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for

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

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ABSTRACT

The ageability of several of the most promising Mg-Sc ternaries was studied. Mg-6Zn-.7Zr-3Sc, Mg-10Sc-5Li and Mg-20Sc-6Ag age harden considerably and provide relatively high strength (32, 53, and 57ksi CYS, respectively) in the T6 temper. Mg-10Sc-5Li is particularly interesting because its strength is increased by solution heat treatment and is further enhanced by natural or artificial aging.

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INTRODUCTION

The Mg-Sc system is being explored in the hope of obtaining improved properties. The initial results indicated that Sc markedly strengthens Mg and that extrusions with yield strengths of 40-76ksi can be obtained at 30-36% Sc. Subsequent work has shown that ternary additions can substantially improve the properties of Mg-Sc and reduce the amount of Sc required for high strength. The ageability of several of the most promising Mg-Sc ternaries was studied during this quarter.

SUMMARY OF EXPERIMENTAL RESULTS

1) Mg-6Zn-.7Zr-3Sc, Mg-10Sc-5Li, and Mg-20Sc-6Ag have good ageability and relatively high strength in the T6 temper (32,53,and 57ksi CYS, respectively). Optimum aging temperature (for one day) varies from about 250F for the Li alloy to about 350F for the Ag alloy.

2) The ternaries containing 10-20% Sc and 10-20% Cd are moderately ageable, while Mg-10Sc-8Y and Mg-10Sc-10In exhibit little age hardenability.

3) Solution heat treatment increases the CYS of Mg-10Sc-5Li in spite of rapid quenching in iced brine and immediate testing. Natural aging increases strength although somewhat higher strength can be obtained by artificial aging at 250F.

CONCLUSION

Mg-6Zn-.7Zr-3Sc, Mg-10Sc-5Li, and Mg-20Sc-6Ag have good ageability and relatively high strength in the T6 temper.

EXPERIMENTAL WORK

Samples of extruded wire 1/8" in diameter were solution heat treated quenched in water, aged under various conditions, and tested in

compression. Samples of the Mg-Sc-Li ternaries were also quenched in brine (24% Na Cl) at 10°F and kept there for the short delay (a few minutes) before testing.

DISCUSSION

The high strength displayed by many of the Mg-Sc alloys in the -F temper may be very sensitive to extrusion conditions (e.g., temperature, speed, section size and shape) and may be impossible, or at least impractical, to attain on a production scale. The properties of the small, simple shape (1/8" diameter wire) used in this mini-scale study is certainly not a reliable indicator of the properties of a large, complicated shape (e.g., a hollow flooring section one foot wide) used as a structural member. One method of gauging the sensitivity of a Mg alloy to extrusion conditions is to heat treat it. The solution treatment tends to erase, or at least minimize, variations in extrusion conditions and to provide a level of properties which can be readily met under most extrusion conditions. The adverse effect of the high extrusion (or solution) temperature may be offset by subsequent precipitation hardening. In fact, it is possible to obtain higher strength in the T6 temper than in the F temper if the Mg alloy is very ageable.

The importance of this approach is reflected in the comparison of the properties of Mg-10Sc ternaries containing 5%Y or 6%Ag. Both alloys have high strength (42-45ksi yield) in the -F temper, and heat treatment at 950F markedly reduces the strength (26-28ksi CYS) of each. However, most of this loss is regained by aging the Ag alloy, but nothing is gained by aging the Y alloy. The relatively high strength Mg-10Sc-6Ag ternary in the T6 temper indicates that good properties can probably be obtained regardless of extrusion conditions. On the other hand, it will probably be difficult to achieve high strength with Mg-10Sc-5Y.

The importance of good ageability to the properties of the Mg-Sc ternaries prompted a thorough evaluation of aging conditions during the past quarter. The alloys selected for this study (Table 1)

contained relatively large ternary additions and appeared to be saturated with solute (contained residual second phase) after solution heat treatment at 950F. Mg-10Sc-8Y was an exception, being single phase even before solution heat treatment. The poor ageability of this ternary may be due to insufficient solute concentration. Larger Y and/or Sc levels should be studied in future work. The ageability of the other ternaries varied from good for Mg-6Zn-.7Zr-3Sc, Mg-10Sc-5Li, and Mg-20Sc-6Ag to fair for the Mg-Sc-Cd ternaries to poor for Mg-10Sc-10In.

