Effects of Thermal Processing and Copper Additions on the Mechanical Properties of Aluminum Alloy Ingot AA 2618

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This study compared the ambient and elevated-temperature T6 tensile properties of "air slip" cast aluminum alloy ingot 2618 and 2618 alloyed with additional copper (as well as some additional manganese, iron, and nickel). The increased alloying appears to increase strength slightly, but to decrease ductility at ambient temperature. At 149 °C, the copper-rich 2618 has slightly lower strength and ductility than 2618. The standard aging temperature and time produce higher ambient-temperature strength but lower ductility than lower aging temperatures at the same or shorter aging times in copper-rich 2618 alloy. Thus, the additional alloying does not significantly improve mechanical properties, particularly strength, even after T6 aging modification.

Keywords
aluminum alloy, copper, high-temperature, piston

1. Introduction

ALUMINUM alloy 2618 has been widely used as a piston material for internal combustion engines. Alloy 2618 has stable elevated-temperature strength compared to other 2*xxx* alloys. The hardening is partly due to the precipitation of Mg_2Si, $Al_4CuMg_5Si_4$, and other complex constituent second-phase particles (Ref 1-3) and not of $CuAl_2$ (as with alloy 2024) since the copper becomes associated with the nickel to form a ternary intermetallic compound. The absence of the $CuAl_2$ constituent gives rise to the superior strength of alloy 2618 at high temperatures.

Recent work (Ref 4) reported that increased copper concentration in alloy 2618 may significantly increase (15%) the elevated-temperature tensile properties of the alloy, described here as 2618 (Cu-rich). An objective of this research was to verify this work. We also determined the effect of various T6 aging temperatures and times at temperature on the ambient-temperature tensile properties for 2618 (Cu-rich) to further assess the potential strength of the alloy. The elevated-temperature properties of alloys 2618 and 2618 (Cu-rich) were also investigated for the optimized T6 condition. The concentration of copper in the 2618 (Cu-rich) was about 0.5 wt% above the composition limits (Ref 5).

2. Experimental Procedure

The 2618 and 2618 (Cu-rich) aluminum alloys were provided in the form of "air slip" direct chill cast 98 mm diam ingots (where the solidification rates are 2 to 10 times faster than the traditional rates). It should be noted that the ingot samples underwent no deformation during any part of these tests. The compositions of the 2618 and 2618 (Cu-rich) aluminum alloy ingots are listed in Table 1. The copper content in 2618 (Cu-rich) is significantly higher (0.5%), and the iron, manganese, and nickel contents are also somewhat higher (0.05, 0.21, and 0.16 wt%, respectively).

Tensile tests were performed on an Instron 4505 screw-driven tensile machine with computerized data acquisition. The accuracy of the mechanical tests was within ±0.5%. The ductility was measured as engineering strain to failure (percentage elongation) equal to $\Delta L/L_0$, where L_0 is initial length. The yield and ultimate tensile stresses were reported as engineering stresses. The yield stress was based on a 0.002 plastic strain offset. Strain rates were 0.67×10^{-3}/s. The homogenization treatments were performed in an air-velocity-controlled furnace with a Partlow controller. The temperature was controlled within ±4 °C of the set temperature. The solution treatments and aging treatments were performed in a case furnace with an accuracy of ±2 °C of the set temperature. Elevated-temperature testing was performed by Koon-Hall Testing in Portland, Oregon.

The typical gage dimensions of the tensile test specimens for ingot characterization were 5.1 mm diameter and 25.4 mm length. Specimens were extracted from random positions within the ingots. It was determined that the mechanical properties were independent of position. The T6 treatment for alloy 2618 consisted of a solution treatment followed by a boiling water quench, 1 h refrigeration, followed by an aging treatment. A 10 min heat-up period was required to achieve the solution temperature (529 °C for 2618 and 2618 [Cu-rich] aluminum alloys) once the specimens were inserted in the furnace. Tensile specimens were maintained at temperature for 1 h. The T6 treatment utilized three aging temperatures: 166, 182, and 199 °C, and various times (up to 24 h).

3. Results and Discussion

The homogenization cycle was optimized to produce the best ambient T6 tensile properties for both alloys. In order to study the effect of aging treatment on the T6 tensile properties

