PURDUE UNIVERSITY
School of Materials Engineering

Mitigation of Edge Cracking in Rolled Aluminum Can Stock Alloys

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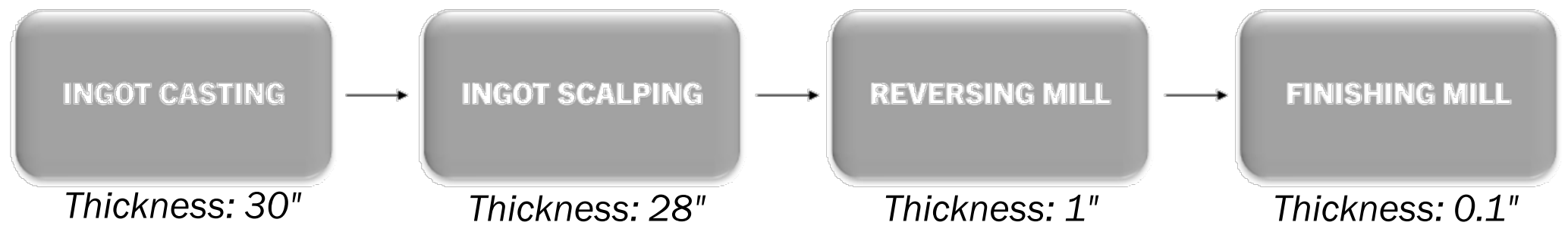
One of the biggest causes of loss for rolled metals, including at Logan Aluminum, is edge cracking – a defect formed at the edges caused by an imbalance of forces during the rolling process. This study aims to find the source of edge cracking in rolled aluminum, and attempt to mitigate it through adjustments in the rolling process. Through characterization and analysis of edge cracking throughout different stages of the process, as well as adjusting the surface finish of rolled aluminum, the amount of edge cracking observed changed. It was found that the best rolled sheet metal at the edges came from a smooth surface with no liquation layer. By reducing the amount of liquation layer on the edges, the amount of edge cracking can be reduced.

This work is sponsored by
Logan Aluminum, Russellville, KY

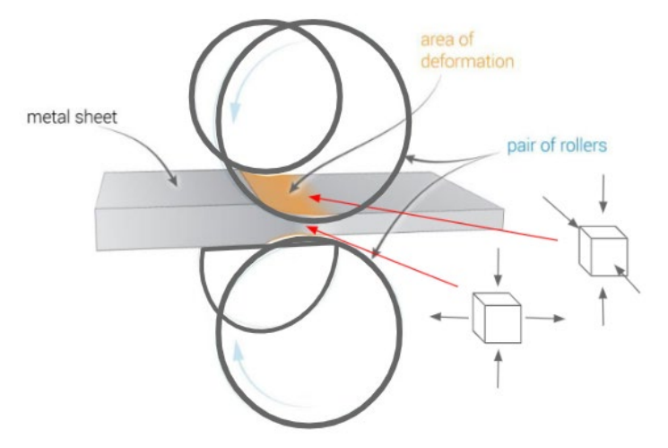
LOGAN ALUMINUM

Background

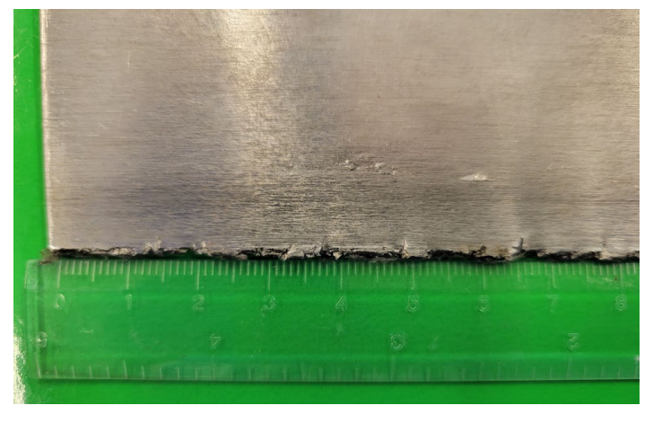


Throughout the entire process, Logan loses approximately 30% of their total yield, and of all yield loss, the second largest source comes from edge cracking. During metal sheet rolling, the edges of the sheet are more susceptible to deformation and failure due to an imbalance of forces. As the sheet undergoes more passes, more edge cracking occurs.

Due to partial remelting during casting, a layer of macrosegregation is present on the ingot. This "liquation layer" at Logan is machined off – or scalped – from the top and bottom of the ingot, but the layer is not removed from the edges, leading to an increased chance of more severe edge cracking during rolling.

