6056 T78 : A CORROSION RESISTANT COPPER-RICH 6XXX ALLOY FOR AEROSPACE APPLICATIONS

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ABSTRACT : AA2024 alloy is widely used for fuselage skin applications, mainly in the form of clad sheet in the T351 temper. However, 2024 can be sensitive to intergranular corrosion (IGC) on unclad parts, and cannot be welded. For this reason, Pechiney has developed an IGC-resistant temper of the copper-rich AA6056 alloy. Based on theoretical reasoning and experimental testing, an overaged temper designated T78 has been chosen. It ensures reliable IGC immunity as well as a limited loss of yield strength with respect to the T6 temper. Industrial 6056 T78 was then characterized. It has a yield strength level comparable or higher than 2024 T351. Within one year in a marine atmosphere, 6056 T78 only experiences pitting corrosion whereas 6056 T6, 6013 T6 and bare 2024 T351 all show clear sensitivity to IGC. Besides, regarding toughness and crack propagation resistance, the properties of 6056 T78 and 2024 T351 are equivalent.

Keywords : Aluminium-Magnesium-Silicium-Copper alloys, corrosion, intergranular

1. INTRODUCTION

Currently, the majority of the sheets used for fuselage skin applications in civil aircraft are made of standard AA2024 aluminium alloy. This alloy displays very good mechanical characteristics (static tensile properties, toughness...) in the stretched and naturally-aged temper T351 which is the most commonly used for 2024.

However, the use of the 2024 alloy has two drawbacks. Firstly, bare 2024 can be sensitive to intergranular corrosion (IGC) in the T351 temper as a function of quench rate (product thickness). For this reason, 2024 is mostly used in the form of clad sheet. The cladding is usually made of 1050 which is resistant to corrosion and anodic to 2024. However, the cathodic protection of 2024 by the cladding is only effective on the outer side of the panels since the inner side is machined in typical fuselage applications. The cladding also entails a loss of static tensile properties (5 to 10%) and may foster crevice corrosion when two clad sheets are joined together. Moreover, 2024 cannot be welded. This might be a drawback if the airframe industry wishes to promote in the future the use of welded fuselage structures for cost and mass-saving reasons.

Answering the demand of the aerospace industry for a weldable fuselage skin alloy with equivalent static and dynamic properties, but with an improved resistance to intergranular corrosion, Pechiney Rhenalu proposed the AA6056 alloy. The objective of this paper is to report on the work conducted by Pechiney to define a new IGC-resistant temper for 6056. The typical corrosion, static and dynamic properties that are obtained on such a material are also displayed.

2. DESENSITISATION OF 6056 TO INTERGRANULAR CORROSION

2.1. Presentation of 6056 T6

The composition registered at the Aluminium Association for 6056 is given in table 1 (in wt%).

	Si	Mg	Cu	Mn	Cr	Zr	Fe	Zn
AA 6056	0.7-1.3	0.6-1.2	0.5-1.1	0.4-1.0	<0.1	0.07-0.2	<0.5	0.1-0.7

Table 1 : AA composition of 6056.

After casting, the alloy is homogenised before hot and cold rolling. It is then solution treated at 550°C, water quenched and stretched. Artificial ageing treatments can then be conducted. For instance, the T6 temper corresponds to an ageing treatment of 8 hours at 175°C. In this temper, a yield strength of 360 MPa and an ultimate tensile strength of 410 MPa (rolling and long-transverse directions) can be typically expected. However, 6056 T6 shows a clear sensitivity to intergranular corrosion.

2.2. Microstructural study of 6056

Intergranular corrosion and, more generally, structural corrosion, are closely related to the alloy microstructure. For quaternary Al-Mg-Si-Cu alloys, the following precipitation sequences may take place during ageing :

$$\text{Solid Solution} \rightarrow \text{GP zones} \rightarrow \lambda' \rightarrow \lambda\text{-}Al_5Cu_2Mg_8Si_6$$

$$\text{Solid Solution} \rightarrow \text{GP zones} \rightarrow \beta' \rightarrow \beta\text{-}Mg_2Si$$

The quaternary phase has already been observed and studied by Dubost et al. [1]. More recently, studies by Donnadieu et al. [2] and Vivas et al. [3] of the 6056 microstructure in the peak-aged T6 temper have shown that two geometrical forms of nanometric hardening precipitates can be observed : needles and laths. Needles are about 3 nm wide and 10 nm to 100 nm long while laths are about 1 nm thick, 5 nm wide and 5 nm to 50 nm long. Both have an orthorombic structure and seem to be a metastable form of the λ-$Al_5Cu_2Mg_8Si_6$ phase. The number density of these hardening precipitates was evaluated as 10^{17} cm^{-3}.