The properties of Mg-6Zn-.7Zr-3Sc are interesting because this is the strongest alloy at this low Sc level. Although its properties in the -F temper can be matched by conventional Mg alloys extruded under carefully controlled conditions, its high CYS (32ksi) in the T6 temper is outstanding. This indicates that Sc not only strengthens ZK60A but also reduces its sensitivity to processing conditions. There are also indications that Sc increases the high temperature properties and solidus of ZK60A. Sc would certainly be a desirable addition to ZK60A if its cost were not so high.

Mg-10Sc-5Li is interesting for a number of reasons. It has high strength (50ksi yield) in spite of a relatively low (10%) Sc content, is stronger in the T6 temper than in the F temper, and naturally age hardens. This is more evident in the properties in Table 2. Note that CYS determined several minutes after solution heat treatment and quenching is significantly higher than that in the F temper. Since the F temper can be considered an "overaged" condition, we assumed that still lower strength would be obtained by more rapid quenching and testing. However, CYS was not affected by quenching in cold brine (24% Na Cl at 10^{O}F) and keeping the sample there for the short delay (a few minutes) before testing. Natural aging increases the strength of the alloy substantially although the maximum CYS (53ksi) was obtained by aging one or two days at 250F. Increasing the Sc beyond 10% and/or the Li content beyond 5% does not increase strength. Larger solute additions simply produce undissolved compound. In fact, higher Li levels

appear to reduce the solid solubility of Sc and impair strength.

Mg-20Sc-6Ag is interesting because it offers the highest strength of any ternary yet studied. Its CYS of 65ksi in the F temper and 57ksi in the T6 temper compares favorably with that of Mg-30Sc processed under the same conditions (54 and 42, respectively). It is possible to produce Mg-30 Sc with a CYS as high as 76ksi by increasing the solution temperature to form increasing amounts of β and aging to decompose the β. Substantial amounts of β can also be formed in Mg-20Sc-6Ag, but melting occurs at a much lower temperature in the ternary, and only about half of the alloy can be converted to β.

TABLE 1

EFFECT OF AGING CONDITIONS* ON THE CYS (KSI) OF Mg-Sc TERNARIES

				AGING TEMPERATURE - °F				
ALLOY NO.	%SC	%OTHER	-F	75F	300F	350F	400F	450F
100,956	3	6Zn,.7Zr	35	24	30	32	30	--
100,900	10	20Cd	42	35	39	41	38	38
100,639	10	5Li	34	48	48	--	--	34
100,902	10	7Li	31	46	48	43	34	33
100,640	10	12Li	15	29	28	--	--	19
100,904	10	10In	45	28	30	30	31	29
100,938	10	8Y	42	25	27	27	26	25
100,897	20	6Ag	65	46	52	57	45	45
100,898	20	10Cd	58	42	45	46	44	43
100,899	20	5Li	41	36	46	41	37	38

*Samples were solution heat treated at 950F for 1/2 or 1 hour, quenched in water, and aged 24 hours at the elevated temperatures, or naturally aged (75F) for 2-3 weeks.

** As extruded

TABLE 2

EFFECT OF HEAT TREATMENT ON THE CYS (KSI) OF Mg-10Sc-Li ALLOYS

SOLUTION Temp. - °F	AGING Temp.	AGING Time	ALLOY 100,639 Mg-10Sc-5Li	ALLOY 100,610 Mg-10Sc-12Li
	75		33,34	15
950	75	∿5 min	38-40	
950	75	3 days	42	
950	75	13 days	46	31
950	75	20 days	49	29
950	75	3 mos.	49	--
950	250	1 day	52,53	27
950	250	2 days	53	--
950	250	4 days	51	--
950	275	1 day	52,51	28
950	275	2 days	52	--
950	300	1 day	49,47	28,29
950	325	1 day	46,47	23
950	450	1 day	34	19
1100F	75	29 days	48	19
1100F	450	1 day	35	20