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Aluminum Alloy (6061-O, 5052-O, and 1100) Dissolution Rate Testing

Summary

The dissolution rates of two aluminum alloys (6061-O and 5052-O) were tested to determine which would be able to replace an aluminum alloy that was difficult to procure (6063-T6). The findings of this memo conclude that the dissolution rates of 6061-O and 5052-O are two orders of magnitude slower than 6063-T6. Therefore, it is unlikely that 6061-O and 5052-O would be adequate replacements for 6063-T6 based on similar dissolution rates in a Hg-catalyzed, nitric acid solution. Another area of interest was how temperature variation would influence the dissolution rate of an aluminum alloy (specifically 1100). This separate study found that the dissolution rate of the aluminum alloy below 86 °C was approximately 0.0014 % of the dissolution rate at 94.5 °C and above. Therefore, at or below 86 °C the dissolution rate reduces significantly which translates to much longer dissolution times.

Introduction

Aluminum alloys are proposed for the fabrication of Multi-Purpose (MP) cans for use during the dissolution of nuclear materials in H-Canyon dissolvers. Previous guidance indicated that the aluminum alloy Al-6063 with a T6 temper, otherwise written as 6063-T6, should be used for the fabrication of the cans [1]. The dissolution rate of 6063-T6 is -2.13 x 10^{-2} $\frac{\mathrm{g}}{\mathrm{cm^2 \cdot min}}$ and would dissolve quickly using an H-Canyon mercury-catalyzed, nitric acid dissolution flowsheet. However, the necessary forms (e.g., plate) of this specific aluminum alloy cannot be easily procured. Several aluminum alloys (6061-O, 5052-O, 6951-O, and 6951-T6) were recommended as possible replacements [2]. Due to issues with procurement, the aluminum alloys 6951-O and 6951-T6 were not studied. Therefore, this report documents the dissolution rate of the annealed aluminum alloys (6061-O and 5052-O) using a typical H-Canyon spent nuclear fuel aluminum dissolution flowsheet and the use of the alloys as possible replacements for 6063-T6.

Aluminum alloys with different heat treatments and additional impurities can have varied dissolution rates. For instance, the dissolution rate of tempered 6061-T6 (-1.27 x 10^{-3} $\frac{g}{cm^2 \cdot min}$) is about 50 times slower than the non-tempered aluminum alloy 1100 (-6.41 x 10^{-2} $\frac{g}{cm^2 \cdot min}$) that has significantly less metal impurities. This study subsequently found that the rapid dissolution of the aluminum alloy 1100 only occurs near and at boiling temperatures. Since 6061-O is annealed with little to no temper, it was uncertain if 6061-O would dissolve slower or faster than 6061-T6. Also, the other aluminum alloy with a different metal composition, 5052-O, was also tested as a possible replacement for 6061-T6.

Experimental

The measured dimensions for the length, width, and thickness of the aluminum coupon were taken as shown in Figure 1. The surface area of the aluminum coupon was then calculated by using Equation 1 [3]. Multiple measurements were taken to ascertain any irregular dissolution of the aluminum coupon. However, the near uniform dissolution of the coupon resulted in a measurement uncertainty of less than 0.7% for measurements taken for the overall surface area.

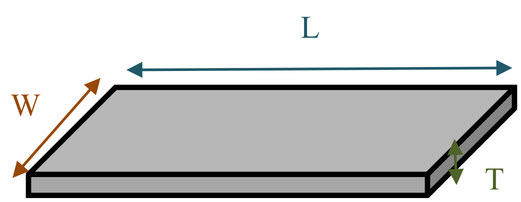

Figure 1: Dimensions of Aluminum Coupon: L-length, W-width, and T-thickness

$$SA = 2 \cdot (L \cdot W + W \cdot T + L \cdot T) \quad (1)$$

The aluminum 6061-O and 5052-O coupons with a 600 grit blast finish were supplied by AG Scientific Glass. Coupons were cut such that the final coupon geometry was 1.5” x 0.5” x 1/16” to allow full immersion in the reactor vessel. Dissolution of the aluminum alloy coupons was done using the existing

H-Canyon flowsheet conditions [1, 3]. The nitric acid solution contained 7 M nitric acid with 0.002 M Hg. The reactor vessel, off gas condenser, and glass basket were made from borosilicate glass by the SRNL glass shop. The configuration of the reactor vessel is shown in Figure 2.

