# New Generation High Strength High Damage Tolerance 7085 Thick Alloy Product with Low Quench Sensitivity

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#### Abstract

The paper reports a new generation of thick section alloy with very low quench sensitivity and high strength-toughness capabilities, that was developed based on extensive laboratory studies of 7xxx phase fields. Registered as AA7085, 152 mm plates of the alloy typically offered about 15% increase in longitudinal TYS in combination with equivalent L-T  $K_{co}/K_{app}$  toughness vs. 7050-T7451. 7085 plates and forgings demonstrated attractive fatigue properties (S-N and FCG). Stress corrosion and exfoliation properties of 7085 were comparable with those of 7050. Because of the significant weight reduction potentials in airframes, 7085 plates and die forgings have been selected by Airbus for the wing spar and rib structures in their upcoming super-jumbo A380 plane.

## 1. Introduction

The new generation of improved thick section alloys with low quench sensitivity started in the late '60s with the replacement of Cr and Mn with Zr for dispersoids leading to the transition from 7075 to the 7050 (or 7010) alloy. High quench sensitivity was also known to be associated with Cu. However, Cu for several thick section alloys was too low (<1%) (all compositions in the paper are given in weight per cent) and resulted in severe stress corrosion cracking (SCC) problems, e.g. 7079, X7080. Mg, a potent strengthener, was too high (>2.5%) in some other alloys that resulted in low fracture toughness, e.g. 7178. A need for optimized Cu and Mg levels became clear. The new high strength upper wing 7055 alloy, introduced by Alcoa in the early '90s, used high Zn together with high Cu to achieve the high strength goals, since Mg had to be restricted to optimize toughness. Relative to 7050 the Zn level for 7055 has been about 2% higher. Thus, along with Cu-Mg optimization, exploration with high Zn for improved thick section alloy appeared worthy of pursuit and was also supported by the internal phase diagram studies.

## 2. Experimental

For the initial laboratory studies a phase diagram based design of experiment (DOE) was undertaken covering the composition ranges of alloys, Zn: 6-11%, Cu: 1.5–2.3%, and Mg: 1.5-2.3%, and later extended down to 1.2% for both Cu and Mg. The sample bars were subjected to different quench rates following the solution heat treatment (SHT) to simulate the quenching of 32 to 203 mm gauge sections.

Multiple aging practices were studied to mimic T74, T76 and T77 tempers. Tensile, fracture toughness (KI<sub>c</sub>), electrical conductivity and exfoliation data were collected. For subsequent industrially produced thick plates and forgings, the above studies were complemented with extensive damage tolerance and durability property studies. This included plane-strain (KI<sub>c</sub>) and plane-stress (K<sub>co</sub>/K<sub>app</sub>) fracture toughness, fatigue life (S-N) and fatigue crack growth (FCG) and alternate immersion (AI-SCC) and seacoast (PJ-SCC) SCC tests.

## 3. Results and Discussion

Figure 1 shows a plot of longitudinal tensile yield strength (L-TYS) vs. L-T KI<sub>c</sub> for the slow quenched (SQ) bars mimicking a 152 mm section from the laboratory DOE trials. Notably, alloy B stood out with much superior strength-toughness properties compared to other alloys including the two control alloys 7050 and 7055 that were also run with the DOE. The L-TYS vs. aging time plot in Figure 2 shows an unusual behavior for alloy B in the overage regime where the strength for the SQ sample, mimicking a 152 mm section, is higher than that for the fast quenched (FQ) sample, mimicking a 32 mm section. This is in sharp contrast to the expected normal behavior as displayed by alloy A, chosen from and representing the pack of all other alloys in Figure 1. The results would suggest that alloy B has superior properties especially for thick section applications. Full size ingots of composition "B" and two composition variants of it (B1 and B2) were cast and fabricated to 152 mm thick plates at Alcoa Davenport Works. Figure 3 shows L-TYS vs. L-T KI<sub>c</sub> plots for the three alloys for three different aging conditions spanning roughly from "T7651" to "T7451" tempers. The results confirmed the laboratory data showing the significant superiority of B (designated as C80A within Alcoa) over the standard 152 mm 7050-T7451 plate alloy. Despite the difficulty of comparing the "typical" data for 7050 against the "actual" data due to the limited studies on the new alloys, the trend appeared convincing.