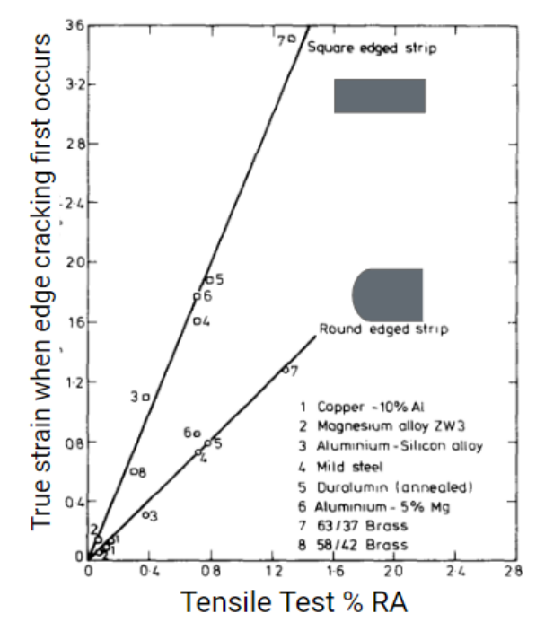


Schematic of forces at different positions under the roller.

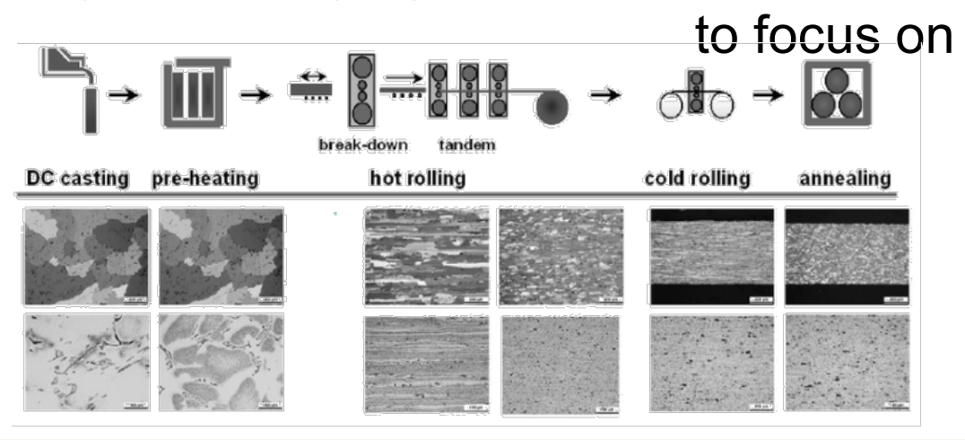


Macrograph of edge cracking in 5182 alloyed hot band.

In 1968, Latham and Cockcroft found a linear relationship cracking reduction and reduction in area. Their results can be found on the right. They found that the cracking in materials could be delayed if the edges of strips were lightly machined, since square edges meant that the material would experience compressive forces needed to prevent edge cracking.



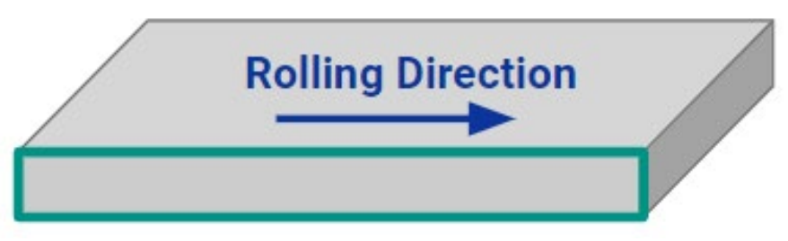
Logan Aluminum produces two alloys: 3104 - can body stock (1.1 Mn, 1.0 Mg) - and 5182 - can end stock (0.4 Mn, 4.5 Mg). In both alloys, edge cracking is present; however, it is worse in the 5182 alloy, likely due to a higher content of magnesium. During homogenization and heating of the alloys throughout the process, short range segregations are removed, and because of the higher magnesium content of the 5182 alloy, more segregations between phases are likely to occur. Therefore, we've elected to focus on the 5182 alloy.



Processing steps and resulting microstructure for 5182 (top) and 3104 (bottom) alloys.

Experimental Methods

Samples were taken from the ingot after casting (left), from the transfer bar, or right after the reversing mill (middle), and from the hot band, or right after the finishing mill (right) for different forms of experimentation.

