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Effect of Addition of Sc and Mg on 2219 Al Alloy

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In the present investigation, an attempt has been made to improve the properties of the commercial 2219 alloy by the addition of small amounts of Sc and Mg. The 2219 alloy with and without small additions of Sc and Mg was cast in a water cooled copper mould in the form of 3 mm thick strips using suction casting technique. The as cast strips were cold rolled to 1 mm thickness, solution treated, quenched in water at room temperature and aged. The microstructural examination and hardness measurements were carried out at each stage for both the alloys. It has been found that the 2219 alloy containing small amounts of Sc and Mg does not yield a higher peak hardness value after the heat treatment employed in the present investigation. However, the microstructural stability of the 2219 alloy containing Sc and Mg at high temperature looks promising.

Keywords: *Aluminium, alloy development, precipitation hardening, microstructure, hardness.*

1. Introduction

The precipitation hardenable 2219 Al alloy has good creep strength at elevated temperatures. However, it has found applications mainly due to its high toughness at cryogenic temperatures and good weldability, and has been used in fuel tanks for storing liquefied gases in missiles and space vehicles [1]. Therefore, if its high temperature strength can be further enhanced, it will find wider applications at elevated temperatures as well. It is reported in the literature that the small amounts of Sc additions to Al and Al alloys not only increase their room temperature strength but also increase high temperature stability and there are two good review papers available on this topic [2,3]. The effect of Sc is also reported to be enhanced in the presence of Mg and Zr atoms [4-6]. There have been few studies reporting the enhancement of the properties of the precipitation hardenable high strength 7xxx and 2xxx Al alloys by the addition of these elements. Senkova et al. have reported a significant increase in the strength of a precipitation hardenable 7xxx alloy with the addition of small amounts of Sc and Zr, and the strength was retained up to 100°C [7]. Koteswar Rao et. al have reported about 50 MPa increase in 0.2% proof stress of a 2219 alloy welded plates at room temperature with the addition of small amounts of Sc and Mg in the weld pool [8]. In another study, the same group reported even a higher increase in strength at higher temperatures by adding small amounts of Sc, Mg and Zr, and heat treating the welded plate [9]. In the present investigation, an attempt has been made to improve the room temperature strength and high temperature stability of the commercial 2219 alloy by the addition of small amounts of Sc and Mg.

2. Experimental Procedure

The commercial 2219 alloy was received from The Boeing Company, USA, having a composition of Al-6.5Cu-0.32Mn-0.13Zr-0.06V-0.03Ti-0.05Si-0.13Fe (wt%). Small amounts of Sc and Mg were added to this alloy, which is henceforth designated as 2219ScMg alloy. Both the alloys, 2219 and 2219ScMg, were melted by producing an arc using tungsten electrode and then suction cast in a water cooled copper mould in the form of strips having a rectangular cross-section of 3 mm ×10 mm. The suction cast strip was cold rolled to 1 mm thickness in 10 passes, solution treated, water quenched at room temperature and aged at different temperatures. Vickers hardness was measured on a Zwick Roell ZHV1-A Vickers micro-hardness tester. Microstructure was examined on a scanning electron microscope (SEM) ESEM Quanta 200 fitted with energy dispersive X-ray spectroscopy (EDS) analysis after polishing and etching the samples with Keller's reagent. Electron

Probe Micro Analysis (EPMA) analysis was also carried out on selected specimens of 2219ScMg alloy using a JEOL JXA-8530F system.

