ALUMINIUM-LITHIUM ALLOYS BASED ON THE Al-Mg-Li-Zr-Sc SYSTEM

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Abstract

The mechanical properties of aluminium-lithium alloys are strongly influenced by structural developments during ingot processing to semi-finished products. In particular the short-transverse ductility and ST-L fracture toughness are strongly influenced by grain structure and heat treatment practice. In this study the mechanical properties of a range of Al-Li-Mg alloys with specific additions of Zirconium and Scandium have been evaluated. The effect of changes in alloy chemistry on (a) the grain structure formed during processing and (b) the tensile properties before and after heat treatment are assessed. Correlations will be drawn between the alloy chemistry, the physical metallurgy and the mechanical properties.

Introduction

Since 1970, the 1420 (Al-5.0%Mg-2.0%Li-0.4%Mn), developed at VIAM, has been used as the main structural material in riveted structures of russian aircraft. This allowed structural weight to be reduced by 10-12% (1,2). The use of this alloy has also enabled a reduction of weight by 24% in replacing a riveted 2024 structure with a welded tank. However the alloy has a number of drawbacks in particular its rather low 0.2%PS which limits its use in higher strength aerospace structures. Hence several alloy modifications with improved technological efficiency, high strength characteristics and corrosion resistance were developed (3,4,5). These include changes in the dispersoid addition from Mn to Zr and/or Sc, and changing the amounts of Mg and Li.

The objective of this study is to examine the alloys of Al-Li-Mg system with Zr and Sc additions using a experimentally designed programme. The programme provides a comprehensive study of the alloy system including processing, microstructure (6) and mechanical properties. In this paper the effect of alloy chemistry on the tensile properties of extruded section is discussed

Experimental Details

Table 1 details the alloy chemistries evaluated. The experimental planning was carried out with the following assumptions :

Table 1 Alloy chemistries evaluated.

ALLOY	Mg	Li	Sc	Zr	PLANE Z1	MATRIX Z2	Z3
1	2.0	1.6	0.23	-	-ve	-ve	-ve
2	5.1	1.75	0.23	-	+ve	-ve	-ve
3	2.0	2.66	0.23	-	-ve	+ve	-ve
4	5.2	2.75	0.23	-	+ve	+ve	-ve
5	2.0	1.90	-	0.11	-ve	-ve	+ve
6	5.0	1.80	-	0.11	+ve	-ve	+ve
7	2.0	2.60	-	0.15	-ve	+ve	+ve
8	5.1	2.75	-	0.09	+ve	+ve	+ve
9	2.3	2.40	0.11	0.09	-ve	=	=
10	5.1	2.42	0.11	0.08	+ve	=	=
11	3.6	1.78	0.11	0.09	=	-ve	=
12	3.5	2.72	0.11	0.09	=	+ve	=
13	3.6	1.90	0.20	-	=	=	-ve
14	3.5	2.25	-	0.12	=	=	+ve
15	3.7	2.30	0.12	0.08	=	=	=

1. Zr is added into Al-Li-Mg alloys as a recrystallization inhibitor.
2. Sc is added to create Al_3Sc dispersoids and is also a recrystallization inhibitor.
3. Sc and Zr were combined into a single variable with the additional examination of Sc or Zr only at the extreme levels

The alloys were cast using high purity aluminium, magnesium and lithium together with Al-2.0%Zr and Al-2.0%Sc master alloys. The impurity content of the melts were Fe < 0.01%, Si < 0.006% and Na < 6 ppm. The melt was approximately 10 kg in weight and was protected during melting by a liquid flux made from an eutectic mixture of LiCl+KCl. The ingots were cast into a water cooled cast iron mould 70 mm in diameter.

The ingots were homogenized after casting at 450°C for 10 hours and furnace cooled to 200°C at 30°C per hour. This homogenization practice is similar to that used for 1420 alloy and may not be the optimum for all alloy chemistries. The homogenized billets were then preheated to a temperature of 365±5°C, held for 2 hours, and extruded to a rectangular bar 0.9m long and having a cross section of 15 x 60 mm. The chamber temperature was 360°C and the extrusion's exit temperature 400°C. The extruded sections were solution treated for 30 minutes at 455±5°C and quenched into boiling water. Tensile

properties were determined using triplicate specimens in the TL orientation in three tempers.

1. Naturally aged; 2. Aged 125°C for 10 hours; 3. Aged 165°C for 16 hours

The second treatment is analogous to 1420 alloy to obtained "adequate" tensile properties with high corrosion performance. The third heat treatment condition is aimed at peak strength.

