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R&D AND EVALUATION OF A LIGHTWEIGHT, HIGH STRENGTH MAGNESIUM ALLOY

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ABSTRACT

Magnesium ternaries containing 10-20% scandium and selected additives (Zr, Mn, Al, Zn, Ag, Pb, Sn, Bi, Cd, Li, Y, and In) were evaluated. The addition of 6% Ag, 10-20% Cd, or 5% Li markedly strengthen Mg-Sc extrusions. Mg-10Sc-5 Li naturally ages after solution heat treatment to a CYS of about 50 ksi. The addition of 6% silver or 10% cadmium increases the yield strength of Mg-20Sc extrusions to about 60 ksi. Comparison with small scale extrusions of ZK60A and HM31A, (two commercial, high strength magnesium alloys) reveals the marked superiority of the Mg-Sc alloys in room temperature strength and also indicates good high temperature properties.

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SUMMARY OF EXPERIMENTAL RESULTS

1) The addition of 6% Ag, 20% Cd, 5% Y, or 10% In increased the yield strength of Mg-10 Sc in the F temper from 32 to over 40 ksi. The addition of 3% Zn, 10% Cd or 1.5% Mn was also beneficial but to a leaser extent, while 0.6% Zr, 2% Al, 12% Pb, 6% Sn, 4% Bi, or 5-12% Li was not beneficial.

2) All of the additions increased the strength of Mg-10 Sc after solution heat treatment. The addition of 5% lithium was particularly beneficial, increasing yield strength from 16 to almost 50 ksi. The addition of Cd, Zn, or Ag also markedly strengthened Mg-10Sc.

3) Mg-10 Sc-5Li age hardened at room temperature. Increasing the lithium or scandium content of this alloy was not beneficial.

4) The addition of 6% Ag or 10% Cd increased the yield strength of Mg-20 Sc from 40 to about 60 ksi in the F temper and from 29 to over 40 ksi in the T4 temper.

5) ZK60A and HM31A, commercial magnesium extrusion alloys, had a CYS of 35 ksi in the T5 temper and about 25 ksi in the T6 temper. The extrusion temperature of many Mg-Sc alloys is comparable to that of HM31A, indicating good properties at high temperatures.

6) The addition of 3% scandium to ZK60A appears to improve properties at room and elevated temperatures.

I. INTRODUCTION

The Mg-Sc system is being explored in the hope of obtaining better mechanical properties. The initial results indicated that Sc markedly strengthens magnesium and that magnesium extrusions containing 30-36% scandium have a yield strength of 40-75 ksi. Since scandium is very expensive ($10/gram), ternary systems containing smaller amounts of scandium are being studied. Alloy additions to magnesium containing 1-3% scandium are beneficial but do not provide the high strength noted above. Therefore, current research is directed toward ternaries containing higher scandium.

II. EXPERIMENTAL WORK

The experimental procedure described in the first quarterly report was followed during this period. Small melts (50-100 grams) of the desired composition were prepared and cast into a 3/4" diameter cylinder. The billets were scalped and extruded into 1/8" diameter wires. Samples of the wire were tested after various thermal treatments.

III. CONCLUSION

Very high strength can be obtained with magnesium alloys containing 10-20% Sc and 6% Ag, 5% Li, or 10-20% Cd.

IV. DISCUSSION

Previous work indicated that alloy additions (0.6% Zr, 1.5% Mn, 4% Al, 3% Zn, 6% Ag, 12% Pb, 6% Sn, or 4% Bi) improve the properties of magnesium extrusions containing 1-3% Sc but do not provide the high strength (e.g. 40-75 ksi CYS) obtainable at high scandium levels (e.g., 30%). Since higher scandium levels are required for higher strength, a similar group of ternaries containing 10% scandium was prepared and evaluated. The results indicate that most of the additives are less beneficial at the higher scandium level. This is apparently due to their lower solid solubility in Mg-10 Sc. An important exception is silver, which is more beneficial at 10%

scandium. The addition of 6% silver increases the yield strength of Mg-10 Sc from 32 to 42 ksi in the F temper (Table 1) and from 16 to about 35 ksi in the T6 temper (Table 2). The addition of 3% Zn, which was most beneficial at the lower scandium level, is not as effective as silver but also contributes considerable strengthening. Only the ternaries containing silver or zinc appear to be very ageable (Table 2). A high aging temperature (400F) appears to be desirable for the zinc alloy, while a low aging temperature (300F) is preferrable for the silver ternary. The dip in CYS for the 350F age (Table 2) is attributed to testing variance.