3. Result and discussion

As suction cast alloys

The SEM micrographs of the as suction cast samples are shown in Fig. 1. The 2219ScMg alloy exhibits marginal grain refinement (25±5 μm) as compared to the 2219 alloy (30±12 μm) but a significant increase in the hardness value (1275±75 as compared to 850±128 MPa). EDS Analyses of both the alloys are shown in Table 1. Both the alloys exhibit a depletion of Cu in the matrix and enrichment in the grain boundary phases, whereas Zr is uniformly distributed. Sc and Mg are also found to be uniformly distributed throughout the microstructure, both in the matrix as well as at the grain boundary in the 2219ScMg alloy. In order to verify this, elemental mapping of all the elements was carried out using EPMA and the results are shown in Fig. 2. EPMA results also show depletion of Al and enrichment of Cu at the grain boundaries, whereas, Sc, Mg and Zr are uniformly distributed throughout the microstructure. The W (Al,Sc,Cu) phase depicted in the equilibrium phase diagram [10] was not observed, as has been reported by many other workers as well. However, the Al_3Sc phase reported by many workers in Sc containing Al alloys was also not observed in the present investigation.

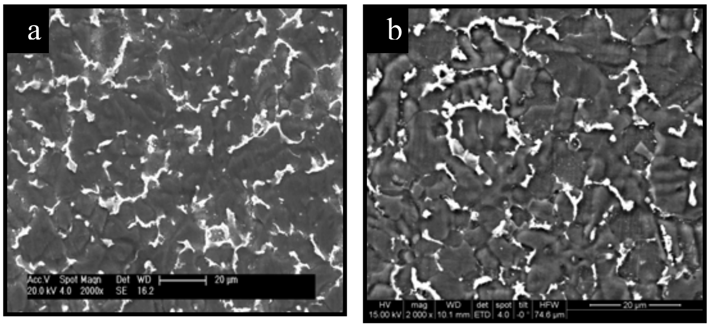

Fig. 1, SEM micrographs of the as suction cast (a) 2219 alloy (b) 2219ScMg alloy.

Table 1, EDS analysis of as suction cast 2219 and 2219ScMg alloys.

Alloy	Matrix (wt%)					Grain Boundary (wt%)				
	Al	Cu	Sc	Mg	Zr	Al	Cu	Sc	Mg	Zr
2219	97.5 ± 0	2.5 ± 0	-	-	-	59.6 ± 5.4	37.7 ± 4.3	-	-	0.2 ± 0.2
2219ScMg	93.2 ±2.6	3.5 ± 1.5	0.8 ±0.5	0.9 ±0.4	0.2 ± 0.6	62.9 ± 4.6	33.1 ± 5.1	0.5 ± 0.2	0.6 ±0.1	0.5 ± 0.4

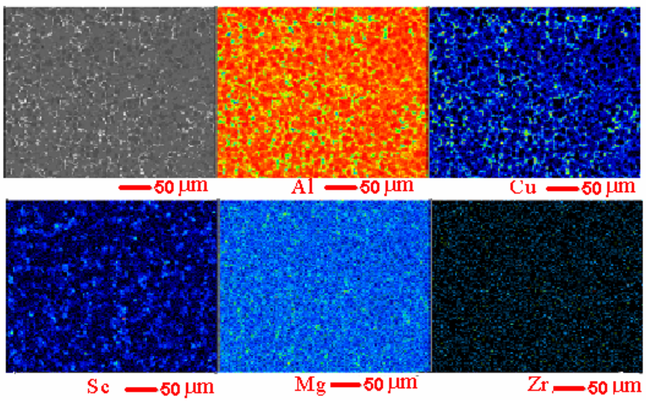

Fig. 2, EPMA Elemental mapping results for the suction cast 2219ScMg alloy.