Results and Discussion

Figure 1 illustrates the grain structure observed in alloys containing 2.25%Li and 3.5%Mg with addition of Sc, Zr and a mixture of Sc and Zr. The Scandium containing alloys show a coarse unrecrystallized grain structure (Figure 1a) whereas the Zr containing alloy has a considerably finer grain structure (Figure 1b). The alloy containing addition of Sc+Zr has a structure closely resembling that of the Zr containing alloy. The worked structures were consistent with the effect of the dispersoid forming additions on the as-cast structure.(6).

Table 2 details the average tensile results obtained from the alloys and figures 2 3 and 4 show the variation of the 0.2%PS with lithium content in the T4 and T6 tempers respectively. The following points may be made regarding the results:

1. The 0.2%PS and UTS increases irrespective of the alloy's magnesium content or type of dispersoid between 1.75% Li and 2.3%Li (nominal values). There is little further increase in 0.2%PS between 2.3% Li and 2.75% Li. This is attributable to the homogenization and solution treatment temperatures used in this work being too low thereby leaving undissolved particles of δ (AlLi) and S ($AlMg_2Li$) phase.

2. Additions of magnesium increases the alloy's 0.2%PS and UTS in T4 and T6 conditions for alloys with the same lithium content and/or the same dispersoid forming element, compare alloys 9,15 and 10 (2.3%Li+Zr and Sc)and 1,13 and 2(~1.75%Li+Sc).

3. Alloys with ductilities in the T6 temper > 10% all contain a lithium content of ~1.75%. The only alloy containing ~1.75%Li with a ductility < 10% is alloy No. 2 (El = 8.0%) which is a high magnesium variant.

4. Alloys with ductilities in the T6 temper < 5.0% all contain 2.75% Li. The only alloy containing 2.75% Li with a ductility > 5.0% is alloy No. 7 (El = 5.5%) which is a low magnesium variant.

5. Comparison of alloy Nos 1,2,3,4 (Sc containing) with alloy Nos. 5,6,7,8 (Zr containing) indicates that there is little difference in strength between them in either the T4 or T6 tempers. The exception to this is alloys Nos 1 and 5 where the Zr alloy has a significantly higher strength. However this is most probably due to the fact that alloy 1 had a lower Li content than aimed for (1.6%).

6. Alloys containing Zr generally have higher ductilities when compared with the equivalent alloy containing Sc. This may be a reflection of the coarser grain structure in the Sc containing alloys. An exception is high Mg and Li alloys (Nos. 4 and 8).

7. Comparison of alloys 14 and 15 would appear to indicate that Sc and Zr together increase 0.2%PS at the expense of ductility. Taking into account point 6 and it may be the ductility reduction comes from the alloy's reduced Zr content.

8. The majority of alloys containing Zr+Sc show little change in ductility between the T4 and T6 tempers (alloy No 11 is an exception).

Table 2. Tensile properties measured. Average values.

CODE	T4 0.2%PS MPa	T4 UTS MPa	T4 EL %	125°C 0.2%PS MPa	125°C UTS MPa	125°C El %	T6 0.2%PS MPa	T6 UTS MPa	T6 EL %
1	165	259	18.7	211	270	10.7	219	296	11.0
2	235	370	15.1	308	432	10.2	351	448	8.0
3	244	300	4.0	292	385	4.3	377	412	2.5
4	284	304	10.6	354	419	2.4	425	444	2.9
5	182	265	19.2	217	325	17.1	284	369	13.0
6	221	355	20.4	271	407	16.9	326	439	13.4
7	246	312	6.5	266	400	13.0	361	465	5.5
8	274	305	2.0	356	429	3.1	419	452	2.5
9	276	364	4.6	271	400	10.8	351	450	4.6
10	287	352	3.2	349	459	3.7	409	479	3.2
11	258	358	15.2	289	406	16.3	338	436	10.9
12	274	311	2.0	335	416	2.9	400	441	2.9
13	228	331	9.2	292	402	8.8	346	433	6.2
14	257	345	8.4	301	415	15.0	346	476	8.7
15	305	350	5.2	320	448	6.5	378	478	5.5.

The strengthening of the alloys during ageing (ie the 0.2%PS aged (T6) - the T4 0.2% PS) would be expected to be a function of the alloys Li content since δ' is the only strengthening phase. Figure 4 shows that this is true as a general trend but that there is a significant scatter in the results. The majority of this scatter appears attributable to the alloys Mg content. For a constant Li content increasing the Mg content from 2.0% to 5.0% increases the ageing response significantly, 54 to 116 MPa for 1.75% Li alloys; 75 to 122 MPa for 2.3%Li alloys and 115 to 145 MPa for 2.75% Li alloys. This is attributed to Mg decreasing the solid solubility of Li thereby making more Li available for forming δ' (7,8). It is presumed that the range decreases due to undissolved δ and S phases.