Vivas and al. [3] have also observed precipitate free zones (PFZ) next to the grain boundaries. The width of these zones is close to 50 nm.

2.3. The mechanism of intergranular corrosion for 6056 T6

First of all, it must be recalled that silicon and copper increase the potential of the aluminium matrix, rendering it more cathodic, whereas magnesium has almost no influence (see [4] for instance). After the solution heat treatment, the sheets are water quenched, stretched and finally artificially aged. During the quench and especially the ageing sequence, heterogeneous precipitation occurs inside the grains and at grain boundaries. This entails the formation of a PFZ adjacent to the grain boundaries. This region is depleted in Si, Mg and Cu whereas these alloying elements, only partially precipitated, are still present in solid solution inside the grains. The PFZ is therefore anodic with respect to the grains, as illustrated by figure 1.

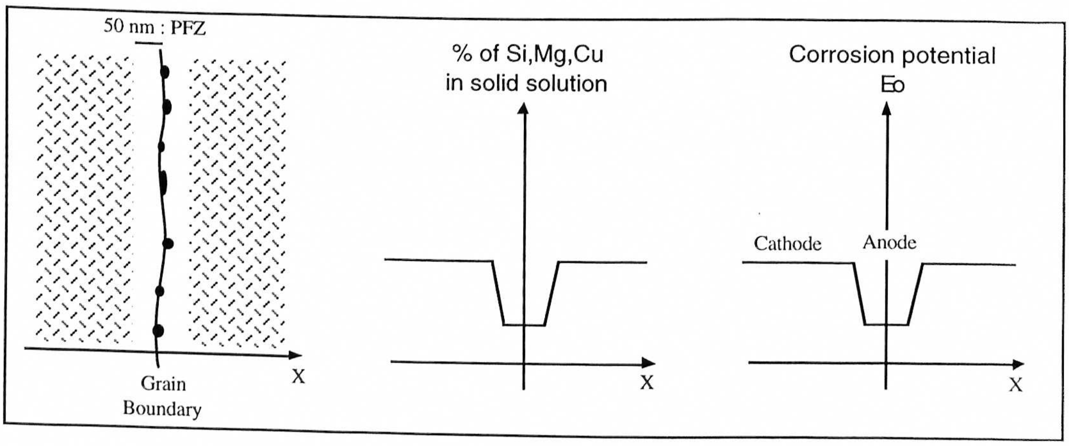

Figure 1 : Schematic mechanism of IGC for 6056 T6.

In the presence of an electrolyte, the PFZ thus becomes the anode of a microgalvanic cell which results in the dissolution of the near grain boundary region, hence intergranular corrosion. The phenomenon is exacerbated by the small size of the anode (PFZ) with respect to the large cathode (grain cores). This mechanism has previously been described by several authors (see Nisancioglu [5], Booth [6] and Reboul [7] for instance).

2.4. Influence of an overageing treatment on IGC sensitivity

The IGC sensitivity of 6056 T6 stems in part from the presence in solid solution of alloying elements (especially Si and Cu which have a significant influence on the corrosion potential). Theoretically, one way of reducing IGC sensitivity thus consists of precipitating more of these elements in order to decrease the potential gap between grain cores and precipitate free zones.

Trials have thus been conducted on a semi-industrial scale, involving overageing treatments at different temperatures and durations for various compositions of AA6056. For each case, mechanical characteristics and IGC sensitivity (ASTM G110 NaCl+H_2O_2 immersion test) were evaluated. The yield strength decreases as the overageing proceeds. Inversely, the resistance to intergranular corrosion increases. A typical yield strength-IGC evolution is given in figure 2.