	Al		Cu		Sc		Mg		Zr	
	Conc	% Area	Conc	% Area	Conc	% Area	Conc	% Area	Conc	% Area
	94.9	0	47.64	0	9.52	0	2.53	0	5.54	0
	94.05	0.2	44.66	0	8.92	0	2.34	0	5.19	0
	93.2	8.3	41.68	0	8.32	0	2.15	0	4.8	0
	92.35	31.5	38.7	0	7.73	0	1.97	0	4.5	0
	91.5	30.4	35.71	0.1	7.13	0	1.78	0	4.16	0
	90.65	13.3	32.73	0.2	6.53	0	1.59	0	3.8	0
	89.8	6.6	29.75	0.3	5.93	0	1.41	0	3.4	0
	88.95	3.6	26.76	0.4	5.33	0	1.22	0.1	3.12	0
	88.1	2.4	23.78	0.6	4.73	0	1.03	0.2	2.77	0.5
	87.25	1.5	20.8	0.8	4.13	0	0.85	0.6	2.43	0
	86.4	0.9	17.82	1.3	3.53	0.1	0.66	1.9	2.08	0
	85.55	0.6	14.83	1.5	2.94	0.2	0.47	10.4	1.74	0
	84.7	0.3	11.85	2.5	2.34	0.7	0.29	17.6	1.39	9.6
	83.85	0.2	8.87	4.4	1.74	2.4	0.15	26.7	1.05	0
	83	0.1	5.89	11.8	1.14	8.8	0.08	25.9	0.7	0
	82.15	0.05	2.9	46.9	0.54	43.9	0.06	13.5	0.35	0
	81.3	0.01	0.01	29.2	0.05	43.9	0.04	3	0.014	89.9

Cold rolled alloys

The microstructures of the cold rolled alloys are shown in Fig. 3. The grain boundary phases are broken down after rolling in both the alloys. Further refinement of grains as compared to the as suction cast microstructure is observed in both the alloys with the 2219 alloy having a grain size of 16±4 µm, 17±4 µm and 13±2 µm, and the 2219ScMg alloy having a grain size of 18±4 µm, 11±5 µm and 9±2 µm in the planes perpendicular to normal, transverse and rolling directions respectively. This is accompanied by a significant increase in hardness value in both the alloys with the 2219 alloy exhibiting a hardness value of 1089±138 MPa and the 2219ScMg alloy exhibiting a hardness value of 1692±52 MPa. The EDS analysis results of both the alloys remain roughly the same as in the suction cast condition, i.e, Cu depletion in the matrix and enrichment in the grain boundary region and Zr being uniformly distributed in both the alloys, and Sc and Mg being uniformly distributed in the matrix and the grain boundaries in the 2219ScMg alloy, as shown in Table 2. EPMA results for the 2219ScMg alloy shown in Fig. 4 again confirm the SEM results with Al being depleted and Cu being enriched in the grain boundary phases, and Sc, Mg and Zr being uniformly distributed throughout the microstructure in the matrix as well as at the grain boundaries.

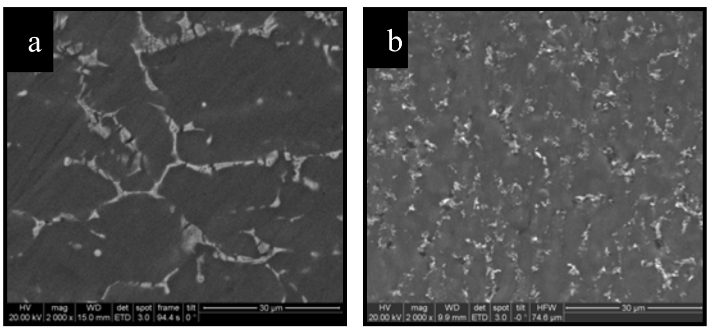

Fig. 3, SEM micrographs of the cold rolled
(a) 2219 alloy
(b) 2219ScMg alloy.

Table 2, EDS analysis of the cold rolled 2219 and 2219ScMg alloys.

Alloy	Matrix (wt%)					Grain Boundary (wt%)				
	Al	Cu	Sc	Mg	Zr	Al	Cu	Sc	Mg	Zr
2219	95.7 ± 1.1	2.2 ± 0.9	-	-	0.4 ± 0.3	78.0 ± 6.1	20.2 ± 5.8	-	-	0.3 ±0.1
2219ScMg	92.5 ± 0.4	3.4 ± 0.3	0.9 ± 0.0	0.8 ± 0.2	0.9 ± 0.2	72.9 ± 6.8	24.0 ± 6.7	0.7 ± 0.4	0.6 ± 0.1	0.2 ±0.5