Since then extensive production of the alloy both as hand and die forgings (Cleveland Works) and plate (Davenport Works) comprising together over 2 million pounds and covering the gauges 76 to 229 mm confirmed the superior (i.e., low) quench sensitivity properties of C80A. In February 2002 C80A was registered with the Aluminum Association (AA) as 7085 with the composition limits listed in Table 1. The T76 alloy temper has been also registered with AA. Figure 4 shows a comparison of the recently measured TYS Ccurve plot for 102 mm 7085 and 7050 plate against literature data for several standard alloys of similar gauge [1,2]. The plots clearly confirm the inherent low guench sensitivity of 7085 over other alloys, including 7050, and nearly matching 7046 having no Cu suited for very low guench sensitivity. Figure 5 shows the practical benefits of the high strength 7085 alloy with low quench sensitivity that allowed Airbus to design the wing spar in their upcoming 555-passenger super-jumbo A380 plane at higher strength levels, particularly at thick gauges, than possible with the incumbent alloys, including 7050 [3]. Figure 6 shows strength and toughness property comparisons between 7085 and 7050 152 mm plates indicating about 15% higher longitudinal compressive yield strength (L-CYS), critical for (upper) wing structure, offered by 7085 at equivalent L-T fracture toughness (both KIc and  $K_{co}/K_{app}$ ) over the incumbent 7050.



Figure 1: L-TYS vs L-T  $KI_c$  (Kq) Plots for Experimental 7xxx Alloys in the Slow Quenched (Simulated Thick Section) Condition. Alloy B clearly distinguishes in strength-toughness.



Figure 2: Composition Influence on Interaction between Quench Rate and Aging Kinetics for Alloy A with Normal Behavior and Alloy B with Atypical Behavior.



Table 1: The Composition Limits of 7085 Registered with the Aluminum Association

	Zn	Mg	Cu	Fe	Si	Zr
Max.	8.0	1.8	2.0	0.08	0.06	0.15
Min.	7.0	1.2	1.3	N/A	N/A	0.08

Figure 3: L-TYS vs. L-T  $KI_c$  Plots for Davenport Processed 152 mm Plates of 7085 and Its Composition Variants B1 and B2 and for 152 mm 7050-T7451 Plate

Depending upon the application, 7085 should also be able to provide combinations of higher toughness at equivalent or desired strengths by adjusting the aging conditions. Figure 7 shows the open-hole S/N fatigue life plots for 102, 152 and 203 mm 7085-T7651 plate, and for the incumbent 152 mm 7050-T6751 plate. The 7085 fatigue properties are equivalent to, if not slightly superior to the 7050 properties. The smooth S/N fatigue properties of 76 mm 7085-"T7451/T7351" plates were likewise found superior to the 76 mm 7475-T7351 plate, the incumbent material for the wings of regional jet, for which the S/N fatigue properties are critical. Figure 8 shows L-T fatigue crack growth (FCG) rate curves for 102 and 152 mm 7085-T7651 plates vs. 152 mm 7050-T7651 plate.



 Fty "B Basis" Static Design Allowable Comparison: 7050 vs 7085

 7085-L

 7085-LT

 7085-LT

 7085-LT

 7050-L

 7050-L

<tr

Figure 4: L-TYS C-Curve Plots for 7085, 7050, 7075 and 7046 Plates. The 7085 and 7050 with double C-curves (solid line) are from recent studies by Shuey et al. [1,2] and are based on 102 mm plates; the dotted c-curves are from earlier studies in Alcoa.

Figure 5: Rolled Plate 7085 vs 7050 Static Strength Comparison (Fty). The static strength design allowable for 7085-T7651 is improved over 7050-T7651. (Low quench sensitivity of 7085 gives larger improvement at higher gauges) [3].

The FCG performance for 7085 is superior (i.e., lower FCG rate) to 7050 at the useful higher  $\Delta$ K ranges (>17-20 MPa $\sqrt{m}$ ), while it is slightly weaker below that range. Alloy 7085 plates and forgings passed the ASTM G44 alternate immersion SCC test at 172 MPa for the T76 temper, as well as at several prescribed higher threshold stress values. Environmental SCC test of the products are also in progress. Exfoliation tests, per ASTM G34, in general gave "EA" ratings in all cases. Thick plates and large die forgings of 7085 are being fabricated at Alcoa and supplied to Airbus for the A380 plane, including the one for the inner center spar which happened to be the largest die forging on record. Table 2 lists the tensile properties for 7085 by gauge for 102 to 178 mm plate as registered in AMS 4329 [4].