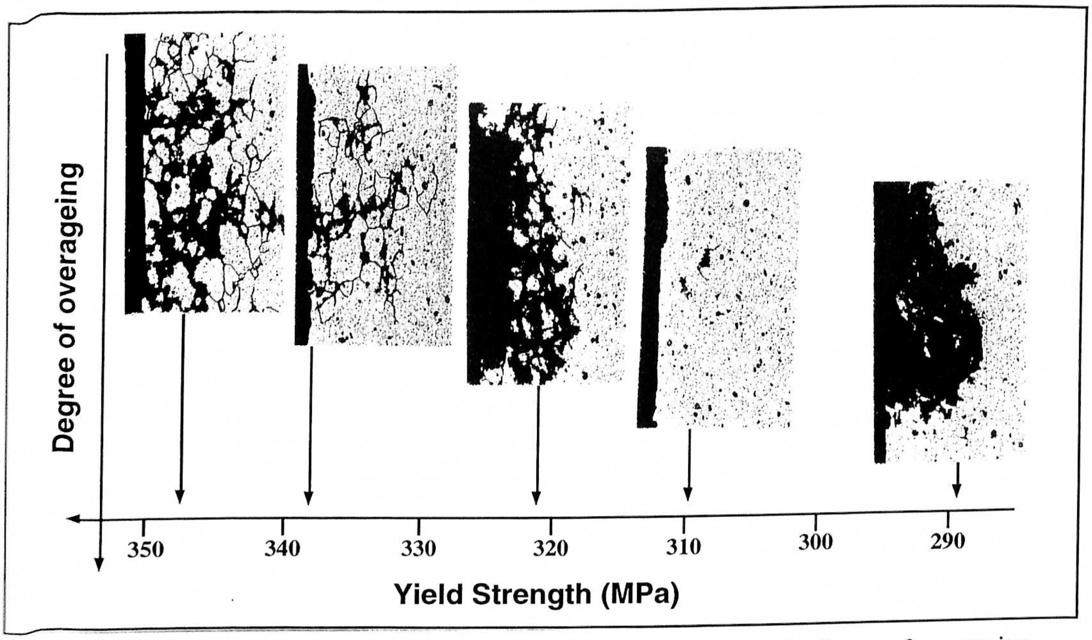

Figure 2 : Typical evolution of yield strength and IGC as a function of the degree of overageing.

We observed that, for the same degree of overageing, desensitisation is more successful when the composition is chosen so that %Si ≥ %Mg. For alloys in the AA6056 range which have more magnesium than silicon, desensitisation might be achieved, but at a degree of overageing such that the loss of mechanical strength is unacceptable.

This beneficial effect of an increase in the silicon content on the IGC resistance was unexpected, because it is generally accepted [5,8] that silicon in excess of the stoechiometric Mg_2Si content is detrimental to the IGC resistance of 6xxx alloys in the T6 temper. A possible explanation of this unexpected effect is that the choice of composition with %Si ≥ %Mg favours the formation of the quaternary λ' precipitate during ageing. Since this phase contains significant proportions of both copper and silicon, its precipitation reduces the solid solution contents of these two elements, which is beneficial with respect to the resistance to IGC. The formation of β-Mg_2Si only reduces the silicon content in solid solution, which is less effective as regards desensitisation.

It is thus possible, for a given range of composition and a controlled level of overageing, to desensitise 6056 to IGC while keeping the yield strength at a relatively high level. This overageing treatment was patented [9] and designated T78. We have checked the industrial reliability of this temper, ensuring that desensitisation occurs for compositions and process conditions in the range of the industrial practice.

3. PROPERTIES OF THE INDUSTRIAL T78 TEMPER

After a long period of research, 6056 T78 has reached industrial reliability. It is still the subject of research in order to allow a good combination of IGC resistance, yield and ultimate strength, toughness, crack propagation resistance, etc...

We will indicate in the following paragraphs some typical properties obtained on 6056 T78 and T6, compared to conventional 2024 T351.

3.1. Mechanical characteristics

Table 2 indicates the range of values obtained : 6056 T78, although showing a loss of strength of 10 to 15% with respect to the peak-aged temper, still has a yield strength level comparable or higher than 2024 T351. The ultimate strength is however significantly lower.