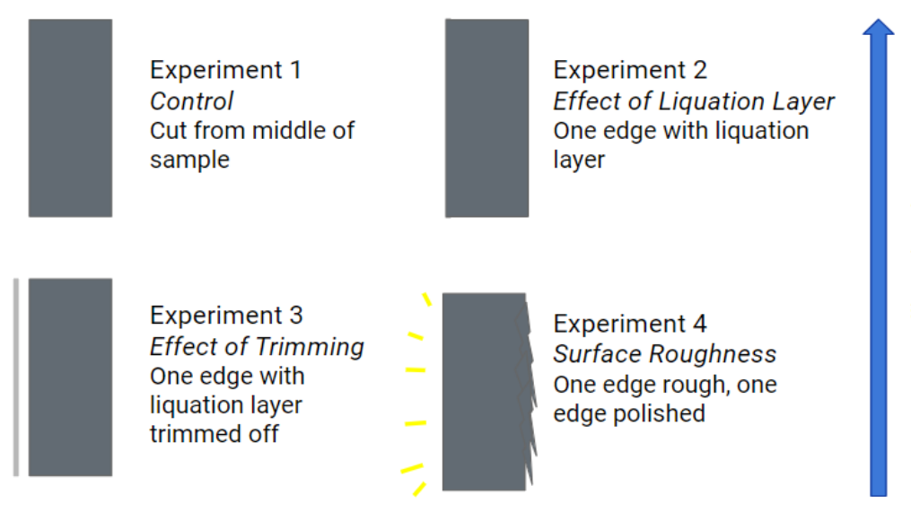


These images are looking perpendicular to the rolling direction, or into the transverse direction, as seen to the right. Here, the edges – and at points, edge cracking – can be seen.

Hardness Measurements: Hardness values were collected from the edge and center of the ingot, transfer bar, and hot band to be compared.

Metallography: Samples of the ingot, transfer bar, and hot band were mounted and polished from 200 grit to 2000 grit with colloidal silica and etched with a 10:1 water-to-NaOH ratio to examine the microstructure.

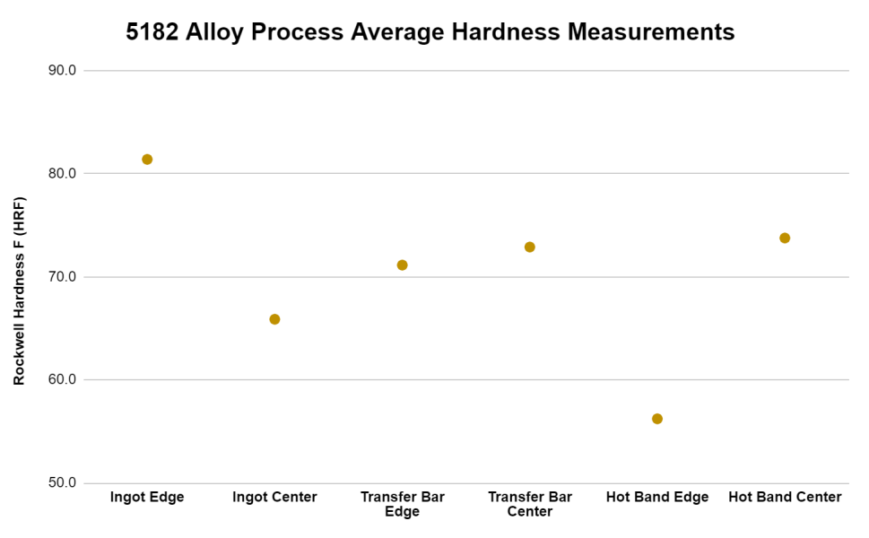
Rolling Experiments: Different experiments – seen below – were conducted on the ingot and transfer bar edges to determine the optimal rolling conditions. Ingot samples were first homogenized at 520°C for 9 hours to simulate the rolling practice at Logan. For each condition, each sample was cold rolled in a mill with 5" rollers. Samples were reduced by approximately 10% of the initial thickness every pass, and at least to 90% total reduction.



Different rolling experiments conducted.

Hardness Measurements

Hardness values of the 5182 ingot, transfer bar, and hot band were first taken in the HRF scale, at both the edge and center of the ingot. Edge values were collected within 1 cm of the edge of the sample, while center values were taken more than 5 cm from the edge.

