HYDROGEN EMBRITTLEMENT OF Al-Li ALLOYS (8090 AND 2091)

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ABSTRACT

This paper describes the hydrogen embrittlement H.E. of two Al-Li alloys (8090 and 2091) aged at 190°C and with different durations of ageing (5,10, 15, 20 and 30 hr). Cathodic polarization in a molten salts bath technique was employed to introduce hydrogen in tensile specimens at 190°C and with -3 V/Ag during the same duration as above. The results show that H.E. is higher when Cu content is high and H.E. is important when the alloys are in the over-aged condition.

INTRODUCTION

Al-Li alloys have gathered strong interest especially in the aircraft industry. Compared to conventional high-strength aluminium alloys of 2000 or 7000 series, it is known that Al-Li alloys offer a 10% increase in Young's modulus along with a 10% decrease in specific weight, thus making them rather competitive to new metallic material like carbon fibre reinforced composites. Moreover, their mechanical properties are equivalent to those of conventional high-strength Al-alloys.

In underaged tempers, the main contributer to the strength increase of Al-Li-Cu-Mg-Zr alloys is δ' phase. δ' and precipitation free zone (PFZ) are more scarce when the alloy contains high contents of Mg and Cu (2091 alloy). In alloys aged to peak strength, the coprecipitation strengthening mainly by S' (and/or S) and δ'occurs in alloys with high Mg content and Cu content (< 2.1%). Increasing Cu content, S' or S becomes more homogeneous and dense (2091 alloy) (1,2,3,4). In this case, S is detected at grain boundaries, even when this alloy is underaged

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heat treated. On the other hand, GPB ---> S' transformation occurs at higher ageing time when the ageing temperature and Cu content are low (2).

In summary, at 190°C ageing temperature (peak ageing), as the ageing time increases, 8090 alloy will have lesser δ' %, a higher ageing time to GPB ---> S' transformation, more coarsed, sluggish and lesser S' precipitation than those which will happen in 2091 alloy (2). In the overaged treatment, S phase with low T_2 precipitation may existe in the grain boundaries of the two alloys (2).

To the best of our knowledge, hygrogen embrittlement of Al-Li-Cu-Mg-Zr alloys (8090 and 2091) have not been studied so far. In this paper, hydrogen embrittlement of 8090 and 2091 alloys in T651 heat treatment were then investigated.

EXPERIMENTAL

The chemical composition of the 8090 and 2090 alloys used in this investigation is given in the following table

Alloy/Element	Li	Mg	Cu	Zr	Si	Ti	Fe	Na, ppm
8090	2.7	1.1	1.3	0.09	0.02	0.02	0.02	3
2091	1.8	1.4	2.0	0.08	0.03	0.04	0.04	---

The experimental material was supplied by CEGEDUR-PECHINEY in the form of 1.6 mm rolled plate in the solution treated (535°C during 1hr and then cold water quenched) and 3% stretched (T-351 condition). Cathodically hydrogen charging was achieved on tensile specimens in a molten salts bath at 190°C during 5, 10, 15, 20, and 30 hours and at -3V/Ag cathodic potential. Uncharged (aged at 190°C in furnace, under vacuum and during the same ageing time) and hydrogen cathodically charged specimens were tensile tested at room temperature using a strain rate of $2.7.10^{-4}s^{-1}$ to study the effect of hydrogen charging on tensile properties.

RESULTS

The variation of tensile properties as a function of ageing time on uncharged specimens shows that when the alloy contains high content of Cu and Mg (2091) alloy), yield strength Re and maximum true stress R are higher than that measured in 8090 alloys (figures 1a,1b). For the later alloy, a maximum of R_e and R levels are observed when the ageing time is about 15 hr. However, for 2091 alloys, R_e increases slightly whereas R remains constant as the ageing time increases form 5 to 30 hr.

Artificially ageing the two alloys during 30 hr reduces R_e and R in 8090 alloy more steeply than those of 2091 alloy. On the contrary, maximum true strain δ_m measured in 8090 alloy is higher than that obtained in the case of 2091 alloy independantly of ageing time, figure 2.

Introducing cathodic hydrogen in the two alloys before tensile test gives the following results : 8090 alloys which have less δ'% and sluggish S' precipitation is, hardened, figures 3a,3b. On the opposite side, the alloy containing high δ'% and high fine S'% (2091) is softened. For the two alloys, R_e and R decrease when the ageing time increases. δ_m measured (maximum true strain) in 2091 alloy hydrogen charged is still lower than that obtained on 8090 alloy at all ageing times, unless at 30 hr, figure 4.