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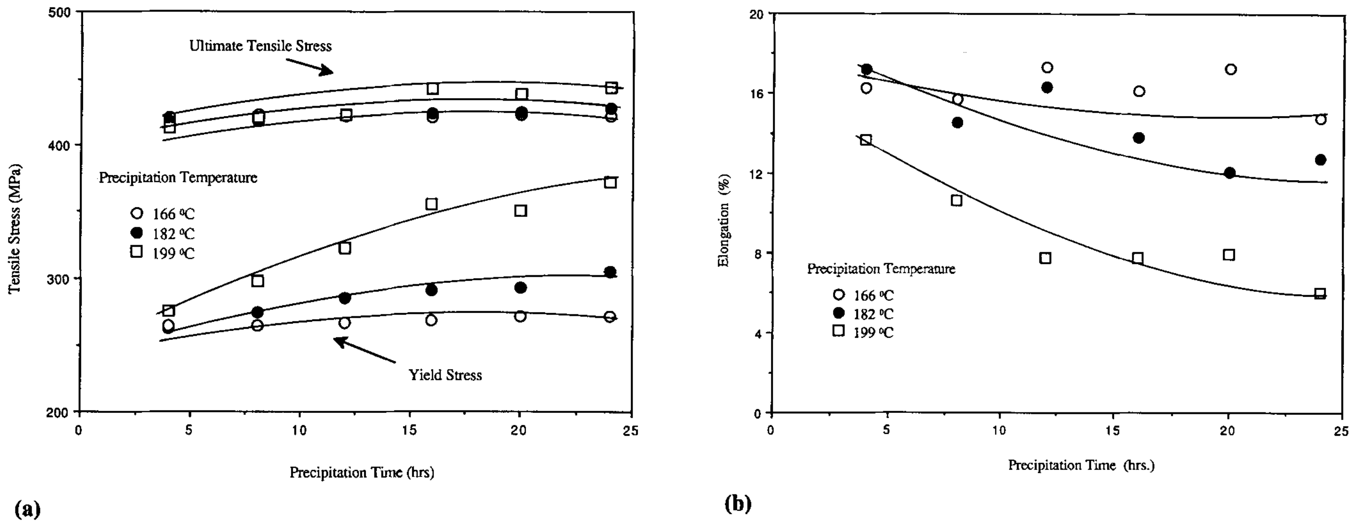

Fig. 1 Effect of aging treatment on the T6 tensile properties of 2618 (Cu-rich) alloy. (a) Ultimate tensile strength and yield strength. (b) Ductility

Table 1 Chemical compositions of the alloys used in this study

Alloy	Composition, wt%										
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	B	Ca
2618	0.24	1.30	2.52	0.004	1.46	0.02	1.14	0.01	0.07	0.003	0.002
2618 (Cu-rich)	0.095	1.35	3.01	0.21	1.61	0.0	1.30	0.02	0.06	0.009	0.005

Table 2 Tensile properties of 2618 alloys

Temperature, °C	Alloy	Yield stress, MPa	UTS, MPa	Elongation, %
21	2618 T6(a)	361	446	8.4
	2618 (Cu-rich) T6(a)	378	450	7.8
	Wrought 2618 (Ref 9)	372	440	10.0
149	2618 T6(a)	361	404	10.3
	2618 (Cu-rich) T6(a)	334	381	10.0
	Wrought 2618 (Ref 9)	303	345	14.0

(a) T6: 529 °C solution anneal for 1 h and 199 °C for 20 h age

of the new 2618 (Cu-rich) aluminum alloy, the specimens were treated at one of the three different aging temperatures—166, 182, and 199 °C (the latter being a standard [Ref 5] temperature)—removed from the furnace after 4, 8, 12, 16, 20, or 24 h for each temperature, and air cooled to ambient temperature.

Figure 1 illustrates the T6 tensile test results of 2618 (Cu-rich) aluminum alloy under the three different aging temperatures and various aging times. Each value is the average of three tensile tests. Yield stress and ultimate stress increase, but ductility decreases as aging time increases. The strength and ductility change only slightly at the relatively low aging temperature of 166 °C. For a fixed aging time, the lower aging temperatures are associated with lower strengths and higher ductilities. The yield stress increases more than the ultimate tensile stress (e.g., the yield stress increases up to 15% at 182 °C and 35% at 199 °C, whereas the ultimate tensile stress increases only 2.5% at 182 °C and 8% at 199 °C as the aging times increase from 4 to 24 h). This result is consistent with studies of most 2*xxx* alloys (Ref 5-8).

Figure 1 also shows that the rate of increase in strength decreases between 16 and 24 h, indicating that maximum age hardening is being approached at these temperatures; overaging, however, is not observed. Optimum properties appear to be achieved at 199 °C for 20 h.

Table 2 compares the ambient and elevated-temperature properties of 2618 and 2618 (Cu-rich) at 149 °C using the optimized T6 treatment. Interestingly, the properties of 2618 (Cu-rich) are clearly *not* superior to traditional 2618. The values in Table 2 are an average of typically five tests. Data from these tests compare favorably with typical wrought properties for alloy 2618 given in Ref 9.

4. Conclusions

Adding extra amounts (0.2 to 0.5 wt%) of manganese and copper to alloy 2618 appears to increase the ambient-temperature T6 strength (especially the yield stress), but to slightly decrease ductility. The properties of traditional 2618 appear superior to the 2618 (Cu-rich) modified alloy at elevated temperature (149 °C), in contrast to other reports in the literature.

Aging temperatures lower than the standard value doe not improve the T6 properties over the 2618 (Cu-rich) alloy. Overall, the alloying of 2618 with extra copper and manganese does not appear to improve the tensile properties.

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