The tensile property data can be statistically analyzed according to the experimental plan (9) and predictions made with regard to the expected mechanical properties. The results are shown in figures 5 and 6 for material in the T4 and T6 tempers in comparison with the predicted values. There is good agreement between the generated empirical model and the experimental data, thus enabling design of the optimal alloy chemistry in terms

of tensile properties.

It should be noted that in this study the homogenization practice has not been optimized in terms of complete dissolution of soluble phases or in precipitation of Al_3Sc. This will be the subject of further work as will optimization of the alloys's ageing response and determination of damage tolerant capability.

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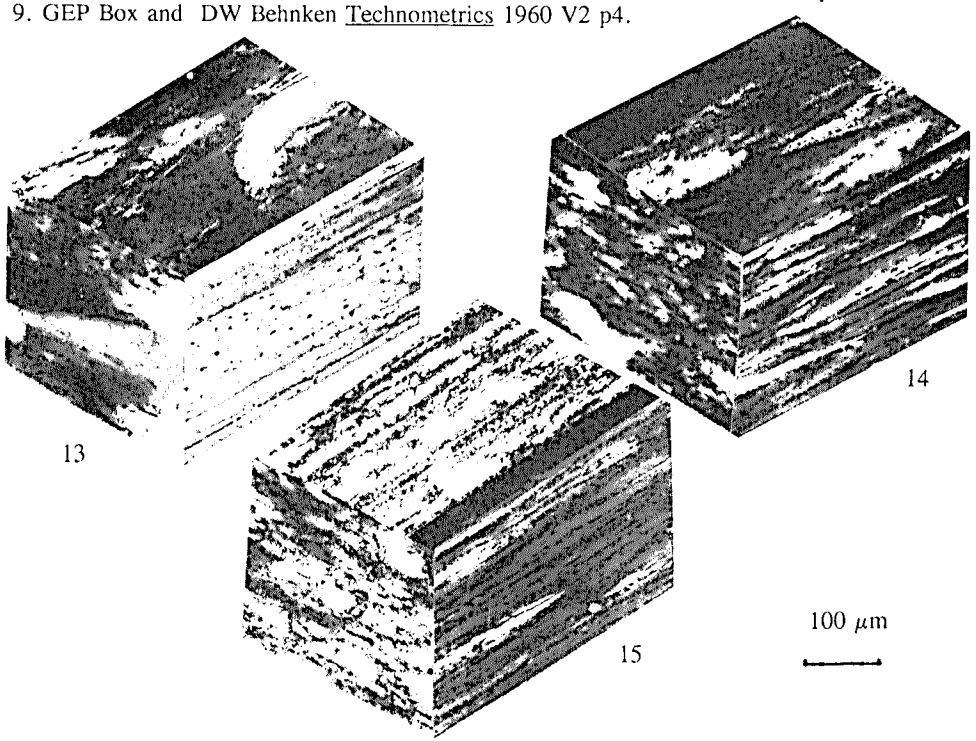

Figure 1. The grain structures of extruded sections from ingots 13 (+Sc), 14 (+Zr) and 15 (Zr+Sc).

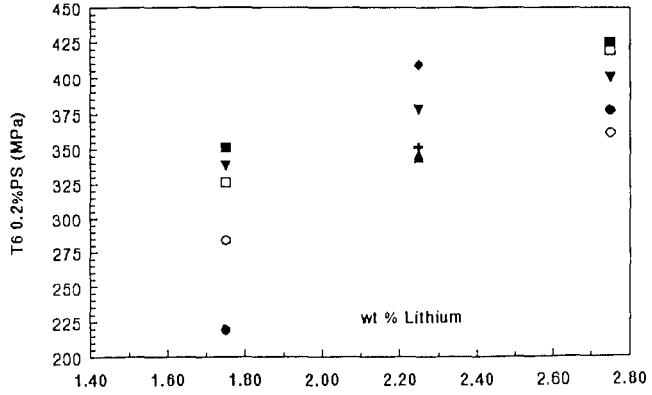

Figure 2. The effect of alloy chemistry on the T4 0.2%PS.