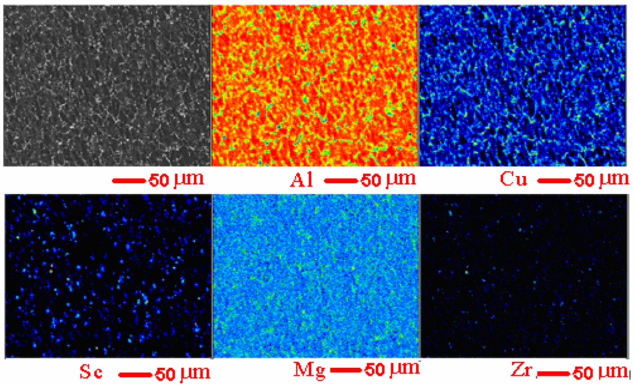

Fig. 4, EPMA elemental mapping results for the cold rolled 2219ScMg alloy.

	Al		Cu		Sc		Mg		Zr	
	Conc	% Area	Conc	% Area	Conc	% Area	Conc	% Area		% Area
	92.79	0	42.39	0	28.9	0	2.78	0	12.45	0
	91.79	0.3	39.79	0	27.06	0	2.57	0	11.67	0
	90.78	9.4	37.19	0	25.23	0	2.35	0	10.88	0
	89.77	30	34.59	0	23.04	0	2.13	0	10.1	0
	88.76	25.6	31.99	0.1	21.57	0	1.91	0	9.32	0
	87.76	14.6	29.39	0.1	19.74	0	1.69	0	8.54	0
	86.75	8.2	26.79	0.2	17.91	0	1.47	0	7.75	0
	85.75	4.9	24.19	0.4	16.07	0	1.25	0.1	6.97	0
	84.74	3	21.59	0.6	14.24	0	1.03	0.5	6.19	0
	83.73	1.7	18.99	0.9	12.41	0.1	0.81	1.8	5.4	0
	82.73	1	16.4	1.6	10.58	0.1	0.59	6.3	4.62	0
	81.72	0.6	13.8	2.4	8.75	0.2	0.37	16.3	3.84	80.1
	80.71	0.4	11.2	4	6.91	0.4	0.16	28.2	3.06	0.1
	79.71	0.2	8.6	7	5.08	0.9	0.1	28.4	2.27	0.2
	78.7	0.1	6	16	3.25	2.2	0.08	14.8	1.49	0.8
	77.69	0	3.4	46.9	1.42	10.2	0.05	3.2	0.71	4
	76.68	0	0.8	19.8	0	85.9	0.01	0.3	0.07	94.9

Solution treated alloys

The SEM micrograph of the solution treated and water quenched 2219 and 2219ScMg alloys are shown in Fig. 5. The 2219 alloy behaves in the classical manner. After giving the standard solution treatment at 530°C for 30 minutes, the solute up to the solid solubility limit of Cu goes into the solid solution and the excess Cu remains in the form of Al_2Cu phase at the grain boundaries, as shown in Fig. 5(a). However, the 2219ScMg alloy behaves in a completely different manner. After the solution treatment at 530°C for 30 minutes, many Cu-rich particles were observed throughout the microstructure (not shown here). Therefore, a solution treatment of 535°C for 1 hour was given to this alloy. However, these Cu-rich particles still do not dissolve, as shown in Fig. 5(b). The EDS analysis in Table 3 shows that these particles also contain small amount of Sc, Mg and Zr. Perhaps, the presence of these elements makes these particles stable at high temperatures. The EDS analysis in Table 3 also shows that the Cu content in the matrix is increased after solution treatment as compared to the suction cast and cold rolled conditions. However, Zr remains uniformly distributed in both the alloys, and Sc and Mg are uniformly distributed in the 2219ScMg alloy.