	L direction			LT direction		
	R0,2 (MPa)	**Rm (MPa)**	**A%**	**R0,2 (MPa)**	**Rm (MPa)**	**A%**
6056 T78	311-333	345-359	8-13	300-334	335-362	9-12
6056 T6	360	410	17	360	420	15
2024 T351 (clad)	> 310	> 425	> 15	> 280	> 420	> 15

Table 2 : Mechanical characteristics of 6056 T78 and T6 compared to minimum values for 2024 T351.

3.2. Corrosion

Bare samples of various fuselage skin alloys were exposed for various periods to marine atmosphere near the mediterranean sea, in the south of France. After one year of exposure, the samples were removed and cross-sections were done in order to observe the type of corrosion that had developed. Micrographs representative of these cross-sections are given in figure 3.

Bare 2024 T351 as well as the 6xxx alloys in the T6 temper exhibit clear intergranular corrosion within one year of exposure, which is consistent with the literature available on the subject [10,11]. 6056 T78 is the only material that displays merely pitting corrosion without any trace of IGC. This shows the reliability of both the industrial T78 process and the laboratory accelerated IGC test.

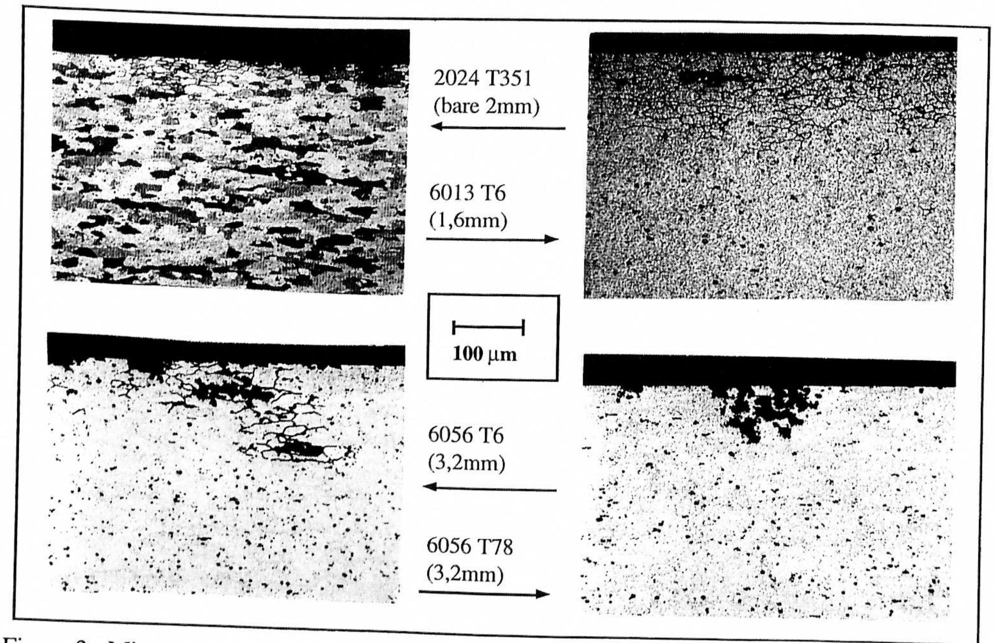

Figure 3 : Micrographs showing the corrosion on samples exposed 1 year to marine atmosphere.

3.3. Toughness

Toughness is assessed through the R-curve method described in ASTM E561. The specimen used for the determination of the R-curve has a width of 760 mm and an initial crack length of 253 mm. The calculation of the toughness (apparent and effective) is made by simulating from the R-curve the tearing of a cracked panel with a given geometry.

Table 3 gives the toughness values in the T-L configuration, calculated on 2024 T351, 6056 T6 and 6056 T78 for a panel width of 400 mm and an initial crack length of 133 mm. With respect to the toughness, 6056 T78 and 2024 T351 show comparable properties.

T-L toughness	Thickness	Kco (apparent) (MPa√m)	Kc (effective) (MPa√m)
2024 T351 (clad)	1.6 mm	80	128
6056 T6	3.2 mm	88	122
6056 T78	3.2 mm	83	118

Table 3 : Toughness of 6056 T78 compared to 2024 T351 and 6056 T6 (W=400, 2ao=133).

