Study of new heat treatment parameters for increasing mechanical strength and stress corrosion cracking resistance of 7075 Aluminium alloy

G. Silva, B. Rivolta, R. Gerosa, U. Derudi

For many years 7075 Aluminum alloys have been widely used especially in those applications for which high mechanical performances are required. It is well known that the alloy in the T6 condition is characterized by the highest ultimate and yield strengths, but, at the same time, by poor stress corrosion cracking (SCC) resistance. For this reason, in the aeronautic applications, new heat treatments have been introduced to produce T7X conditions, which are characterized by lower mechanical strength, but very good SCC behavior, when compared with the T6condition. The aim of this work is to study the tensile properties and the SCC behavior of 7075 thick plates when submitted to a single step ageing by varying the ageing times. The tests were carried out according to the standards and the data obtained from the SCC tests were analyzed quantitatively by an image analysis software. The results show that, if compared with the T7X conditions, the single step ageing performed in the laboratory can produce acceptable tensile and SCC properties. The data should be confirmed by experiments carried out on thick plates submitted to heat treatments in industrial furnaces.

Keywords:
Aluminium and its alloys. Precipitation, Heat Treatment, Corrosion

INTRODUCTION

7075 aluminium alloy has been used for more than 50 years in aeronautics for the production of critical parts and only very recently it has also been used in mechanical applications, due to its high mechanical strength.
Earlier applications in aeronautics and almost all mechanical applications use the alloy in the T6 condition, which is characterized by the highest ultimate and yield strength, but, at the same time, in the case of heavy sections, by poor stress corrosion cracking (SCC) resistance. For this reason, in new projects in the aeronautic applications, the use of 7075-T6X plates and bars has been forbidden since 1975 (Mil-STD-1568) and new heat treatments have been introduced to produce T7X conditions. These are characterized by lower mechanical strength, but very good SCC behavior, when compared with the T6 condition. For this reason, many mechanical designers are considering the possibility of expressly making the T7X condition a requirement, instead of the T6 condition, when using the 7075 alloy. One important difficulty which shall not be neglected in performing this conversion is the poor availability of semi-finished products ex stock in T7X condition in the market, outside the aeronautic circuit.
In the technical literature, the problem of SCC of 7075 aluminium alloy was considered (Domack, 1986) and widely investigated for many applications. The influence of the heat treatment parameters was demonstrated experimentally in Swanson et al. (1982), Ferrer et al. (2003) and Yue et al. (2006) and some models theoretically describing the behaviour were introduced in Onoro et al. (1989). All the main results were summarized in The Military Handbook (2003) and in SAE AMS 2772 (2008).
The authors extensively studied the influence of the heat treatment parameters of 7075 aluminium alloys, starting from the problems of the quench sensitivity of large thickness plates whose results were published in [8] and the influence of the ageing parameters on SCC behavior, whose results were collected in [9]. One of the main results of the work published in [9] was that a single step ageing to the T73 and T76 tempers could be considered as a good approach for obtaining an acceptable SCC behavior and mechanical properties typical of the above mentioned tempers. That's why the effect of different ageing times during a single step ageing at 163°C was considered to be an interesting topic of investigation, especially for the mechanical applications where the two ageing steps are often thought as a heavy charge in the production management. The aim of this work is the study of the influence of the ageing time on the tensile and SCC properties of 7075 Aluminium alloy after a single step ageing at 163°C. As a comparison, the T73, T76 and T6 tempers were investigated.

MATERIALS AND METHODS

The chemical composition of the investigated alloy is reported in Table 1. The material was delivered as T651 thick plate (90 mm thickness). The samples for the mechanical and corrosion tests were machined in the short-transverse direction of the plate, which is reported to be the most critical direction for SCC. A previous work [9] demonstrated that the second step of the

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Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
0,4 max	0,5 max	1,2 2,0	0,3 max	2,1 2,9	5,1 6,1	0,18 0,28	0,2 max	Bal.

TAB. 1 ***Chemical composition of the considered material.***

Composizione chimica del materiale.

Temper	Ageing condition
T6	121°C x 24h
T73	107°C x 7h + 163°C x 27h
T76	121°C x 4h + 163°C x 16h
163_3	163°C x 3h
163_5	163°C x 5h
163_8	163°C x 8h
163_16	163°C x 16h
163_24	163°C x 24h

TAB. 2 ***List of the investigated ageing conditions.***

Elenco degli invecchiamenti investigati.

