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Research Article

A Study of the Quench Sensitivity of 6061-T6 and 6069-T6 Aluminum Alloys

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The purpose of this study is to investigate the quench sensitivity of the mechanical properties of 6061 and 6069 aluminum alloys. The relationship between mechanical properties and quench delay time at various temperatures between 200–500°C was determined. It was concluded that the 6069-T6 was somewhat more quench sensitive than 6061, which may be consistent with the composition difference. This study also provides increased data on the quench sensitivity of the traditional alloy, 6061-T6.

1. Introduction

The mechanical properties of the relatively new 6xxx series alloy, 6069, were extensively discussed by the authors in [1–3]. The objective of this study was to determine the quench sensitivity of the new alloy 6069, especially as compared to the traditional 6061 alloy. That is, on rapidly cooling from the solution annealing temperature by quenching, any reduction in the cooling rate translates to longer times at intermediate temperatures where "uncontrolled" nucleation can occur and lead to lower T6 properties subsequent to aging. The mechanical properties response varies for a given, decreased, cooling rate depending on the alloy composition. Gullotti et al. [4] and others [5, 6] found that for the 6xxx alloys, those that had higher Mg, Si, Mn, Cr, and Zr were more likely to have relatively accelerated Mg_2Si precipitation leading to diminished T6 mechanical properties. Mondolfo [7] reported that Cu increases quench sensitivity, but Zoller et al. [5] found that Cu actually alleviates quench sensitivity somewhat. The alloy 6069 has been demonstrated to have superior T6 fatigue, tensile, and fracture toughness properties over 6061 [1, 2]. However, the improved properties are provided in association with alloy additions Mg, Si, Cr (and Cu for which the effect is uncertain) which may render 6069 more quench sensitive. Thus, this investigation assessed the quench sensitivity of 6061 and 6069, both prepared identically from extruded air slip direct chill casting (Air-Slipor'ASDC). Both were solution treated at the same temperature and "quenched" into salt baths at various temperatures for various times followed by a water quench. The times at temperatures for a fixed deterioration (e.g., 5%) of T6 tensile (yield stress and ultimate tensile stress) were determined.

2. Experimental Methods

The 6061 and 6069 aluminum alloys used in this study were extruded at Anodizing Inc. (Portland, Ore) from Air-Slip Direct Chill Cast (ASDC) ingots provided by Northwest Aluminum Company. 6061 ingot was extruded into solid flat bar with a thickness of 9.53 mm and width of 38.1 mm. 6069 (228.6 mm diameter) ingot was extruded into solid round bar of 38.1 mm in diameter. The 6061 and 6069 ingots were pre heat treated before extrusion. The compositions of 6061 and 6069 aluminum alloys used in this study as well as 6061 sheet of an earlier (comparison) study from [4] are listed in Table 1.

The tensile specimens of 6061 and 6069 aluminum alloys of this study were cut along the extrusion direction and machined into round specimens with 2.54 mm diameter and 10.2 mm gage length. The specimens were solution heat-treated at 566°C for 1.5 hours with an accuracy of 1.5°C.