3.4. Crack propagation

The determination of the da/dn=f(ΔK) curves is made on compact tensile specimens (width : 75 mm) which are tested at a frequence of 30 Hz. The crack length is derived from the deflection through a compliance method. Figure 4 displays the da/dn=f(ΔK) curves in the T-L configuration for 2024 T351 and 6056 T78 (respectively 5 mm and 6 mm thick, 2 curves for each alloy).

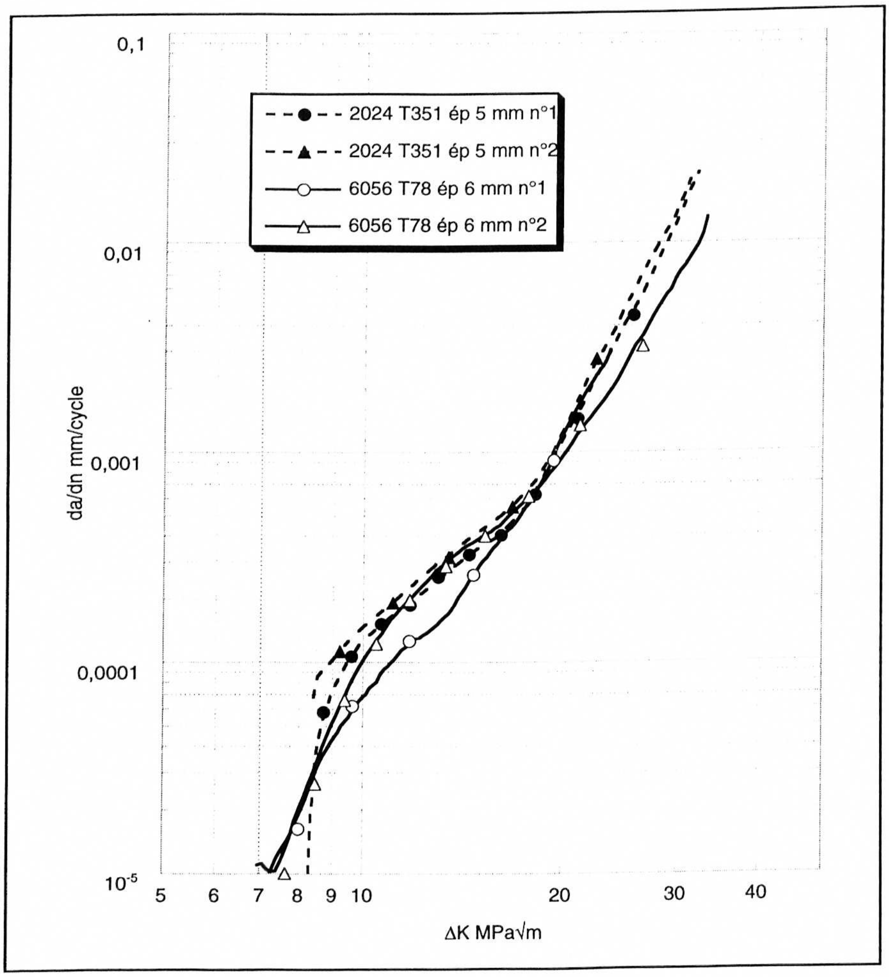

Figure 4 : Crack propagation curves for 2024 T351 and 6056 T78 (T-L configuration).

It appears that 6056 T78 is at least as resistant as 2024 T351 as regards the crack propagation.

4. CONCLUSIONS

1 - Alloy AA6056 T6, as well as 6013 T6 or bare 2024 T351, is sensitive to intergranular corrosion (IGC). This susceptibility is associated with the formation of precipitate free zones around grain boundaries. For copper-rich 6xxx alloys, these regions mainly appear during the artificial ageing treatment and are depleted in silicon and copper, hence anodic with respect to the grains.

2 - Semi-industrial trials showed that a given composition range associated with a controlled degree of overageing desensitises the alloy to IGC, keeping the yield strength at an acceptable level with respect to the T6 temper. This new temper was designated T78.

3 - Marine atmosphere exposure tests confirm that 6056 T78 is desensitised to IGC. As regards mechanical properties (yield strength, toughness and crack propagation), the resistance of 6056 T78 and standard 2024 T351 are equivalent.

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