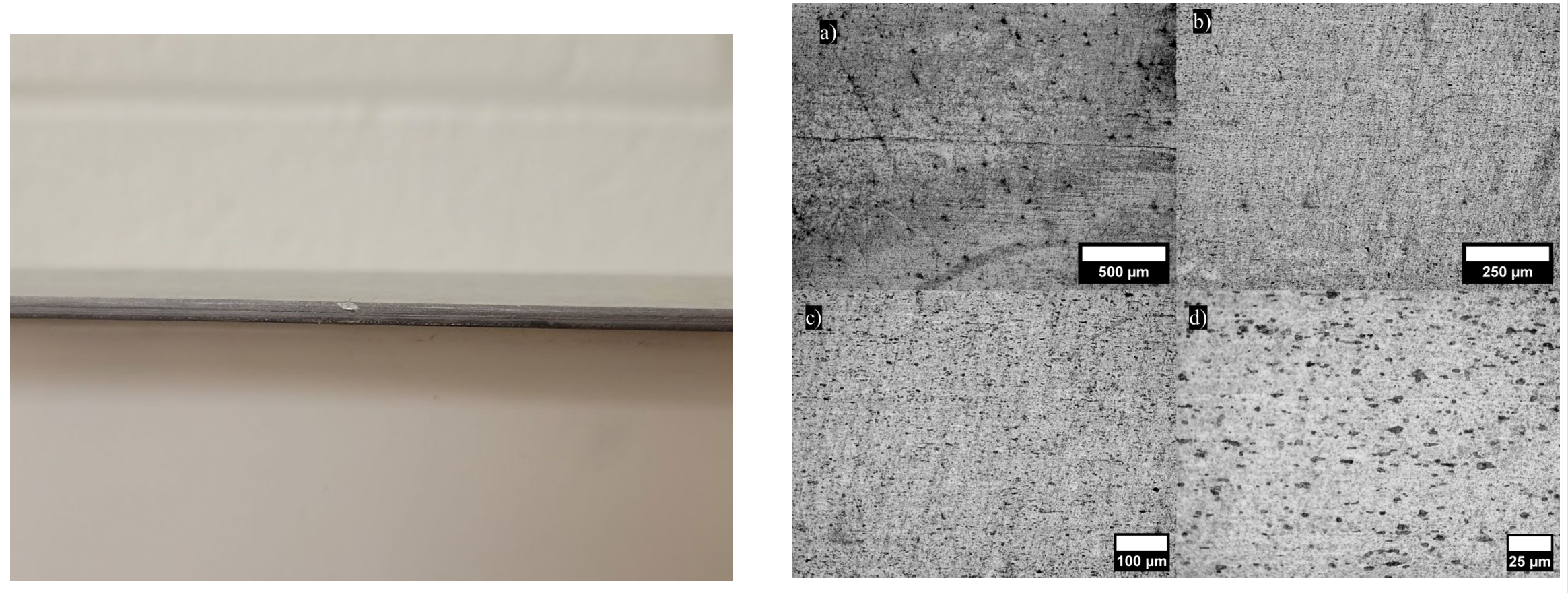


Generally, as the sample is rolled more, the hardness at the edges decreases while the hardness at the center increases. Since hardness should increase with decreasing grain size when worked, edges may not be rolled enough at Logan.

