Identifying the Origin of Sliver Defects in Rolled Aluminum Sheets

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Slivers are common elongated surface defects in rolled aluminum sheet that lead to a significant decrease in yield. The hypothesized causes of slivers are an insufficient removal (scalping) of ingot surface macrosegregation and mechanical damage in hot rolling. Examination of the root causes of sliver defects was performed through a scaled replication of the Logan Aluminum rolling process on aluminum alloys 5182 and 3104 and characterization through metallography and compositional analysis. Lack of compositional variations on the scale of the depletion layer in production slivers led to the conclusion mechanical damage is the more likely culprit.

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Project Background

Ingot Casting → Surface Scalping → Hot Rolling → Cold Rolling

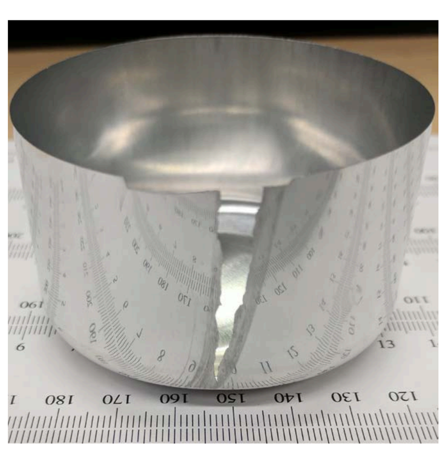

Figure 1: Crack in can originating at and propagating through sliver during deep drawing.

Slivers are elongated surface defects found in rolled aluminum sheet, seen in Figs. 4A and 5A, and if not removed, result in failure when drawn into a can (Fig. 1). During Direct Chill (DC) casting, ingot-scale segregation, not correctable by heat treatment, occurs due to the solute rejection into the molten aluminum and subsequent fluid motion[1]. Two layers are formed: a strongly solute-rich layer at the surface, and a moderately depleted layer further from the surface. These layers are removed on each rolling face of the ingot by scalping up to 2.5 cm (1 in.), while the side faces are unaltered. Insufficient scalping may leave remnants of a depleted layer which may elongate into sliver defects during rolling.

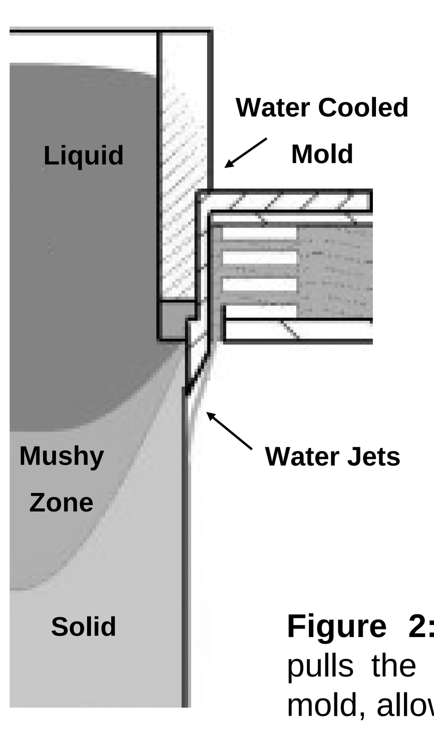

Figure 2: Typical DC Caster. Solidification shrinkage pulls the initial solid shell away from the water cooled mold, allowing partial remelting and exudation to occur.[2]

[1] Haug, Mo, and Thevik. Inter. J. Heat Mass Transfer (1995).
[2] Figure Adapted from D. Eskin, "Macrosegregation in direct-chill casting of aluminium alloys", (2008).

Experimental Procedure

To isolate potential causes of sliver formation, samples of a DC cast 5182 alloy ingot were cut into thin bars and hot rolled with 15% reductions. Samples were rolled with different scalp depths in order to evaluate surface layer effects on finished sheets:

- **Unscalped**: The as-cast surface remains on the rolling face of the sample.
- **Logan's scalp**: The rolling face was at the scalp depth typically used by Logan Aluminum.
- **Over-scalped**: The rolling face was at least 10 cm (4 in.) below the as cast surface.
- **Transverse**: The rolling face contains the exudation layer at one end and bulk material along the rest.