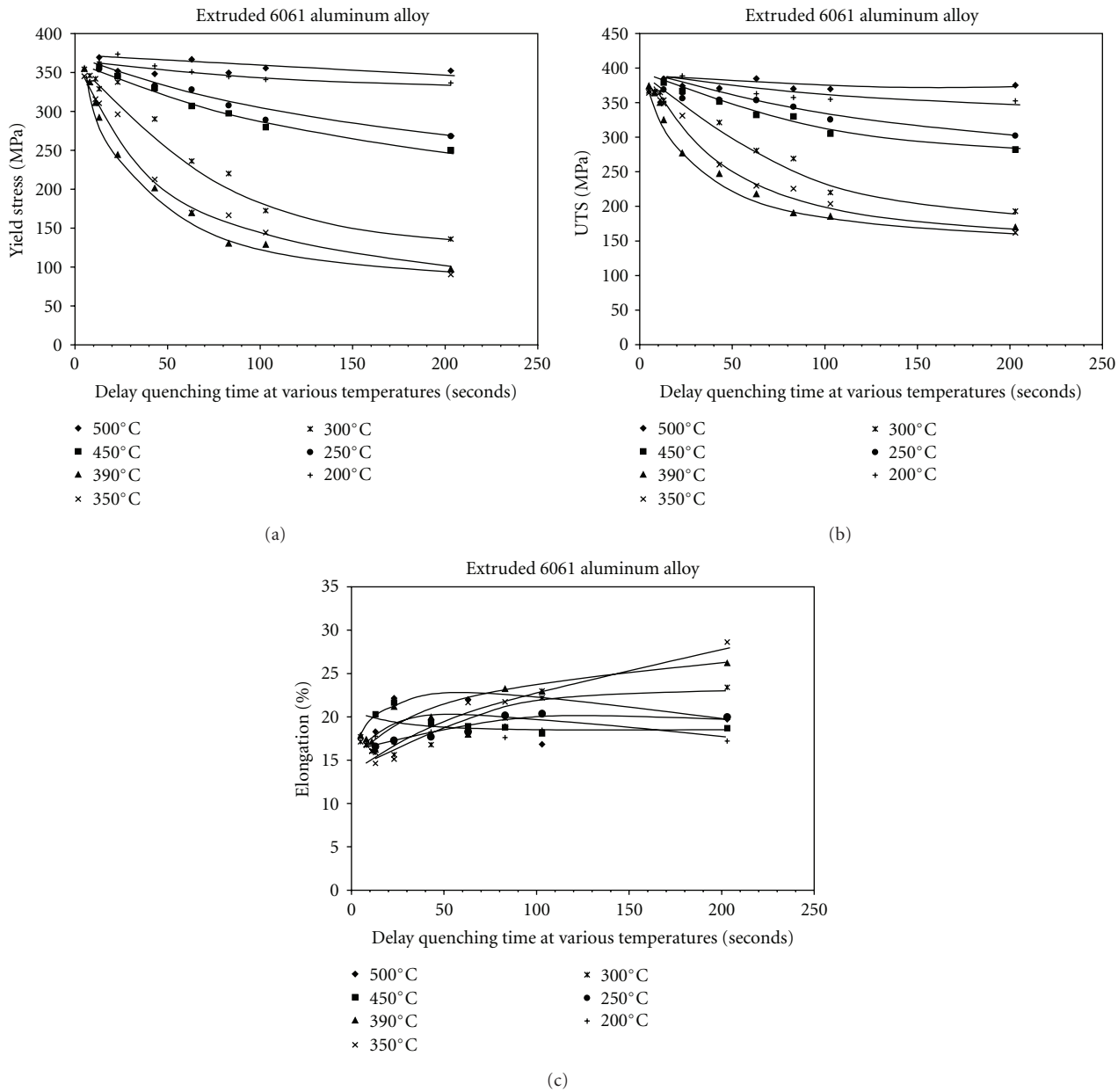

Figure 1: The effect of delayed quenching on the 6061-T6 (a) yield strength, (b) UTS, and (c) elongation.

Table 1: The composition of extruded 6061 and 6069 alloys used in this study as well as 6061 sheet [4].

	Composition, %wt.									
	Si	Fe	Cu	Mn	Mg	Cr	Ti	V	Ga	Zn
6061 (this study)	0.65	0.23	0.23	0.02	0.89	0.06	0.024	0.01	0.01	—
6069 (this study)	0.88	0.30	0.71	—	1.4	0.22	0.032	0.01	0.02	0.01
6061 (from [4])	0.66	0.38	0.23	0.12	0.98	0.12	0.014	—	—	0.07

The specimens were then quenched into a molten salt bath at various temperatures (200–500°C) for various times (3–200 seconds) and then water quenched to ambient tem-perature. The (molar) composition of molten salt used in the temperature range of 300 to 500°C was 18.3% KCl, 50.4% LiCl, 8% NaCl, and 23.3% RbCl. The (molar) composition of molten salt used in the temperature range of 200 to 300°C was 56% $AlCl_3$, 7% KCl, and 37% LiCl. Thermocouples were placed inside the center of a "control" specimen, and the time was recorded when the temperature of thermocouples was within