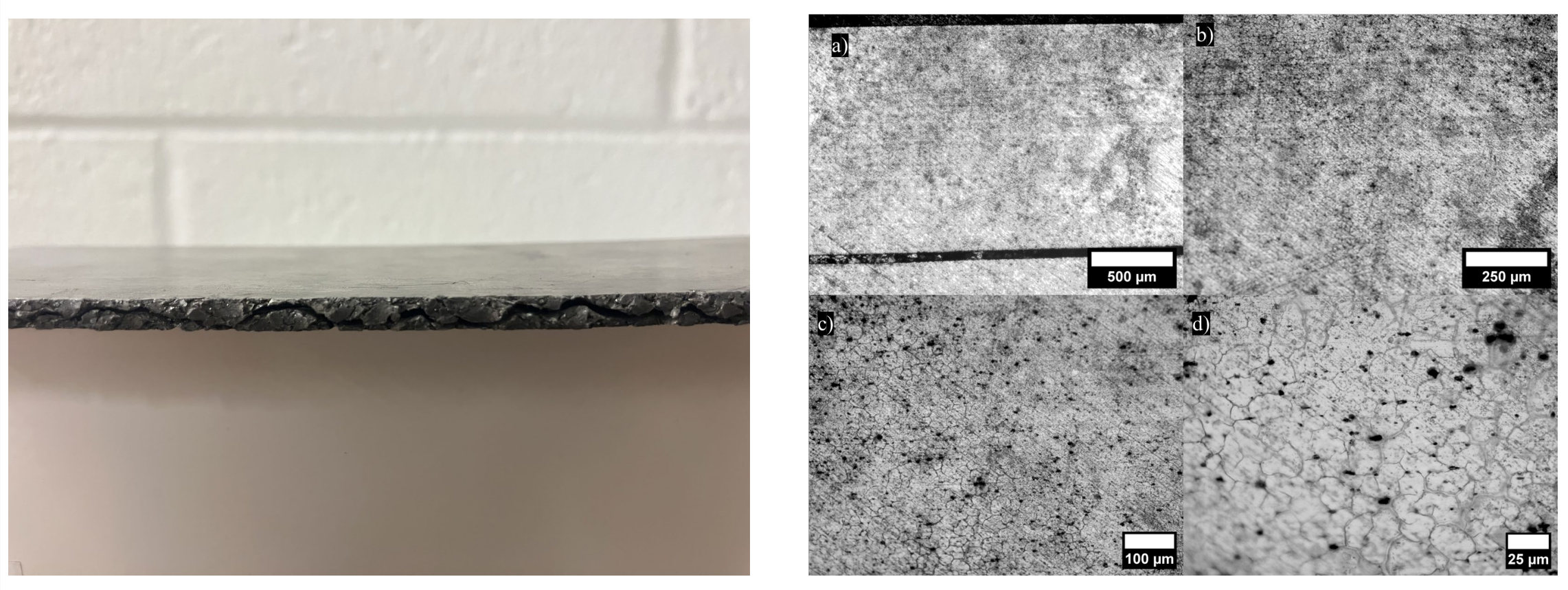
Metallography

Metallography was performed on various points of the samples received to observe microstructural and macrostructural defects and differences between samples.

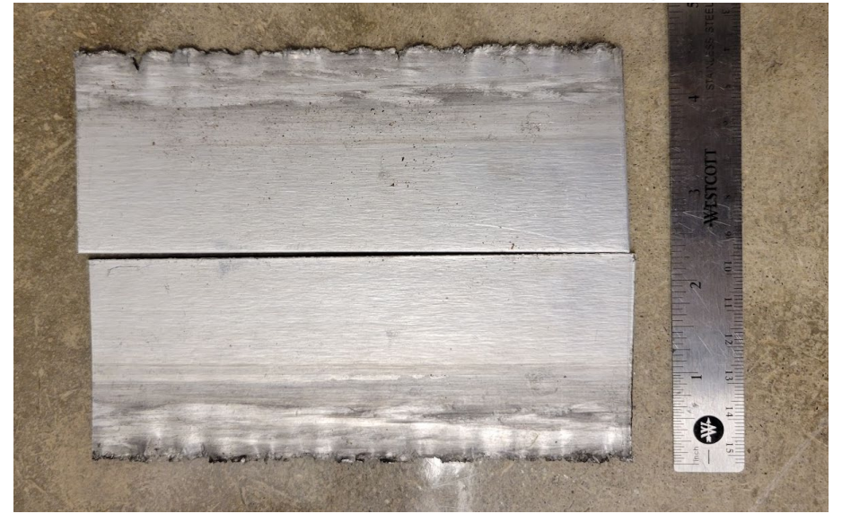
Metallography was first conducted on the hot band samples of 3104 and 5182.