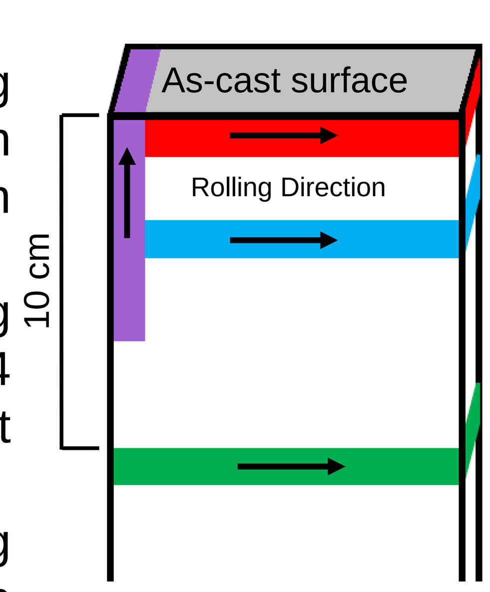

Figure 3: Sample location and orientation.

Over-scalped samples were then rolled with the following modifications :

- Scoring: The rolling face was deeply scratched.
- Debris: Fine particles or coarse fragments were placed onto the rolling face during rolling.

A transverse sample was tested to illustrate the effect hot rolling had at different depths. Findings led to further rolling experiments with a larger sample having an unscalped and scalped side (edge).

Production Sliver Characterization

Production slivers in samples provided by Logan Aluminum were classified as either Smeared (Fig. 4A) or Ruptured Surface (Fig. 5A) Slivers. No distinct compositional or metallographic differences between the smeared surface sliver and the sheet suggests the defect is caused by mechanical damage, whereas a distinct boundary divides the ruptured surface sliver from the sheet. Slivers responsible for failure during drawing (Fig. 1) share topographical characteristics such as striations with ruptured surface slivers.

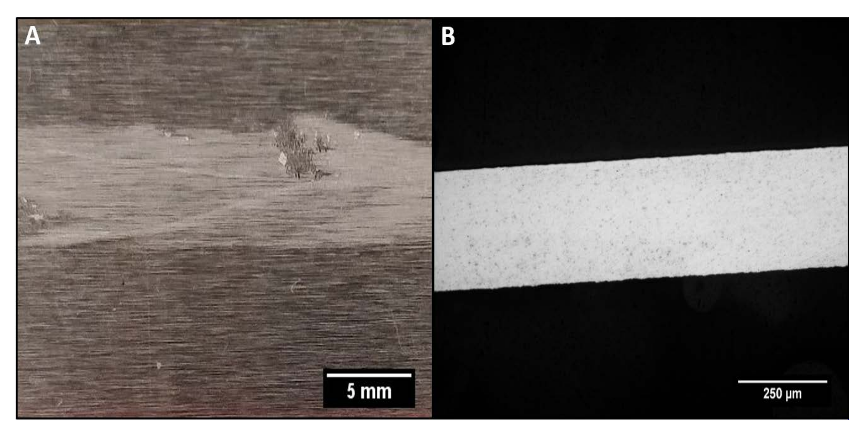

Figure 4: (A) smeared sliver on surface. No sign of sliver is found in cross section (B), suggesting it being a surface discoloration.

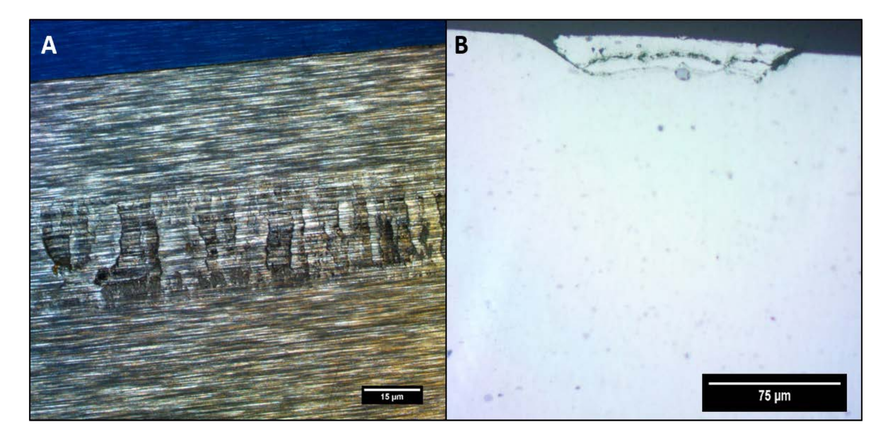

Figure 5: Example of ruptured surface sliver (A) on surface and (B) in cross section. Lack of composition difference between sliver and bulk metal suggests the defect is caused by mechanical damage.