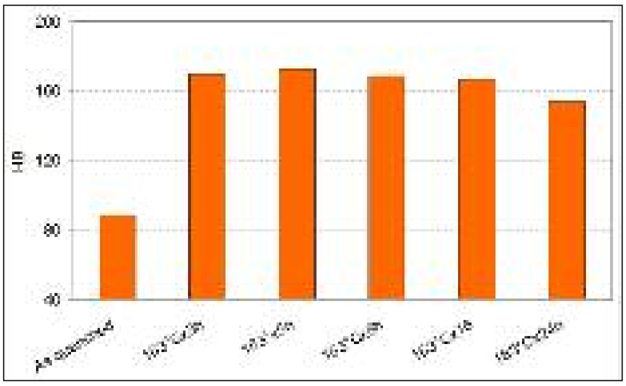

FIG. 1 ***Hardness values at 163°C.***

Valori di durezza a 163°C.

ageing treatment to the T73 and T76 tempers could be considered as a good potential temperature for obtaining an acceptable SCC behavior so that in this work the effect of different ageing times were investigated during a single step ageing at 163°C. As a comparison, the T73, T76 and T6 tempers were investigated. The list of the investigated ageing conditions is reported in Table 2. For all the conditions, the solution was carried out at 480°C. Hardness measurements were carried out on the samples after ageing at 163°C with different times. The results are shown in Figure 1.

Samples for tensile and SCC tests were machined from a 90 mm x 90 mm x 1500 mm bar along the short-transverse direction; the solution heat treatment was carried out at 480°C for 30 and 60 minutes respectively. The SCC tests were performed according to ASTM G39-99 [10] and ASTM B117-11 [11] using samples with the following dimensions, 25 mm x 90 mm x 3 mm. The tests were performed in a salt fog chamber at 35°C for 480 hours using a 5% NaCl aqueous solution. Two specimens per ageing condition were tested.

The tensile tests were performed according to the requirements reported in [12].

The SCC behavior is traditionally evaluated following a standard corrosion rating and the Military Handbook 5J specifies the SCC resistance classes as follows:

A = Equal to or greater than 75% of the specified minimum yield strength. A very high rating. SCC not anticipated in general applications if the total sustained tensile stress is less than 75% of the minimum specified yield stress for the alloy.

B = Equal to or greater than 50% of the specified minimum yield strength. A high rating. SCC not anticipated if the total sustained tensile stress is less than 50% of the specified minimum yield stress.

C = Equal to or greater than 25% of the specified minimum yield stress or 14.5 ksi, whichever is higher. An intermediate rating. SCC not anticipated if the total sustained tensile stress is less than 25% of the specified minimum yield stress.

D = Fails to meet the criterion for the rating C. A low rating. SCC failures have occurred in service or would be anticipated if there is any sustained tensile stress in the designated test direction.

For 7075 Aluminium alloy, the corrosion rating for different heat treatment conditions is reported in Table 3.

The samples were tested by four point bending loading (Figure 2) at a stress value equal to 85% of the measured yield stress, according to the procedure reported in [8]. The tensile specimens had a round section, Ø=8mm, and a span length equal to 40mm.

Alloy and Temper	Corrosion rating
7075-T6	D
7075-T73	A
7075-T76	C

TAB. 3 ***Data from literature [6] about stress corrosion cracking behaviour of 7075 from plates, short-transverse direction.***

Resistenza a SCC per piastre in lega 7075, in direzione del trasverso corto come riportato in [6].