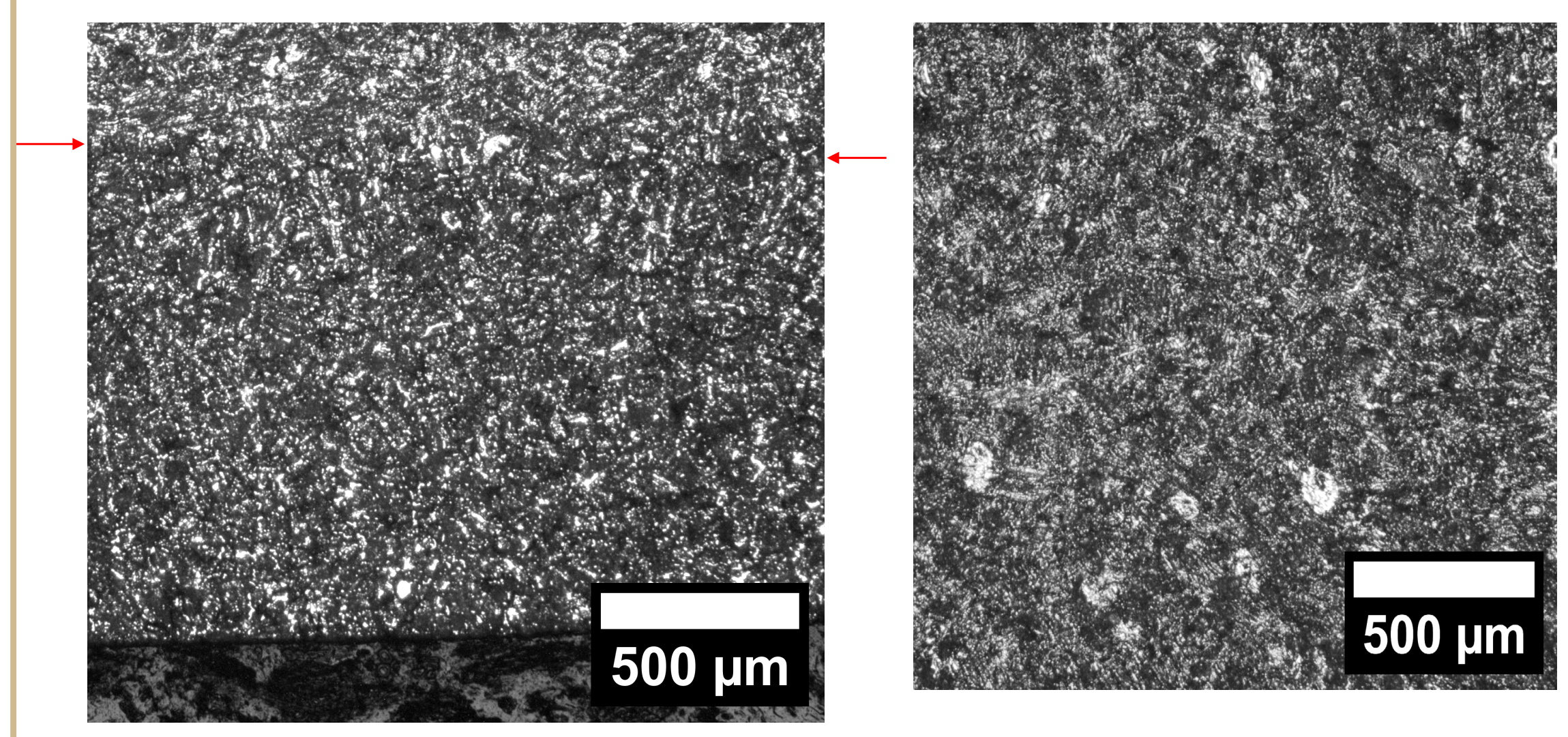
Micrographs of the cross section of 3104 hot band show a typical microstructure for this aluminum alloy. No issues or abnormalities are seen in the microstructure after all the hot rolling, even at the edges of the sample, save for some oxides likely introduced during the polishing and etching processes. Because of this, not further testing of the 3104 was done.



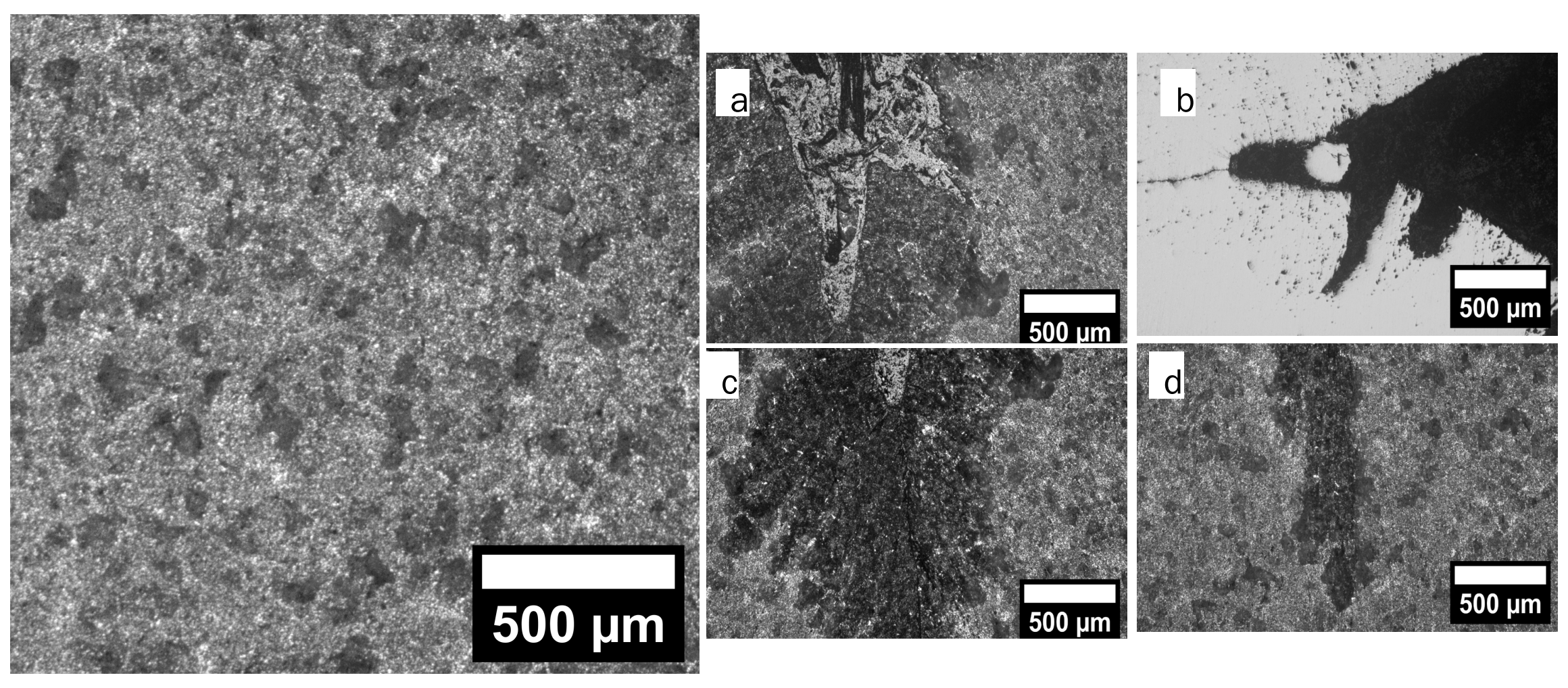
The macrograph of 5182 hot band shows extensive edge cracking along the full length of the sample. When examined further, micrographs of the cross section reveal inclusions and segregations within the microstructure that indicate a brittleness or proneness to cracking within the 5182 sample.