Figure 6: 7085-T7X51 vs. 7050-T7451 Type III 152 mm Plate Longitudinal Properties.

Figure 7: 7085-T7651 102 mm, 152 mm and 203 mm Plates vs. 7050-T7651 152 mm Plate Open-Hole Fatigue (Kt=2.3): L-T Orientation (T/4, W/2), R=0.1, Freq.= 30 Hz, RH>90%.



Plates of 102 mm to 178 mm Gauge Registered in AMS 4329									
	Grain	Tensile	Yield Strength	Elongation in					
Nom. Thickness	Direction	Strength	at 0.2% Offset	50.8 mm or 4D					
Millimeters		MPa	MPa	%					
	L	510	476	7					
101.62-127.00	LT	503	462	5					
	ST	493	434	3					
	L	510	476	7					
127 02-152 40	LT	503	462	4					

483

503

503

476

434

469

448

434

ST

L

LT

ST

Table 2: Minimum Tensile Properties of 7085-T7651

Figure 8: 7085-T7651 102 mm and 152 mm Plates vs. 152 mm 7050 Plate Fatigue Crack Growth Rate: L-T Orientation (T/4, W/2), R=0.1, Frequency = 25 Hz., RH>95%.

152 42-177 80

Figure 9 shows L-TYS vs. L-T KI<sub>c</sub> plots of actual (not minimum) data from the T/4 location of 7085-T7651 plates for 4 different gauges. The plots show that the strength-toughness relationship progressively improves as plate thickness decreases from 152 to 76 mm as expected due to the increased quench rate. However, the trend reverses at 38 mm gauge. The L-T KI<sub>c</sub> values appear to generally increase with thinner gauge and do not reflect similar gauge reversal effects. However, the L-TYS at T/4 suffers from a similar reversal for 76 to 38 mm gauge. Figure 10 displays L-TYS variations with plate gauge as a function of aging time.



Figure 9: Longitudinal Tensile Yield Strength vs. L-T  $\rm KI_c$  Fracture Toughness for 38 mm, 76 mm, 127 mm and 152 mm Thick 7085-T7X51 Plate at T/4.



Figure 10: Longitudinal Tensile Yield Strength at T/4 vs. Thickness for 7085 Plate for Different Artificial Aging Times. (38 mm:L# 409-241; 76 mm: L# 09-251;152 mm:L# 531-124).

The plots show the strength reversals with gauge the extent of which, however, varies with aging time. Such strength reversal though not uncommon (e.g., 7075) occurs at much thinner gauges, and is associated with increased recrystallization. Quantitative texture and recrystallization studies are not able to account for this property reversal in 7085. Pending

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further studies, the results suggest complex aging kinetics changes with respect to strength for different quench conditions (i.e., thickness) of the alloy. Figure 11 displays the effect of such complex aging kinetics from the laboratory basic studies on the 7085 alloy that shows an interesting crossover of the aging curves. Thus in the overage regime, the strength of the FQ sample tracks below the SQ sample, thereby confirming the atypical results presented in Figure 2 earlier. Careful microstructural studies are needed to understand this phenomenon.



Figure 11: Longitudinal Tensile Yield Strength vs. Aging Stages for Slow Quench and Fast Quench Conditions for Alloy B from Figure 1. The results support the plot for Alloy B in Figure 2.

As for thick section applications, to date qualification studies have been completed for Airbus for 76 to 202 mm plate and 102 to 229 mm hand forgings, both in T765X temper and for die forgings in T7652 and T7452 tempers. Limited qualification work has also been completed on 152 mm 7085-T7451 plate. Application for registering the property data with MMPDS (formerly MIL-HDBK-5) is being planned for early 2004.

#### 4. Summary

7085 is a unique alloy with very low quench sensitivity and high strength and damage tolerance property combinations in thick gauges. It is in commercial use with Airbus for the wing spar and rib structures of the forthcoming A380 plane. The properties of 7085 also raise several basic issues the studies of which will be of fundamental interest and will help further enhance the potentials of this alloy.

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#### References

- [1] M. Tiryakioglu and R.T. Shuey, Proc.1<sup>st</sup> Int. Symp. Mod. Al Alloys, Pittsburgh, 2003.
- [2] R.T. Shuey, Alcoa Technical Center Private communication.
- [3] Paul Wood, Airbus, Filton, U.K. Private communication.
- [4] Aluminum Alloy, Plate (7085-T7651), Aerospace Material Specification, AMS 4329, SAE, July 2003.