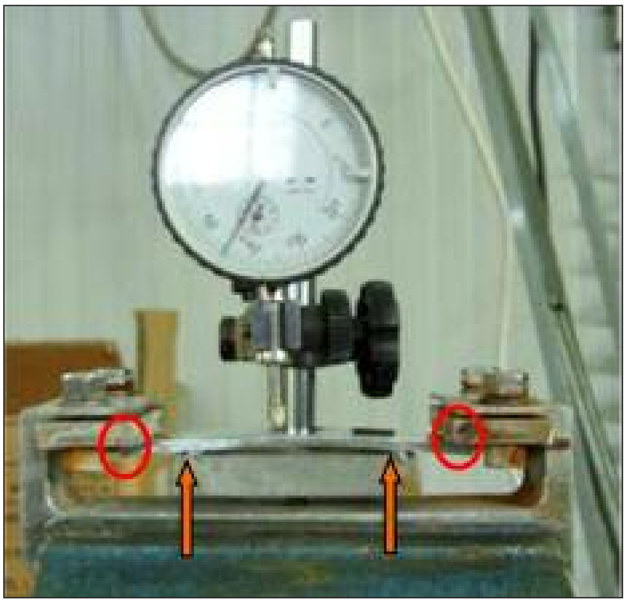

FIG. 2 ***Four point bending loading of the SCC samples.***

Applicazione del carico ai campioni per le prove di resistenza a SCC mediante flessione su quattro punti.

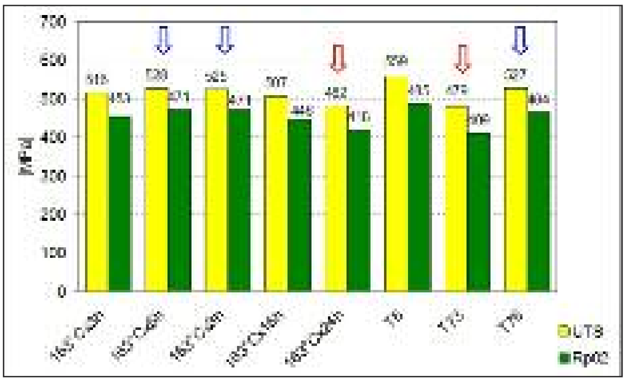

Fig. 3 ***Tensile results for the investigated heat treatment conditions.***

Proprietà tensili al variare del trattamento termico.

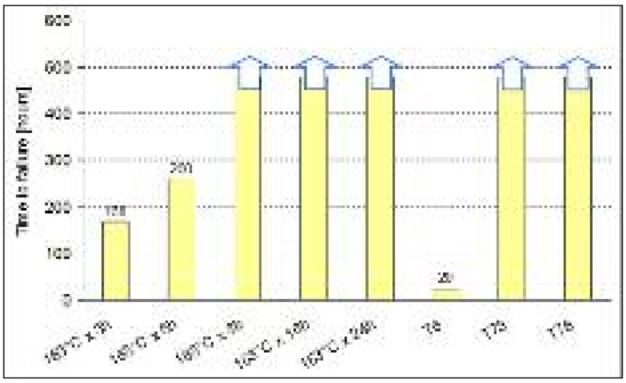

FIG. 4 ***SCC resistance in the salt fog chamber (480 hours maximum exposure time).***

Resistenza a SCC dopo permanenza in camera a nebbia salina (massimo tempo di esposizione, 480 ore).

RESULTS

The tensile properties are reported in Figure 3.

From the previous data, two classes of mechanical strength can be found:

1. T76 and 163°C, 5 and 8 hours aged samples;
2. T73 and 163°C, 24h aged samples.

The results of the SCC tests are reported in Figure 4.

After 480 hours exposure, T73, T76 and 163°C, 8h, 16h, 24h aged samples didn't show any failure.

In order to perform a deeper investigation of these samples, the corroded surfaces were observed by a stereomicroscope and the defects were analyzed by an image analysis software. In Figure 5 some pictures are reported. In Figure 6 the relationship between the roundness ($R=P^2/4\pi A$, P and A are the perimeter and the area of a defect) and the area of the corrosion defects is presented.

The roundness of the defect can generally be considered as a measure of its notch effect. The comparison in Figure 6(a) shows that samples aged at 163°C, 8 and 16 hours have a similar behavior and both better than T76 ones. In Figure 6(b) instead, the comparison between T73 and 163°C, 24 hours aged samples shows very similar results.

CONCLUSIONS

The previous results led to the following concluding remarks.