There was also some delamination within the 5182 sample. This separation is along the rolling direction, about two inches in depth. It is suspected to be related to the same problem or mechanics as edge cracking but was outside of the scope of this project. All these problems determined that the reduced ductility and higher hardness of 5182 contribute to it being a more problematic alloy when it comes to edge cracking.



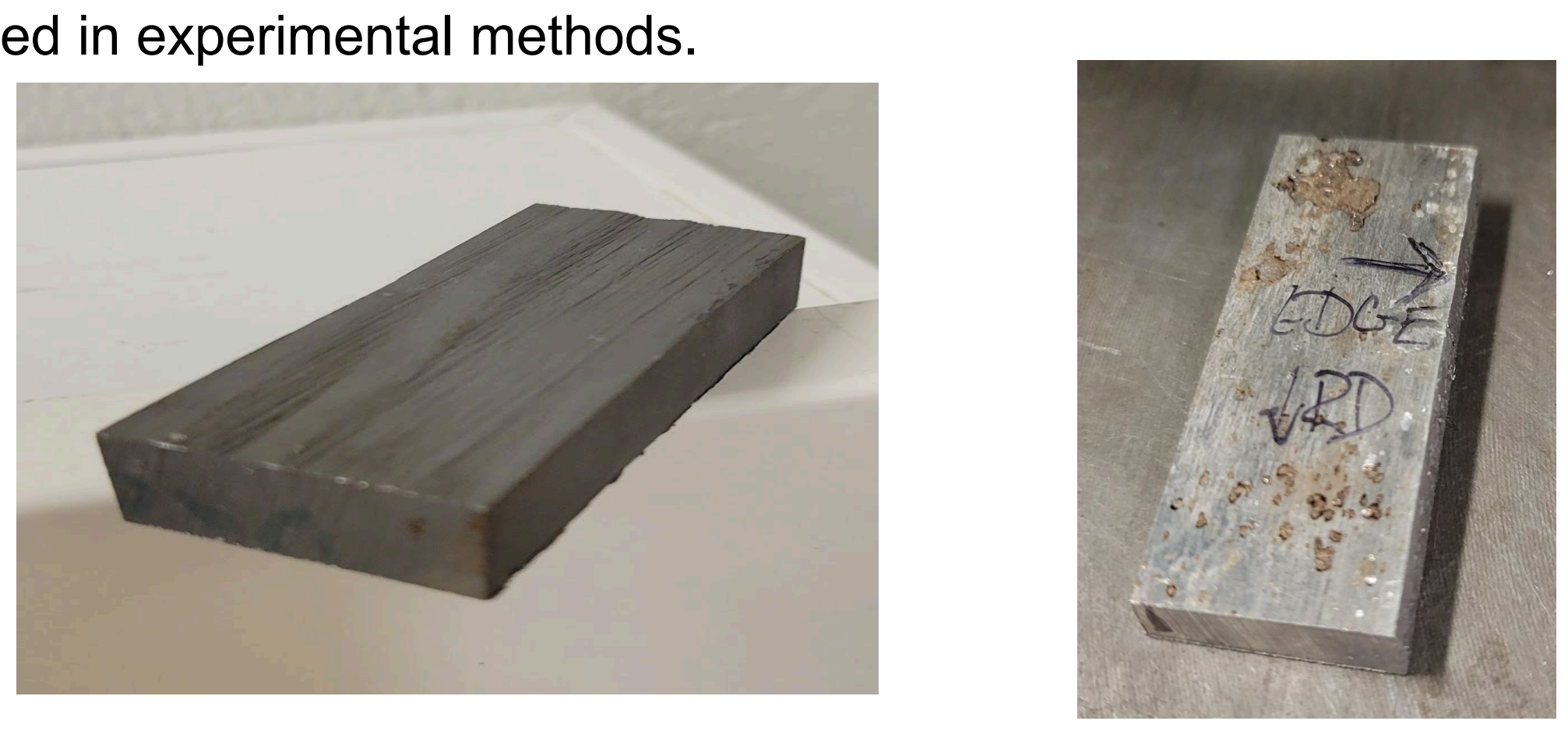
These micrographs of the cross section and edge of the ingot respectively show the liquation layer. This layer is shown under the line in the micrograph on the left and looking directly into the liquation layer in the micrograph on the right. There is a difference in composition between the bulk alloy and the liquation layer, with the liquation layer having much more magnesium than the bulk alloy. Because of the increased magnesium content, the liquation layer is more brittle and will see failure with tensile stresses much sooner than the bulk alloy. This could be one of the keys to reducing edge cracking in 5182: reducing or removing the liquation layer.