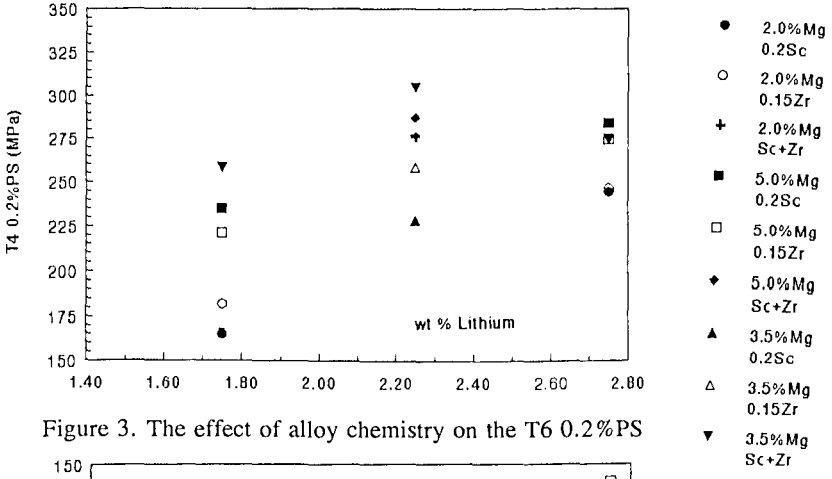

Figure 3. The effect of alloy chemistry on the T6 0.2%PS

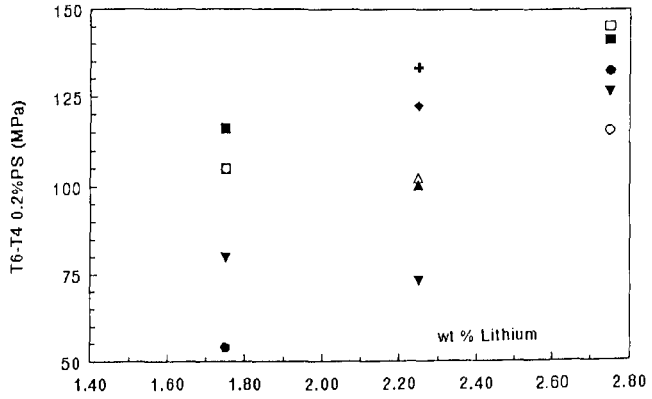

Figure 4. The effect of alloy chemistry on the difference in 0.2%PS in the T4 and T6 conditions.