The results obtained with this group of ternaries suggested that elements which are more soluble in magnesium and/or interact less strongly with scandium should be used in the ternaries containing high scandium. On this basis lithium, cadmium, yttrium, and indium were selected and another group of Mg-10 Sc ternaries was prepared and evaluated. All of the elements but lithium are beneficial to the properties of Mg-10 Sc extrusions in the F and T5 tempers (Table 1). The addition of 20% Cd, 5% Y, or 10% In increase the yield strength of Mg-10 Sc to 40-45 ksi - about the same level attained by the addition of 6% silver.

Heat treatment (Table 2) of the extrusions interacts strongly with the additions. All are beneficial, but the addition of 5% lithium is the most effective, increasing CYS to almost 50 ksi (compared to only 16 ksi for the Mg-10 Sc base). The high CYS obtained by heat treating Mg-10 Sc -5Li at 950F and quenching was initially puzzling because this value is considerably higher than the CYS in the F temper and aging at 300F has no effect. However, subsequent tests indicate that this alloy ages at room temperature. When the alloy was tested only 3 minutes after the solution treatment, its CYS was only 38 ksi - about 10 ksi lower than the value obtained two weeks later. After three days natural aging CYS is 42 ksi. Aging at 300F for 24 hours is apparently equivalent to a natural age of two weeks, but over-aging occurs at 450F. Further work is required to optimize aging conditions. Increasing lithium level beyond 5% tends to decrease strength, apparently due to decreasing solid solubility of scandium.

The addition of cadmium also markedly enhances the strength of Mg-10 Sc after heat treatment (Table 2). CYS is increased from 16 to 28 to 41 ksi as the cadmium level is raised from 0 to 10 to 20%. Aging at 300F or 450F has little effect. Although Mg-10 Sc- 20 Cd is not as strong as Mg-10 Sc-5Li, it is not affected by exposure at 450F and should therefore be superior at elevated temperatures. It is also interesting to note that 20 w/o cadmium is much smaller than 5 w/o lithium on an atomic per cent basis (5.2 vs 15.6).

A few ternaries containing 20% scandium and the most effective additions were briefly evaluated. The addition of 6% silver or 10% cadmium increases the yield strength of Mg-20 Sc extrusions from 40 to about 60 ksi (Table 1) but sharply reduces ductility. They also increase strength in the T4 and T6 tempers although no age hardening was noted at 450F. The addition of 5% lithium was disappointing because it was much less beneficial at the higher scandium level. In fact, Mg-20 Sc-5 Li is not as strong as Mg-10 Sc-5Li after solution heat treatment (Table 2). Further work in this area is obviously warranted.

ZK60A (Mg-6Zn-0.6Zr) and HM31A (Mg-3Th-1.5Mn) are extruded commercially to provide high strength at room and elevated temperatures, respectively. These alloys were included in this program for comparative purposes. Since zinc markedly improved the properties of Mg-3 Sc extrusions, Mg-6Zn-0.6Zr-3Sc was also evaluated in this group. As shown in Table 1, the properties of ZK60A are not impressive in the F temper but are improved considerably by aging at 300F (T5 temper). HM31A and ZK60-3 scandium are much stronger in the F temper but have the same CYS (35 ksi) in the T5 temper because they did not age harden. Although HM31A exhibits high strength when extruded at its minimum temperature, it is adversely affected by extrusion at the higher temperatures and speeds normally used in production. This is reflected in its much lower properties in the T4 temper. ZK60A is similarly affected but is more ageable and offers higher strength in the T6 temper. The addition of 3% scandium markedly increases the strength of ZK60A in the T4 temper. This advantage is reduced in the T6 temper because of decreased ageability. It is possible, however, that scandium changes the optimum aging conditions for ZK60A and does not actually impair age hardening. Another interesting point is the minimum extrusion temperature of these alloys. Note in Table 1 that 3% scandium increases the extrusion temperature of ZK60A by 100°F, indicating a substantial improvement in high temperature strength. Note also that the extrusion temperature of HM31A is comparable to that of some of the Mg-Sc alloys. This suggests that Mg-Sc alloys may also offer high strength at elevated temperatures.

