 130% respectively. Therefore, the trace addition of V with the single type of Al_3V phase will significantly increases the EL and deformation obviously but the UTS and YS slightly.

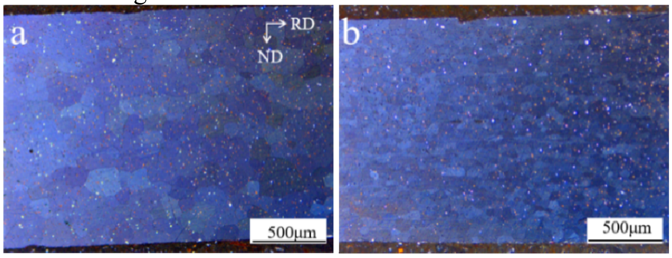


Fig. 6 Micrographs of T6-alloys in the transverse direction by polarised light:
(a) V-free alloy; (b) V-added alloy.

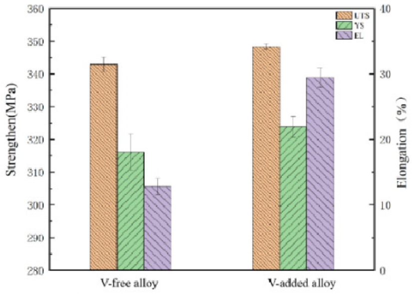


Fig. 7 Mechanical properties of alloys after T6 heat treatment.

4. Discussions

The experimental results show that the addition of Al-4V (wt. %) master alloy with the single type of Al_3V phase to Al-1.6Mg-1.2Si (wt. %) alloy has a more obvious refining effect on the as-cast grains (Fig. 3). The Al-V phase diagram [7] shows, that the Al_3V phase is sub-stable. So it is easy to disperse and more uniform during the melting process, which will form fine V-containing phase during the subsequently cooling and solidification process, resulting in a grain refining effect. After the homogenization heat treatment, the V-containing phase will be precipitated. The atomic ratio of Al to V in this phase is close to 7:1 by energy spectrum analysis, so the V-containing phase might be determined as Al_7V phase (b-1 phase in Fig. 4b). Due to vanadium additions form stable V-containing phase dispersion in the matrix [8], restrict the growth of the recrystallized grains, as a result of the significantly inhibition effect on the recrystallization process in the T6 heat treatment (Fig. 6). This result is consistent the effect of element V on T6 heat treatment process of alloy by Camero S et al [9]. Besides, the presence of a trace amount of Fe in the alloy will formation β-AlFeSi phase with V elements is solid soluted in the β-AlFeSi phase, the presence of V will stabilize β-AlFeSi phase [10,11]. Due to the significant inhibition effect of V on recrystallization grain growth in the T6 treatment, the recrystallized grain size the V-added alloy is much smaller than that of V-free alloy after T6 heat treatment. So the grain deformation coordination increases [12] and the elongation of the alloy improves significantly.

5. Conclusion

In this study, Al-1.6Mg-1.2Si(-0.15V) (wt. %) wrought aluminum alloys were prepared by adding the Al-4V (wt. %) master alloy containing the single type of Al_3V phases. The effects of V on the microstructure of the Al-Mg-Si alloy and the mechanical properties of the alloy after T6 heat treatment were investigated. The following conclusions can be drawn:

(1) The addition of Al-4V (wt. %) master alloy with single type Al_3V phase would results in the grain refinement of the as-cast Al-1.6Mg-1.2Si (wt. %) alloy.

(2) The addition of V with single type Al_3V phase to the Al-1.6Mg-1.2Si (wt. %) alloy would precipitate a spherical V-containing phase in the homogenization heat treatment.

(3) After T6 heat treatment, comparing to the V-free alloy, the UTS and YS of V-added alloy increased by 1.21% and 2.42% respectively, and the EL increased significantly by 130%.

Acknowledgments

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