Micrographs of the transfer bar give further insight into the effects of rolling on the microstructure of the 5182 alloy. The micrograph on the left shows the typical microstructure of the alloy at the transfer bar stage of rolling. The micrographs on the right show the edge crack at a higher magnification. It is much worse than it seemed upon initial inspection. The depth and porosity created by the crack are most visible when etched (a,c,d) with dark areas showing over etching of the alloy due to crack porosity. This crack is likely related to the delamination phenomenon seen in the hot band sample above.

Rolling Experiments

Rolling experiments were performed on the received 5182 samples to determine at what degree of reduction edge cracking began to from, as well as to observe how alterations to the edge conditions of these samples affected the degree of reduction that the edge cracking began. Rolling experiments were performed on primarily the ingot (Left) and transfer bar (Right) samples, with the experimentation outline being listed in experimental methods.



The samples used for the rolling experiments, seen above, were modelled to be an approximate scale model of the actual ingots of aluminum that are used at Logan Aluminum via width and thickness. Ingot samples were roughly 6 mm wide and 2.5 mm thick, while transfer bar samples were roughly 25 mm wide and 9 mm thick.

	Liquation Layer	Without Liquation Layer	120 Grit Polish	320 Grit Polish
Ingot	50%	74%	63%	84%
Transfer Bar	59%	71%	89%	86%

With the liquation layer removed from both the ingot and the transfer bar, it was found that the onset of edge cracking was delayed in both cases, since the softer cracking layer was removed from the sample.

Cracking found on the 120 grit polished samples of ingot (Left) and transfer bar (Right)

When polished with 120 grit, it was found that, when compared to the edge with the liquation layer removed, the onset of edge cracking was hastened in the ingot sample and delayed in the transfer bar sample. Thus, a 120-grit polish is not consistent enough to act as a mitigator for edge cracking.

Cracking found on the 320 grit polished samples of ingot (Left) and transfer bar (Right)

When polished with the 320 grit, it was found that the onset of edge cracking was delayed in both the ingot and transfer bar samples, since the higher polish created an ideal condition for the obstruction of edge cracking.

Process Recommendations

With the presence of the liquation layer causing a higher degree of edge cracking, we recommend that the liquation layer be removed via scalping of the sides of the ingot, which would yield more favorable results than if it were scalped as a transfer bar. Using cost analysis, it was determined that Logan Aluminum will stand to gain a 5% increase in potential yield by not needing to remove the edge cracked material created from this layer.

Due to not falling within the scope of our project, we were not able to come to any substantiated conclusions about the delamination phenomenon, but we believe that performing further experimentation on the delamination phenomenon may also prove beneficial to the quality of the rolled aluminum. Because of the presence of delamination in many of our samples from different stages of the rolling process, we have found this issue to be on the same level of importance as edge cracking and believe that it should be investigated with great interest.

MSE Senior Design