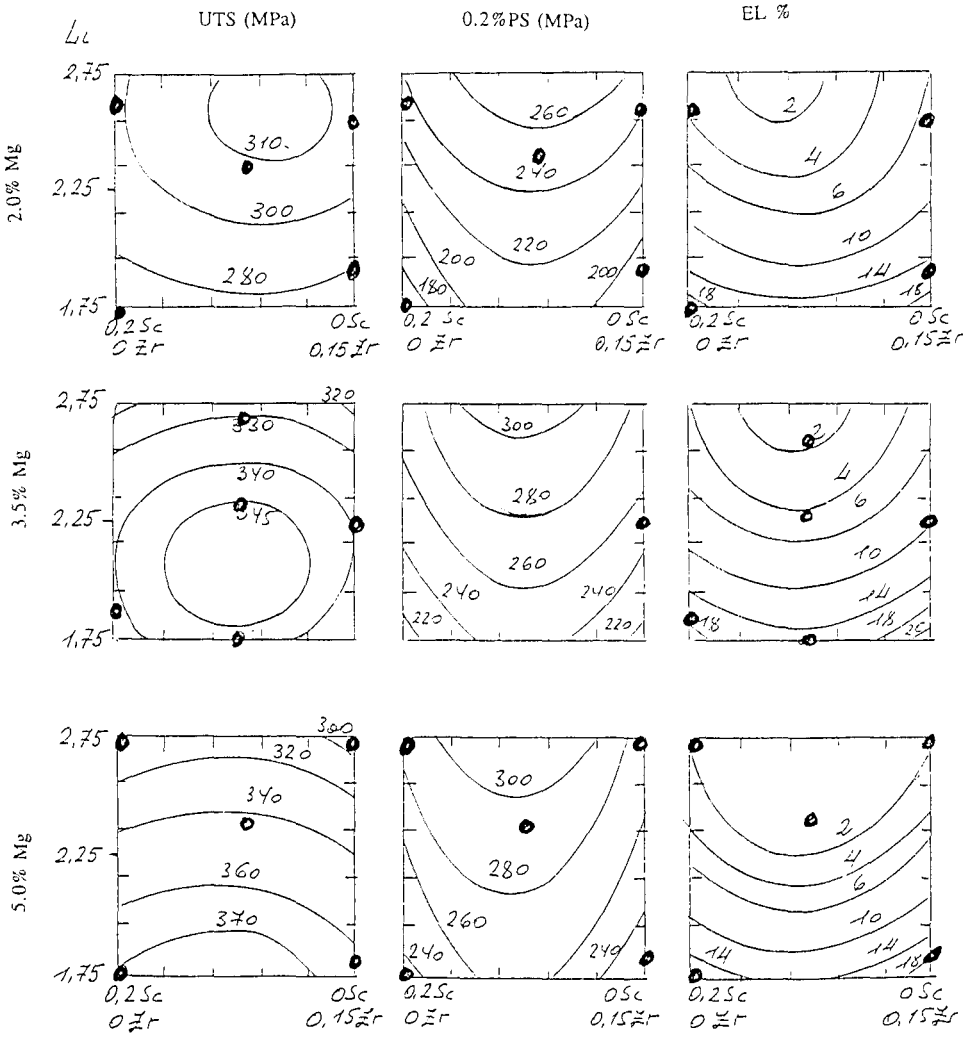

Figure 5. A comparison of the model predictions and the experimental data points for material in the T4 temper.

● Indicates position of alloys investigated. Compare predicted results with the experimantal data given in tables 1 and 2.

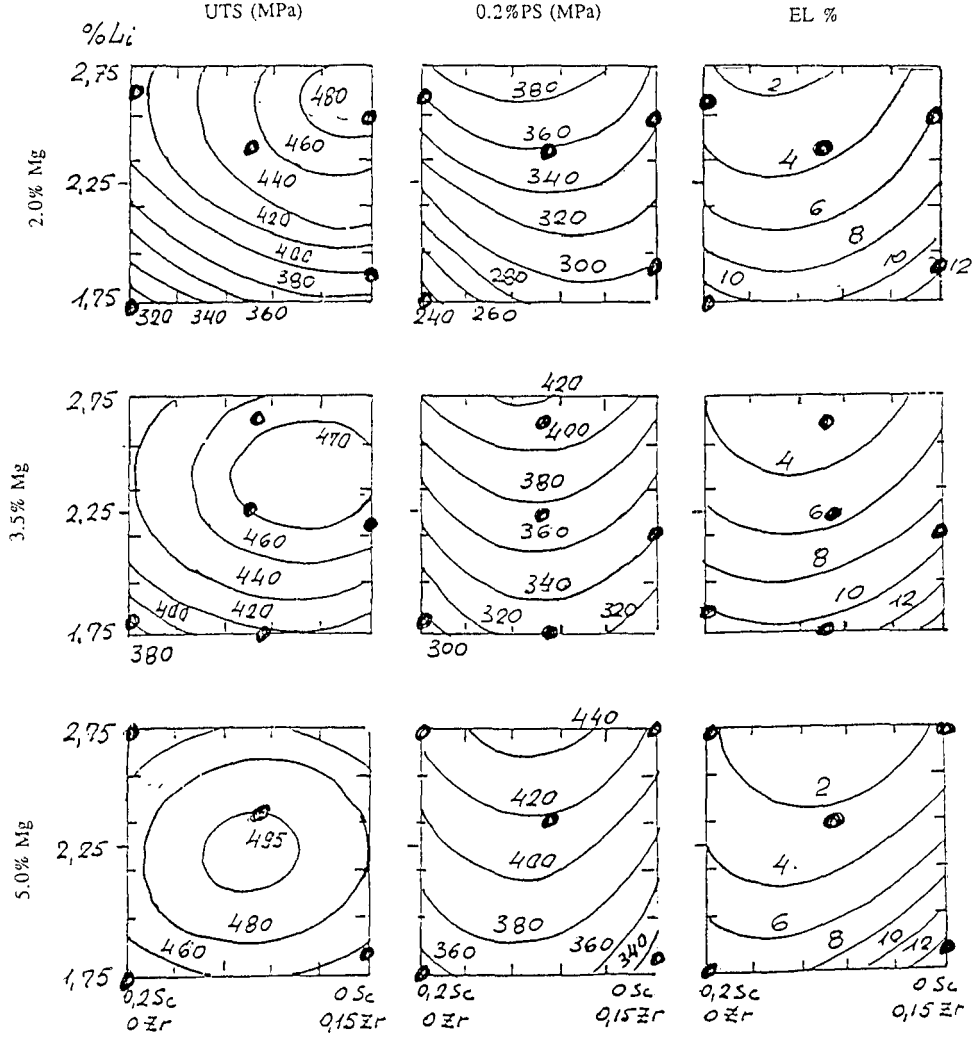

Figure 6. A comparison of the model predictions and the experimental data points for material in the T6 temper.

● Indicates position of alloys investigated. Compare predicted results with the experimantal data given in tables 1 and 2.