Figure 2: Apparatus Diagram for Aluminum Dissolution

One port of the reactor was used to allow entry of a thermocouple to control the constant application of heat. Another port was connected to a condenser to help reclaim nitric acid solution components. The nitric acid solution reached boiling and constant vigorous mixing before the aluminum alloy coupons were lowered into the solution. The coupons were held in a perforated glass basket to allow uniform fluid flow while maintaining ease of removal for taking measurements.

<u>Results and Discussion</u>

The dissolution of the aluminum alloy coupon masses divided by the surface area as a function of time are plotted in Figure 3. The aluminum coupons took longer than expected to dissolve. The dissolution rate of the 5052-O alloy was -3.12 x $10^{-4}\ \frac{\mathrm{g}}{\mathrm{cm^2 \cdot min}}$ (standard deviation of 3 x 10^{-6}) and the dissolution rate of the 6061-O alloy was -4.44 x $10^{-4}\ \frac{\mathrm{g}}{\mathrm{cm^2 \cdot min}}$ (standard deviation of 9 x 10^{-6}). Interestingly, the dissolution rate of 6061-O and 6061-T6 are only different by a factor of 2.8, whereas the Al-1100 and 6061-O are two orders of magnitude different [1]. This observation indicates that temper does not impact the dissolution rate as much as metal impurities. A comparison of the purity, alloying elements, and Hg-catalyzed nitric acid dissolution rates of aluminum 5052-O, 6061-O, 6061-T6, 6063-T6, and 1100 alloys are provided in Table 1. As noted above, the 5052-O alloy had a lower dissolution rate than the 6061-O alloy; although, the rates only differed by approximately 30%. In either case, the dissolution rates of 6061-O and 5052-O alloys are about two orders of magnitude slower than the 6063-T6 alloy and would not provide materials of construction for MP cans which dissolve at rates similar to the 6063-T6 alloy.

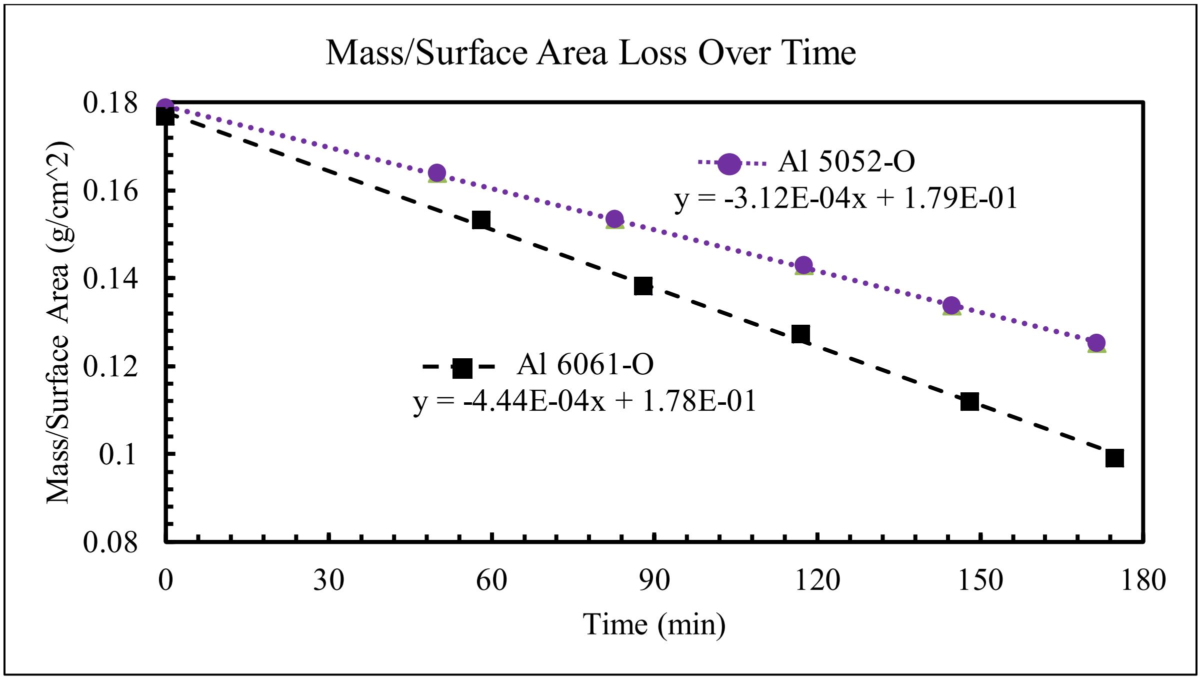

Figure 3: Dissolution Rate ($\frac{g}{cm^2 \cdot min}$) of Aluminum Alloys (5052-O and 6061-O)

