Standardization of Annealing of Aluminum Alloys

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Abstract: Logan Aluminum produces several aluminum alloys for beverage can applications, but differences in annealing practice can reduce process efficiency. This project investigates whether a more standardized annealing approach can be developed for AA1100, AA3104, and AA5052. Samples were cold rolled to four different reduction levels (20%, 50%, 70%, and 85%) and then annealed at 230°C and 320°C for 3 hours to evaluate how processing conditions influence microstructure and hardness. Optical microscopy and Vickers hardness were used to characterize these changes. The goal is to determine practical annealing windows that can support more efficient and consistent processing across the three alloys.

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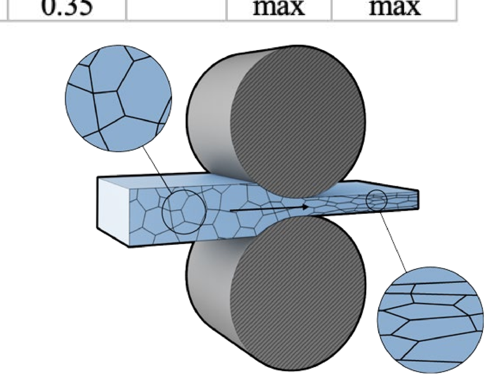
Background

Alloys: AA1100, AA3104, and AA5052 are wrought aluminum alloys from the 1xxx, 3xxx, and 5xxx series, respectively. AA1100 is a commercially pure aluminum alloy, while AA3104 and AA5052 are alloyed primarily with Mn and Mg, respectively [1]. These alloys are commonly used in beverage can applications because they provide a useful combination of corrosion resistance, strength, and formability [2]. Since they are non-heat-treatable alloys, they rely on strain hardening processes to achieve the desired mechanical properties [2].

Table 1. Composition of Investigated Alloys [1]

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ti	Zn	Other (Total)
1100	0.95 Fe + Si max		0.05-0.20	0.05 max	…	…	…	0.10 max	0.15 max
3104	0.60 max	0.80 max	0.05 - 0.25	0.80 - 1.4	0.80-1.3	...	0.10 max	0.75 max	0.15 max
5052	0.25 max	0.40 max	0.10 max	0.10 max	2.2 - 2.8	0.15 - 0.35	…	0.10 max	0.15 max

Cold Rolling: Cold rolling strengthens through strain hardening. As thickness is reduced, grains become elongated in the rolling direction and dislocation density increases, raising hardness and strength but reduces ductility [3]. This deformation introduces internal stresses into the material, making it less suitable for further forming if left unannealed [3].



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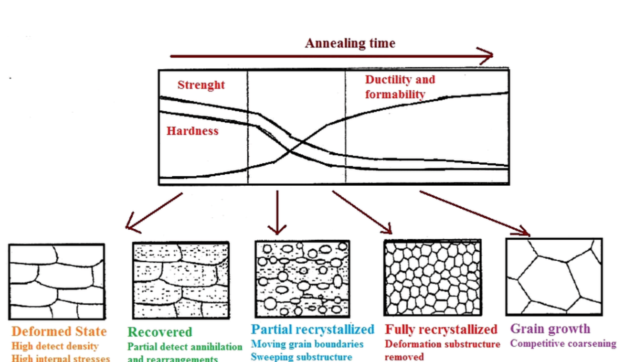

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Annealing: Annealing is done to soften the material and restore ductility. During annealing, the alloy undergoes recovery and recrystallization, which reduces internal stress and replaces the deformed microstructure through growth of strain-free grains [3]. These changes lower hardness and strength relative to the cold-worked state while improving formability [3].

The combination of cold rolling and annealing is therefore critical for controlling the balance between strength, hardness, ductility, and microstructure in aluminum sheet.

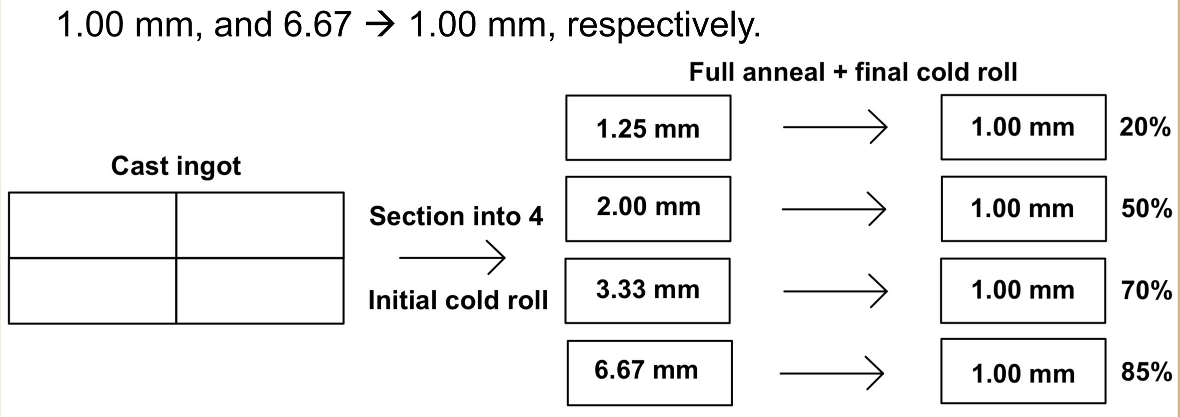
Experimental Setup

Sample Preparation:

- Scrap AA1100, AA3104, and AA5052 supplied by Logan Aluminum was melted and cast into ingots.
- Each ingot was sectioned into four sub-ingots and cold rolled to initial thicknesses of 1.25, 2.00, 3.33, and 6.67 mm.
- The sub-ingots were then fully annealed to reset the microstructure before cold rolling to strips with a final thickness of 1.00 mm.