It is obvious then that the 2091 alloy is more affected by hydrogen charging than the 8090 alloy. The reasons are numereous :

a) high hydrogen concentration (4, 28, 40, 57 and > 80 ppm for 0, 10, 15, 20 and 30 hr respectively (5)) may promote dislocations in the matrix. The dislocations initiate S' formation (3) and the later contributes to strengthen the metal. This is the case of 8090 alloy.
b) When the precipitation of δ' is favoured (2091 alloy), free precipitated zones due to depletion of Li and Cu at grain boundaries (1) are also promoted and hydrogen embrittlement is then accelerated.
c) Sluggish and low S' precipitation (8090 alloy) with low misfit within the matrix lower hydrogen embrittlement.
d) Grain boundaries precipitation S and T_2 improve this embrittlement.

The relative ratio variation of the absorbed specific energy till failure (6), W_c%, as a function of ageing time is taken as criterion to evaluate the degree of hydrogen embrittlement. $W_c = \int_0^{\delta_m} \sigma \, d\delta$, with $\sigma = K\delta^n$, K constant, n strain hardening exponent. The results show that hydrogen charging during 30 hr is very harmful for the two alloys, figure 5, with :
[$F(W_c)\% = ((W_{Cair} - W_{CH})/W_{Cair})\times 100 > 50$].

CONCLUSION

In this work we have investigated the hydrogen embrittlement of two Al-Li alloys ; 8090 and 2091. The results obtained lead to the following conclusions :

1) Using the molten salts bath technique and cathodically hydrogen charged the 8090 and 2091 alloys from T351 to T651 conditions (190°C). The outgased quantity of hydrogène is an increasing function as the time of charging (ageing time) increases.

2) Hydrogen may promote dislocations density which are the initiation sites of S' phase. This phase contributes to strengthen the metal.
3) Higher Cu content favours δ' and S' precipitation and promotes free precipitated zones which accelerate hydrogen embrittlement, especially when the alloy is in overaged condition.

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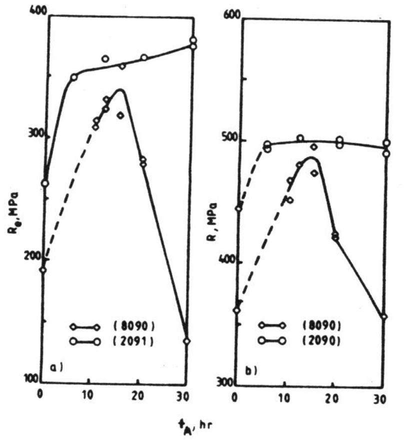

Figure 1 Variation of Re and R as a function of ageing time at 190°C : 8090 and 2091 alloys.

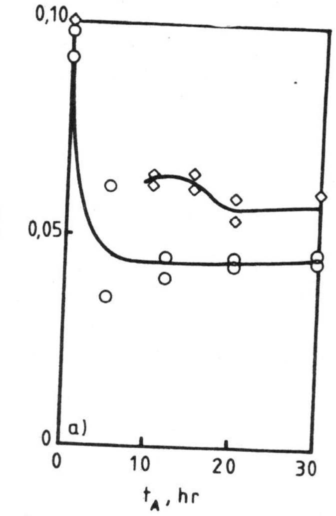

Figure 2 :

Variation of δ_m as a function of ageing time at 190°C : 8090 and 2091 alloys.

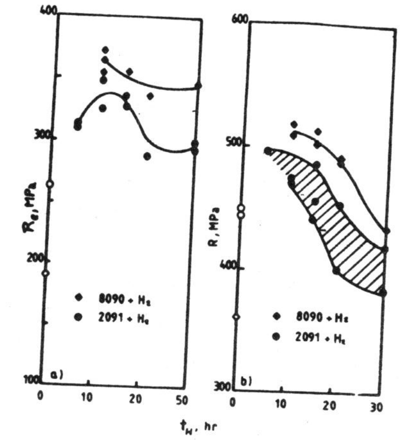

Figure 3 :

Variation of Re and R as a function of cathodic charging time at 190°C : 8090 and 2091 alloys.

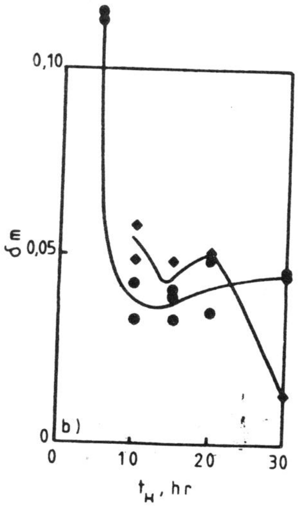

Figure 4 :

Variation of δ_m as a function of cathodic charging time at 190°C : 8090 and 2091 alloys.

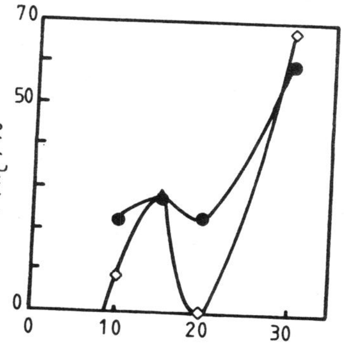

Figure 5 :

Variation of relative ratio fo W_C% as a function cathodic charging time at 190°C : 8090 and 2091 alloys.