V. FUTURE WORK

Future work will involve the study of additional ternary alloys in order to select the optimum composition. A larger scale evaluation of Mg-30Sc is planned.

TABLE 1

PROPERTIES* OF MAGNESIUM-SCANDIUM TERNARIES - 1/8" DIAMETER EXTRUSIONS

ALLOY NO.	% Sc	% OTHER	EXTRUSION TEMPERATURE	-F % E	-F TYS	-F CYS	-F TS	-T5 CYS
100,335	10	------	800F	23	32	33	38	34
100,567	10	0.6 Zr	820	20	32	32	39	
100,568	10	1.5 Mn	850	16	37	37	43	
100,569	10	2 Al	850	11	28	29	36	
100,570	10	3 Zn	850	17	37	39	46	
100,571	10	6 Ag	850	8	42	42	50	
100,572	10	12 Pb	825	10	32	35	40	
100,573	10	6 Sn	825	15	32	32	40	
100,574	10	4 Bi	825	10	32	35	41	
100,638	10	10 Cd	700	16	39	38	48	
100,900	10	20 Cd	930	12	42	42	53	45
100,639	10	5 Li	700	2	29	33	37	
100,902	10	7 Li	700	2	27	31	35	30
100,640	10	12 Li	700	--	--	15	10	
100,752	10	5 Y	925	18	43	45	50	44
100,938	10	8 Y	930					
100,904	10	10 In		15	40	45	47	44
100,336	20	---	900	15	40	41	49	37
100,897	20	6 Ag	825	3	62	65	66	59
100,898	20	10 Cd	930	5	58	58	66	56
100,899	20	5 Li	700	2	36	41	42	36
100,955	--	6 Zn-.7Zr	700	20	28	29	44	35
100,956	3	6 Zn-.7Zr	800	12	48	35	53	35
100,957	--	3 Th-1 Mn	950	14	46	34	48	35

*Strength is expressed in ksi (1000 psi) units

TABLE 2

EFFECT OF HEAT TREATMENT ON THE CYS (KSI) OF MAGNESIUM - 10 SCANDIUM TERNARIES

ALLOY NO.	% Sc	% OTHER	SOLUTION TEMPERATURE	AGING TEMPERATURE* - °F				
				75	300	350	400	450
100,335	10	--	950F	16				16
100,567	10	0.6 Zr	1100	20	22	21	23	
100,568	10	1.5 Mn	1100	24	26	24	26	
100,569	10	2 Al	1100	17	22	20	22	
100,570	10	3 Zn	1100	22	27	25	30	
100,571	10	6 Ag	1000	28	37	32	34	
100,572	10	12 Pb	1100	18	21	19	21	
100,573	10	6 Sn	1100	17	22	20	21	
100,574	10	4 Bi	1100	20	23	20	23	
100,638	10	10 Cd	950	28	30			30
100,638	10	10 Cd	1100	27				27
100,900	10	20 Cd	950	41				43
100,639	10	5 Li	950	49	49			34
100,639	10	5 Li	1100	48				35
100,902	10	7 Li	950	45				33
100,640	10	12 Li	950	29	28			19
100,640	10	12 Li	1100	20				
100,752	10	5 Y	950	26				26
100,752	10	5 Y	1100	25				27
100,938	10	8 Y	1050	25				26
100,904	10	10 In	950	27				29
100,336	20	--	950	29				31
100,897	20	6 Ag	950	45				45
100,898	20	10 Cd	950	41				43
100,899	20	5 Li	950	36				38
100,955	--	6 Zn-.7 Zr	950	14	26			
100,956	3	6 Zn-.7 Zr	950	23	30			
100,957	--	3 Th-1 Mn	950	17				22

*About 2 weeks at 75F, 24 hours at elevated temperatures.