Cold Rolling:

- Final cold work of 20%, 50%, 70%, and 85% were produced from thickness reductions of 1.25 → 1.00 mm, 2.00 → 1.00 mm, 3.33 → 1.00 mm, and 6.67 → 1.00 mm, respectively.



Hardness Specimens & Annealing:

- Two 2cm by 2cm specimens were cut from each cold worked strip and Vickers hardness measurements were taken.
- Specimens then underwent annealing treatments in a furnace for 3 hours at a temperature of either 230°C or 320°C, then were measured for hardness using Vickers hardness testing.

Hardness Characterization:

- Vickers hardness measurements were performed at HV0.5, corresponding to a 0.5 kg load with a 10 second dwell time.
- Three indents were taken on each sample, and the average hardness value was used for analysis.
- Vickers hardness values were converted to MPa (HV = 9.807 MPa).
- These values were converted to estimated yield strength using a correlation based on Tabor's approximation, $H \approx 3\sigma_y$ [4].

Hardness Results

Table 2. Average Vickers hardness values for AA1100

Cold Work (%)	No Anneal	230°C	320°C
85	48.4	47.3	27.2
70	86.6	85.1	72.0
50	45.6	43.6	25.2
20	74.9	69.7	65.6

Table 3. Average Vickers hardness values for AA3104

Cold Work (%)	No Anneal	230°C	320°C
85	86.0	85.7	72.7
70	85.0	86.0	76.2
50	44.8	43.2	27.4
20	30.1	29.2	29.3

Table 4. Average Vickers hardness values for AA5052

Cold Work (%)	No Anneal	230°C	320°C
85	96.5	81.8	56.6
70	94.3	82.6	55.4
50	94.1	82.2	56.2
20	80.5	66.6	62.0

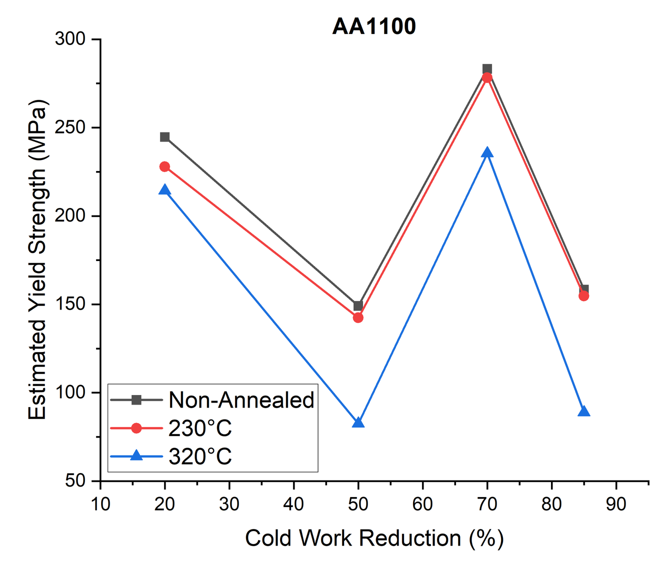


Figure 1. Estimated yield strength vs. cold work reduction for AA1100 under different annealing conditions.

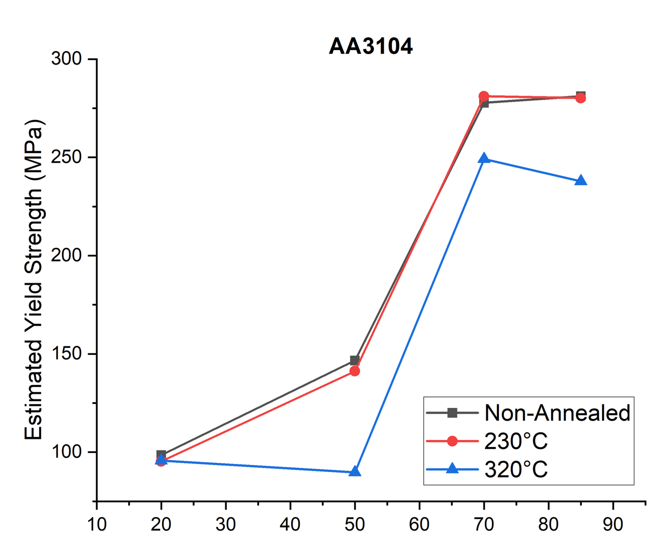


Figure 2. Estimated yield strength vs. cold work reduction for AA3104 under different annealing conditions.