1. The tensile tests resulted in two resistance classes: the first one includes T76 and 163°C, 5 and 8 hours aged samples and the second T73 and 163°C, 24 hours aged samples.
2. Only the T6 and 163°C, 3 and 5 hours aged samples failed the SCC test.
3. A further and deeper investigation was carried out on the unfailured corrosion samples using an image analysis software. The comparison between the tested conditions revealed a weaker corrosion behavior of T76 samples if compared with 163°C, 8 and 16 hours aged samples, whereas no clear

Fig. 5 ***Image analysis of a corroded surface.*** *Analisi di una superficie corrosa.*

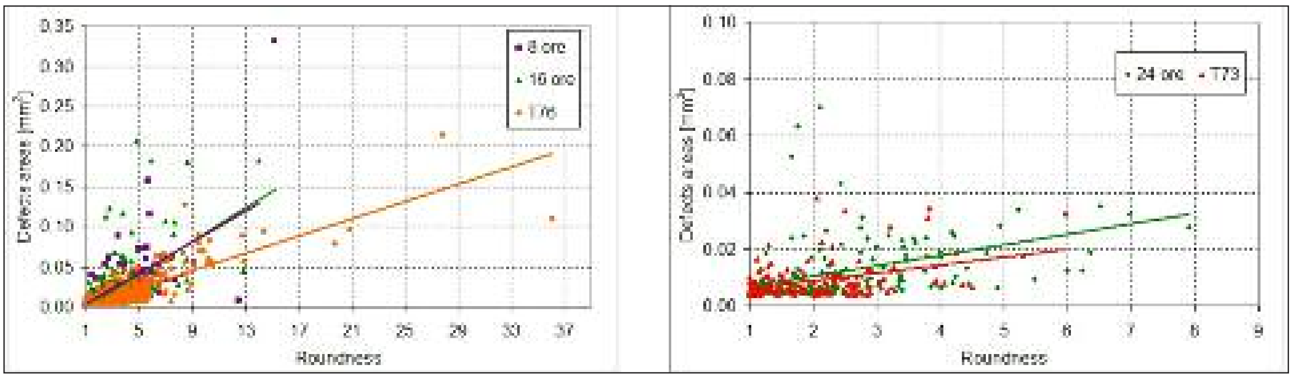

FIG. 6 ***Roundness versus defects areas.*** *Valori di rotondità in funzione dell'area dei difetti.*

difference was observed between T73 and 163°C, 24 hours aged samples.

4. Considering both the mechanical properties and the SCC resistance, the T76 temper could be replaced by the 163°C, 8 hours ageing, even if a more complete evaluation should be carried out on larger plates submitted to heat treatments in industrial furnaces; moreover other mechanical tests such as fatigue and fracture toughness should be added to complete the test plan.

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Abstract

Studio di nuovi parametri di trattamento termico per aumentare le proprietà meccaniche e la resistenza a corrosione sotto tensione di una lega di alluminio tipo 7075

Parole chiave: Alluminio e Leghe, Precipitazione, Trattamento Termico, Corrosione

Da molti anni la lega di alluminio tipo 7075 è impiegata specialmente in quelle applicazioni dove sono richieste alte proprietà meccaniche. E' ampiamente riconosciuto che questa lega raggiunge le massime prestazioni meccaniche allo stato T6, ma è altrettanto noto che in questa condizione di trattamento la resistenza a corrosione crolla, specialmente quella sotto tensione. Per questa ragione, nel campo aeronautico, sono stati studiati ed introdotti nuovi parametri di trattamento al fine di sviluppare degli stati T7X caratterizzati da proprietà meccaniche leggermente inferiori, ma con resistenza a corrosione decisamente più elevata. In questo lavoro sperimentale sono state studiate le caratteristiche meccaniche e la resistenza a corrosione sotto tensione di campioni ricavati da piastre di grosso spessore in lega 7075 solubilizzati e poi invecchiati ad una sola temperatura (anziché le due richieste dagli stati T7X) coincidente con il secondo passo degli stati T73 e T76. Tutti i test sono stati condotti in accordo alle normative vigenti e i dati ottenuti dalle prove di corrosionie sono stati utilizzati per una analisi più approfondita in grado di fornire una valutazione quantitativa del fenomeno. I risultati mostrano che in alcune condizioni di trattamento, i campioni invecchiati con una sola temperatura sono confrontabili con quelli negli stati standard T7X, sia dal punto di vista tensile che di resistenza a corrosione. Per una definitiva conferma dei risultati, sarebbe tuttavia importante ripetere i test su campioni estratti da piastre di grosso spessore trattati in forni industriali.