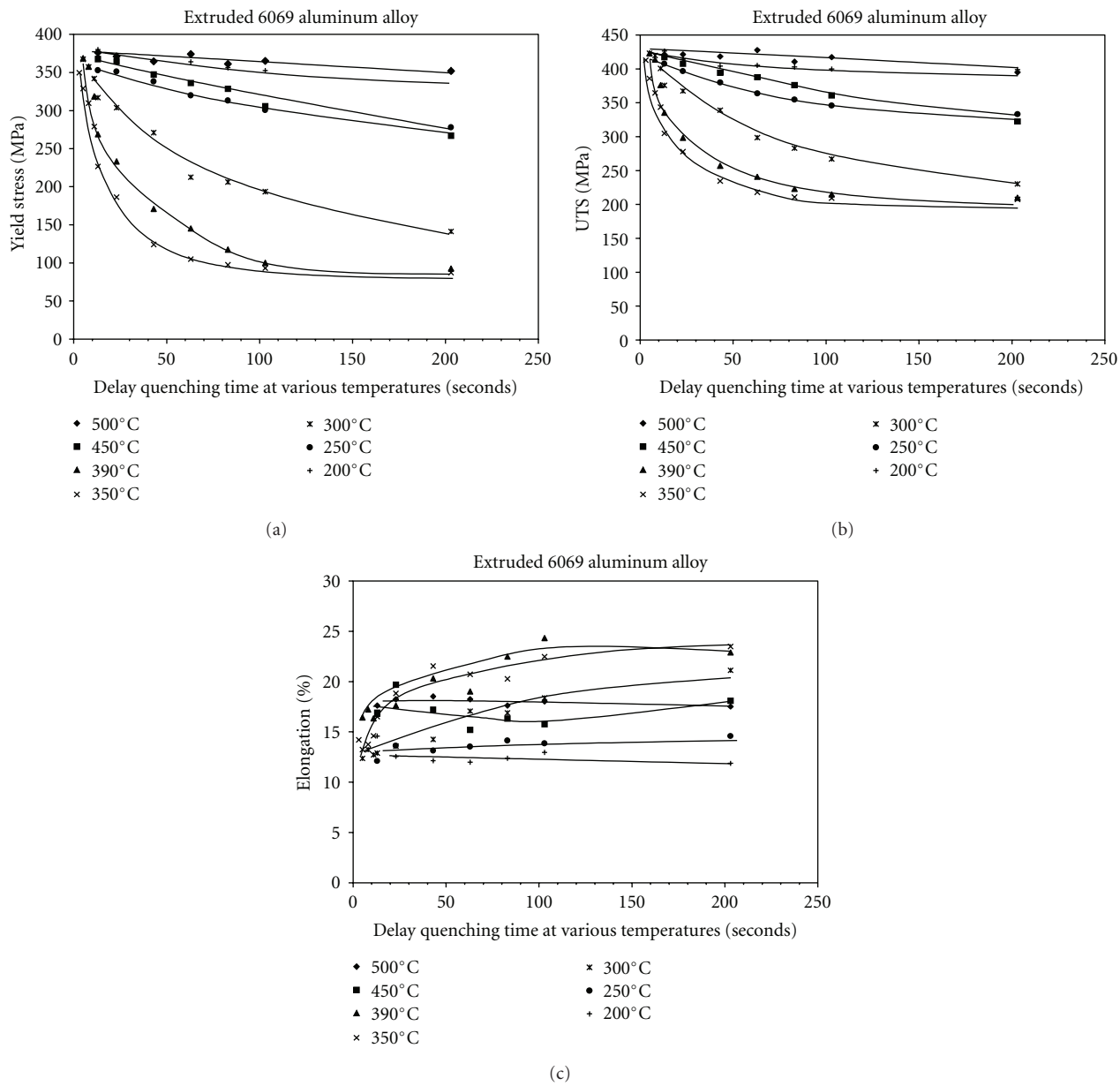

Figure 2: The effect of delayed quenching on the 6069-T6 (a) yield strength, (b) UTS, and (c) elongation.

3°C of molten salt. The precipitation (T-6) treatment for extruded 6061 and 6069 specimens was 185°C for 8 hours.

3. Results and Discussion

Figures 1 and 2 show the relationship between mechanical properties (yield stress, UTS, and elongation) of the extruded 6061-T6 and 6069-T6 alloys and the delay quenching time at various (isothermal) temperatures (200–500°C). It was found that the (0.2% offset) yield stress and UTS of both alloys decreased as the hold time increased at a given isothermal temperature. It was also observed that, at a given hold time, the strength of both alloys decreased as isothermal temperature decreased (from 500 to 350°C) and then increased again (from 200 to 300°C). The largest decreases in strength (yield and UTS) are observed at isothermal temperatures of 350–390°C for extruded 6061 and 6069. It was also observed that elongation (%) slightly increased as the hold time increased, especially at isothermal temperatures of 300–390°C.

Based on these results, the time-temperature curves at 95% of maximum (small decrease in mechanical behavior) yield stress and UTS for extruded 6061-T6 and 6069-T6 aluminum alloys are illustrated in Figure 3. The data of 95% of maximum strength were sometimes interpolated from the strength data. It is observed that extruded 6061 allows more time for a decrease to 95% of maximum strength than extruded 6069 at a given isothermal temperature. This