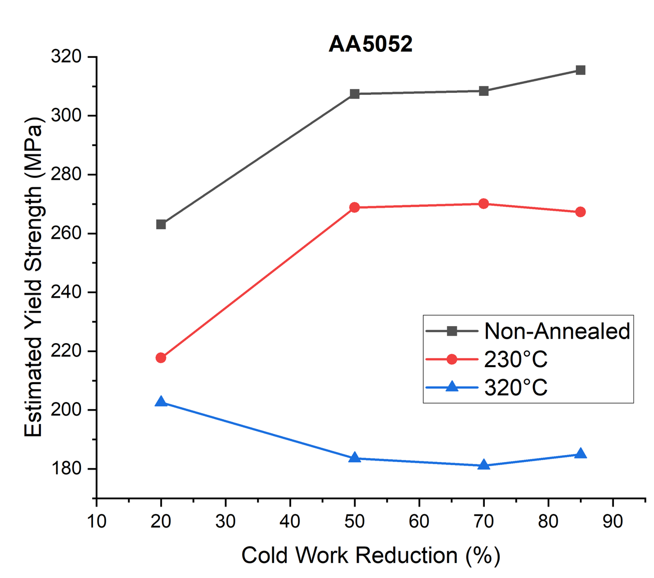


Figure 3. Estimated yield strength vs. cold work reduction for AA5052 under different annealing conditions.

General observations:

- Across all three alloys, the expected decrease in hardness with annealing and with increasing annealing temperature was observed.
- AA1100 showed the most unusual trend, with the 50% and 85% conditions having mostly expected values, whereas 20% and 70% conditions exhibited very high hardness.
- For AA3104, hardness increases rapidly with cold work, but beyond 70% reduction, there was no significant increase in hardness.
- For AA5052, this effect appeared earlier, as hardness did not change significantly with increasing cold work over 50% reduction.
- For AA1100 and AA3104, the non-annealed and 230°C conditions did not show much difference, whereas 320°C condition showed a much larger decrease in hardness.

Discussion

- Hardness trends will be used by the sponsor to estimate target yield strength and select suitable cold work and annealing conditions for each alloy.
- Comparison of the AA1100, AA3104, and AA5052 cold work reduction versus estimated yield strength curves indicates that there is a viable processing window for all three alloys.
- While alloy-specific responses vary, overlapping trends across the three alloys suggest that this common annealing processing window is viable.
- Despite identical processing, AA1100 exhibited pronounced hardening mainly due to its near-pure Al composition, thus promoting greater dislocation storage and grain refinement during rolling versus solute-strengthened AA3104/AA5052.
- This sensitivity underscores the need for processing standardization.

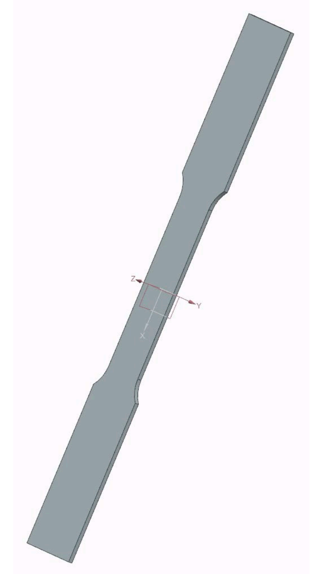
Future Work & Recommendations

Optical Microscopy:

- 2cm by 2cm specimens were cut from each alloy, cold work percentage, and annealing treatment sample material variation. Samples from as-cast ingots were also taken.
- Specimens have been mounted and polished to reveal the sample material cross section perpendicular to the rolling direction.
- Once etched, micrographs will be taken via optical microscopy, and the revealed grains and microstructures will be characterized.

Tensile Testing:

- Two sub-sized tensile dogbone specimens will be machined from the remaining material of each alloy and cold work variation.
- Each tensile specimen will undergo either the 230°C or 320°C annealing treatment for 3 hours.
- Each tensile specimen will undergo tensile testing to obtain stress-strain curves which will be used to determine the specimens' tensile strength, yield strength, and elongation properties.



Investigation Into Unexpected Results:

- Unexpected high hardness and yield strength values achieved by the 20% and 70% coldworked AA1100 sample will be studied.
- Tensile testing will confirm if yield strength values obtained through hardness testing are valid and provide other tensile properties for the sample materials.
- Optical microscopy performed will reveal grain size and boundary microstructures for explanation the cause of high-strength AA1100.

Recommendations:

- To acquire an accurate yield strength vs. cold work reduction graph and tensile properties for AA1100, the experiment and testing should be repeated.
- This experiment may also be replicated with other annealing temperatures to get a fuller range of properties due to annealing temperature.
- Annealing soak temperature is not the only variable that can be controlled as annealing soak times are a crucial variable in a material's final properties. Therefore, this experiment can be replicated to investigate the effects of varying annealing soak times.
- With the results acquired from this experiment, Logan Aluminum may be able to adjust the processing parameters needed to achieve the desired properties of each alloy so that the cold worked alloys can undergo a standardized annealing treatment.

Acknowledgement & References

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