Table 1: Properties and Dissolution Rate of Aluminum Alloys [4]

Al Alloy	**Purity (%)**	**Alloying Elements/Impurities**	**Dissolution Rate** $\frac{g}{cm^2 \cdot min}$
5052-O	95.75 - 96.55	Si, Fe, Cu, Mn, Mg, Cr, Zn	-3.12×10^{-4}
6061-O	95.85 - 97.21	Si, Fe, Cu, Mn, Mg, Cr, Zn, Ti	-4.44×10^{-4}
6061-T6	95.85 - 97.21	Si, Fe, Cu, Mn, Mg, Cr, Zn, Ti	-1.27×10^{-3}
6063-T6	97.50 - 98.35	Si, Fe, Cu, Mn, Mg, Cr, Zn, Ti	-2.13×10^{-2}
1100	> 99	Cu, Fe, Mn, Si, Zn	-6.41×10^{-2}

The dissolution at various temperatures of the aluminum alloy coupon mass divided by the surface area as a function of time are plotted in Figures 4 and 5. Figure 4 shows the dissolution rate of 1100 at 80 and 86 °C. The average dissolution rate of the 1110 alloy before boiling (average of 80 and 86 °C) is -7.2 x 10^{-5} ± 3.7E-5 $\frac{\mathrm{g}}{\mathrm{cm^2 \cdot min}}$. However, once the solution reaches 94.5 °C (Figure 5), the dissolution rate of the aluminum coupons is essentially at the boiling rate or -5.3 x 10^{-2} ± 0.003 $\frac{\mathrm{g}}{\mathrm{cm^2 \cdot min}}$. These results indicate that the aluminum alloy will dissolve much more slowly at or below 86 °C, but once the solution reaches 94.5 °C, the aluminum alloy will dissolve at rates equivalent to being at boiling or 108 °C. It is believed that once the dissolver temperature reaches 94.5 °C that the activation energy needed to sustain the Hg-catalyzed surface reaction has been reached.