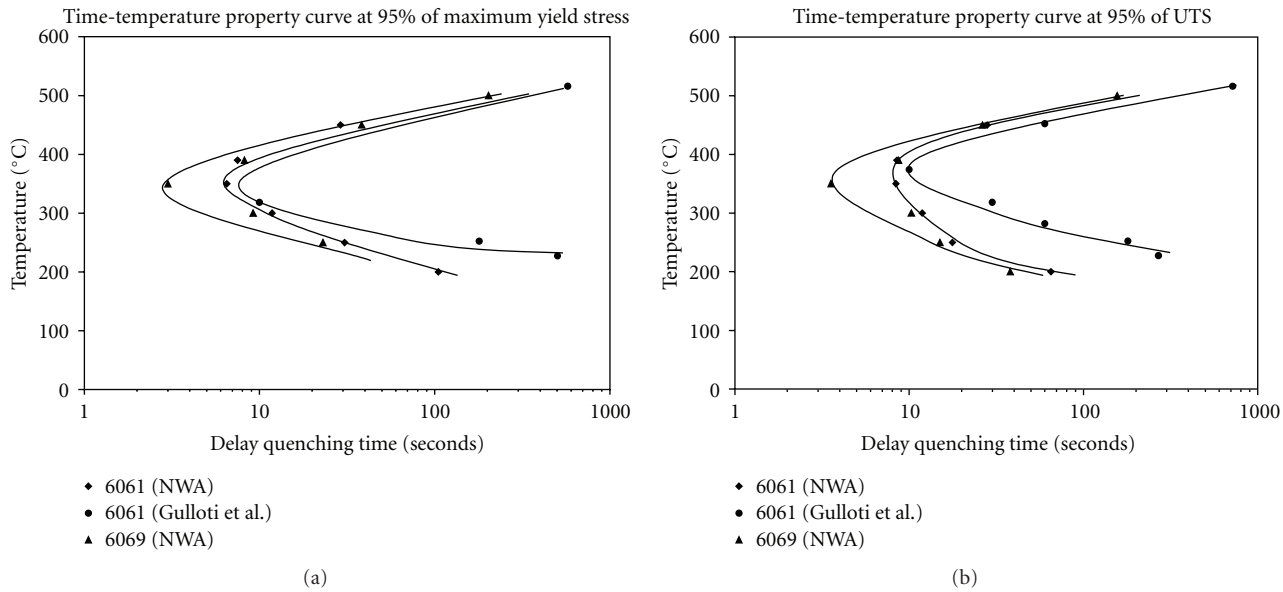

Figure 3: The time-temperature (a) yield, (b) UTS behavior of 6061-T6 and 6069-T6. Earlier work [4] on the 6061-T6 is also indicated.

indicates that mechanical properties of extruded 6069 are more sensitive to quench rate than those of extruded 6061. This is consistent with the higher levels of Mg, Si, Cu, and Cr reported in Table 1. The figure also reports other data for 6061 [4, 5]. The increased amount of magnesium, silicon and chromium may increase Mg_2Si concentration and nucleation rate, which is consistent with other studies [4]. The discrepancy between the 6061-T6 of this and the earlier study by Gullotti et al. [4], particularly at low temperatures, is not fully understood. It is curious that the 6061 of the present study shows more quench sensitivity, since the Cr, Mg, Mn, Si are all (slightly) *lower*, than that of the Gullotti study. However, a study by Camero et al. [8] of alloy 6063 shows that vanadium accelerates the precipitation kinetics of the β' and β' phases. The absences of V in [4] may explain this discrepancy. Additionally, the ratio of Mg to Si was 1.34 in this study and 1.48 in [4], with the stoichiometric ratio being Mg/Si = 2 as the β precipitates are Mg_2Si. The resulting greater excess of Si in the current study may be favorable to the formation of β' phases due to the presence of heterogeneous nucleation sites [9, 10]. Thus the increased quench sensitivity of this study, may be explained by the higher level of excess Si and the presence of vanadium. It should also be noted that the solution treatment temperature used in the present study for 6061 was 37°C higher than the standard suggested temperature, resulting in higher initial properties.

4. Conclusions

(1) 6061 and 6069 extruded aluminum alloys were solution-treated and quenched to various temperatures in salt baths between 200 and 500°C for various times, followed by water quenching. The strength of extruded 6061-T6 and 6069-T6 alloys decreased as isothermal temperature decreased from 500–350°C and then increased again from 300–200°C for fixed times at temperature. The largest strength (yield and UTS) decreases occurred at isothermal temperature of 390°C and 350°C for extruded 6061-T6 and 6069-T6, respectively.

(2) Time-temperature curves at 95% of maximum yield stress and UTS for extruded 6061-T6 and 6069-T6 aluminum alloys indicate that mechanical properties of the new alloy 6069 are more sensitive to quench rate than those of the traditional alloy, 6061.

(3) The increased quenched sensitivity appears to be due to increased amount of magnesium, silicon, and chromium (and possibly Cu), which may increase the Mg_2Si concentration and nucleation rate.

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