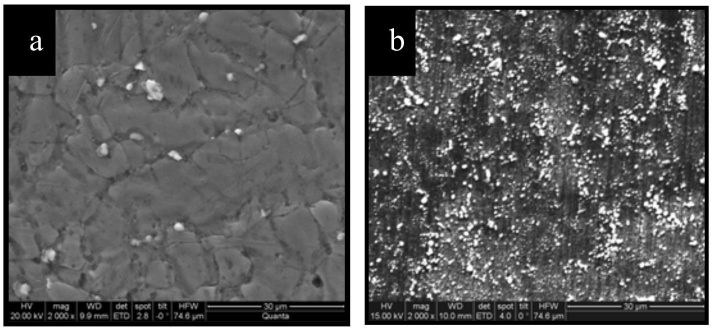

Fig. 5, SEM micrographs of (a) 2219 alloy solution treated at 530°C for 30 minutes.
(b) 2219ScMg alloy solution treated at 535°C for 1 hour.

Table 3, EDS analysis of solution treated 2219 and 2219ScMg alloys.

Specimen	**Matrix (wt%)**					**Grain Boundary (wt%)**				
	Al	**Cu**	**Sc**	**Mg**	**Zr**	**Al**	**Cu**	**Sc**	**Mg**	**Zr**
2219	92.4 ±0.3	5.8 ± 0.7			0.4 ± 0.5	67.0 ± 2.9	30.5 ± 3.2			0.3 ±0.2
2219ScMg	90.4 ±1.4	6.8 ± 0.8	0.6 ±0.2	0.5 ± 0.1	0.3 ± 0.3	71.8 ± 4.3	25.4 ± 5.1	1.0 ± 0.1	0.4 ± 0.0	0.5 ±0.2

Ageing curves

2219 alloy was given the standard ageing treatment at 190°C after solution treatment at 530°C for 30 minutes followed by water quenching, and the ageing curve is shown in Fig. 6. It exhibits peak ageing after 10 hours of ageing. The 2219ScMg alloy was solution treated at 535°C for 1 hour followed by water quenching and aged at 200°C. However, it does not exhibit any ageing response, as shown in Fig. 6. At 250°C, it exhibits a small peak at 25 hour but it is well below the peak hardness obtained for the 2219 alloy, as shown in Fig. 6. However, the microstructural stability of the particles containing small amounts of Sc, Mg and Zr at high temperatures, as discussed in the previous section, is promising. Therefore, if a suitable heat treatment is developed for the 2219ScMg alloy to obtain high room temperature strength, this alloy may be expected to retain that strength at higher temperatures as well. More work needs to be done to establish that.

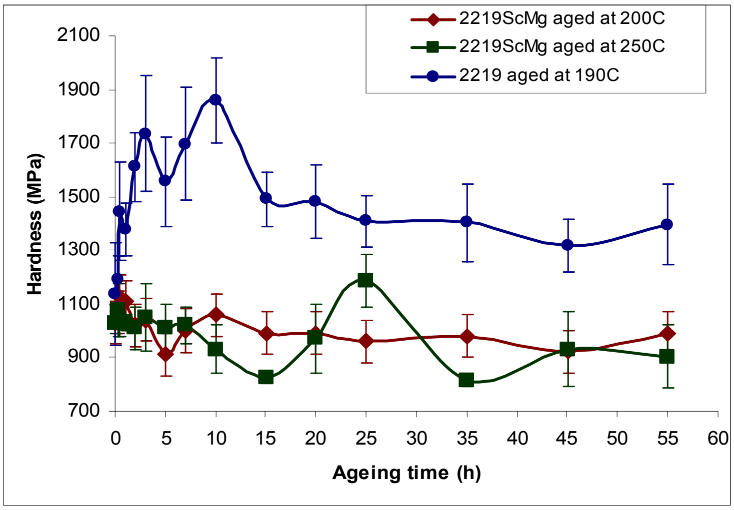

Fig. 6, Ageing curves for 2219 and 2219ScMg alloys.

4. Conclusions

The addition of small amounts of Sc and Mg to the 2219 alloy does not yield a higher hardness value after the heat treatment employed in the present investigation. The heat treatment needs to be optimized in order to obtain higher hardness values. However, the microstructural stability of the particles obtained on addition of Sc and Mg at high temperatures looks promising.

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