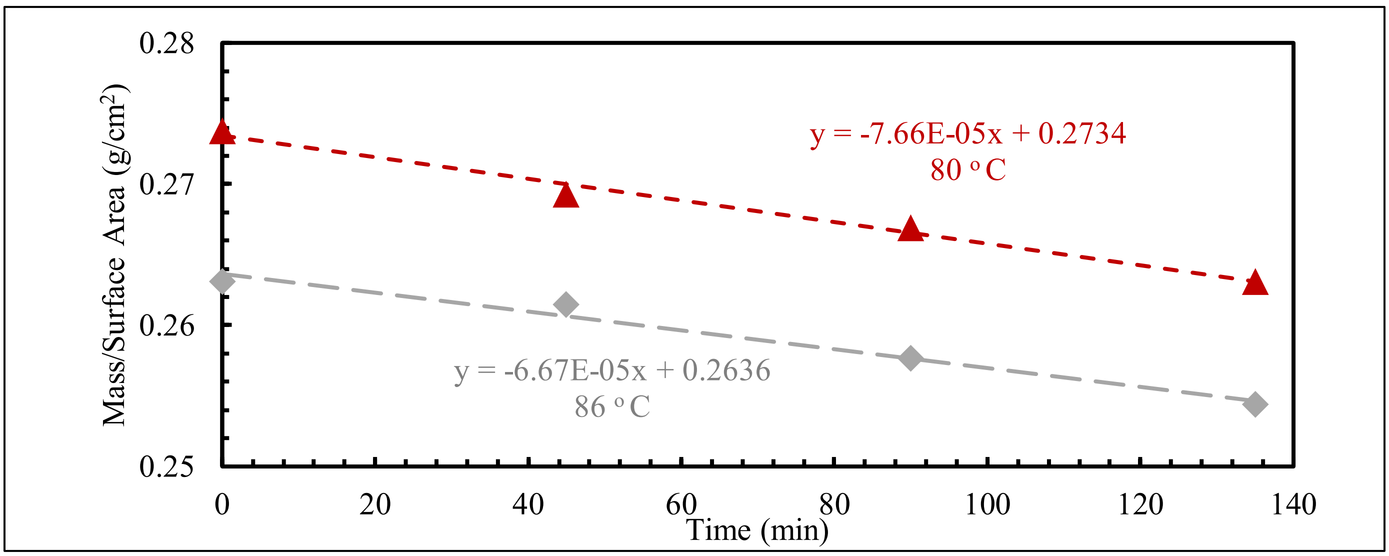

Figure 4: Dissolution Rate ($\frac{\mathrm{g}}{\mathrm{cm^2 \cdot min}}$) of Aluminum Alloy 1100 at 80 and 86 °C. Standard deviation of slope for 80 °C is 6 x 10^{-6} and for 86 °C is 7 x 10^{-6}.

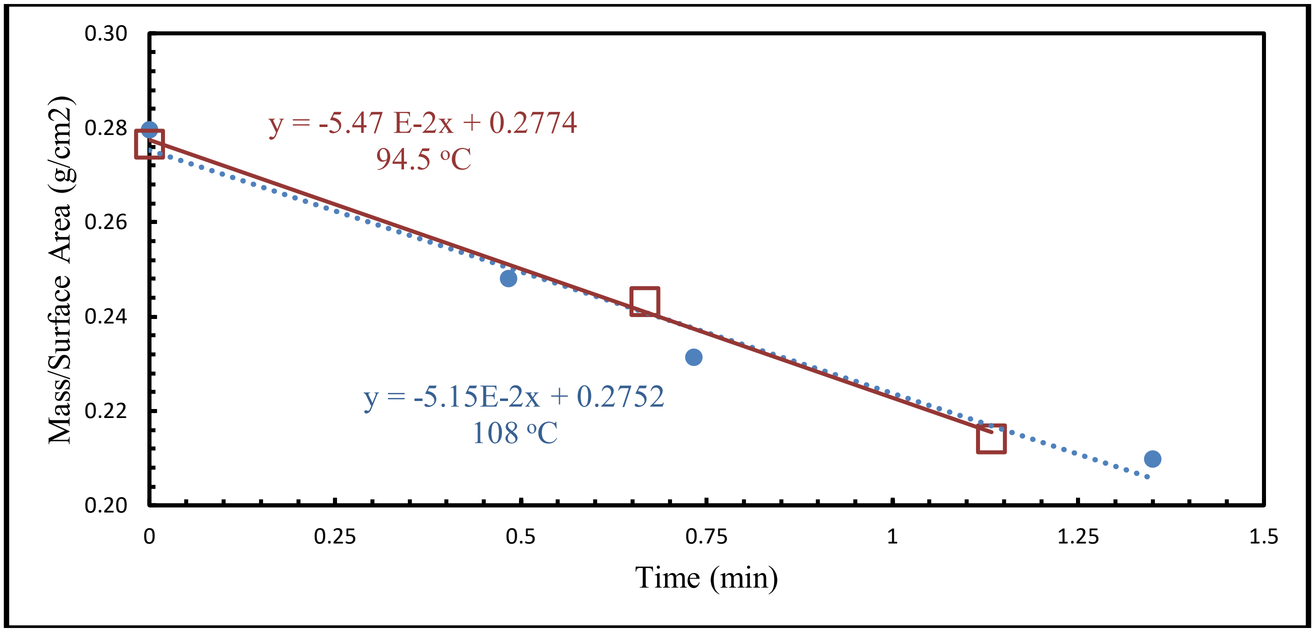

Figure 5: Dissolution Rate ($\frac{g}{cm^2 \cdot min}$) of Aluminum Alloys 1100 at 94.5 and 108 °C. Standard deviation of slope for 94.5 °C is 3.7 x 10^{-3} and for 108 °C is 6.5 x 10^{-3}.

References

[1] Daniel, W. E., Rudisill, T. S., & Mickalonis, J. I. (2020). *Evaluation of the Dissolution Behavior of L-bundle End Caps and HFIR fuel carriers* (SRNL-STI-2019-00146). Retrieved from Savannah River National Laboratory.

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[4] *International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys*. (2015). Retrieved from The Aluminium Association, Inc., Arlington, VA.

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