Macrosegregation Analysis

Composition profiles were measured from the surface into the bulk ingot to characterize the exudation and depleted layer depths and to compare these depths to Logan's scalp depth. The solute enrichment measured 1.1 $\pm$ 0.3 mm for 5182, and contained up to 2.5 times the nominal Mg content of the alloy's (4.5wt%). Due to the lower Mg content of 3104 (1wt%), no significant composition variation near the surface was found. The 5182 exudation layer was found to have a higher hardness (Fig. 8), due to higher solute content, leading to a decrease in ductility. This results in edge cracks and a potential source of debris on the unscalped sides of the ingot.

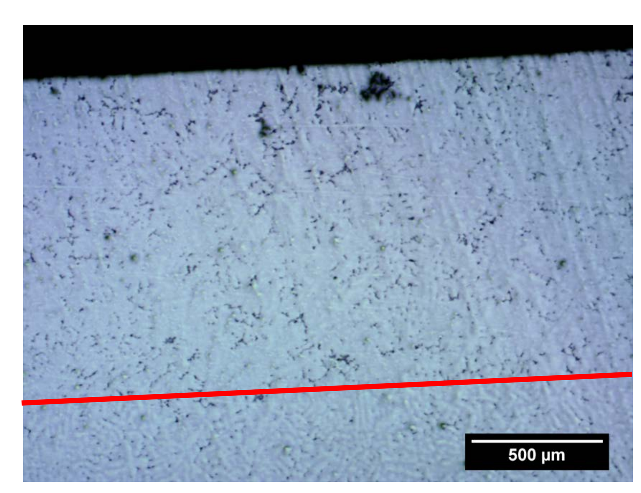

Figure 6: A thick exudation layer in 5182 above the red line, while a dendritic structure is seen below.

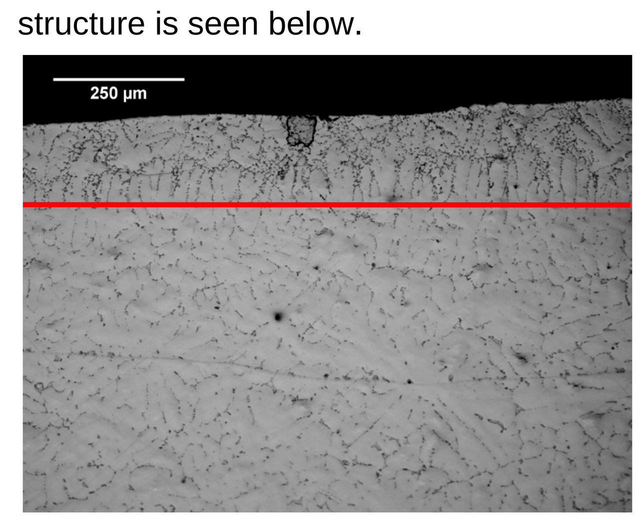

Figure 7: A thinner exudation layer in 3104, ~250 µm, is seen above the red line, while a dendritic structure is seen below.

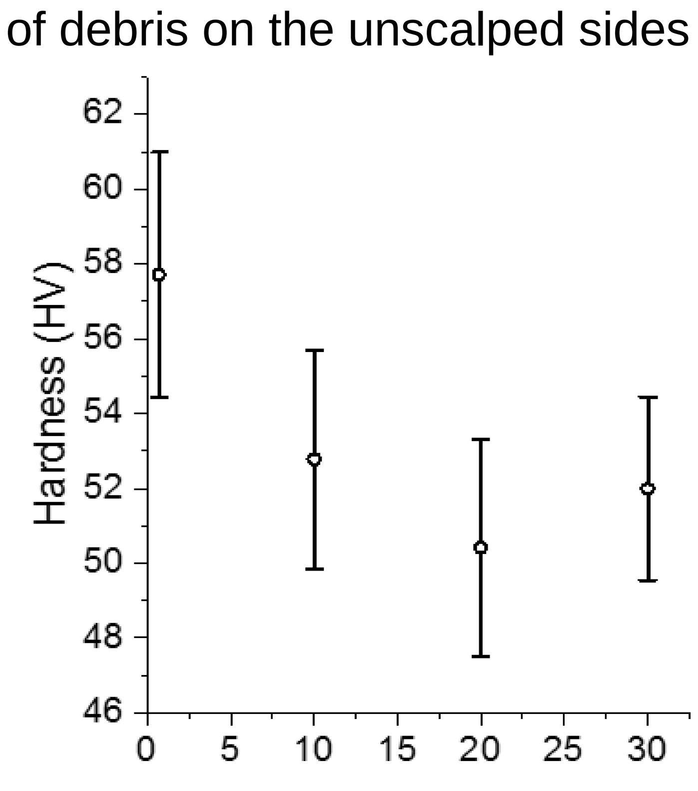

Figure 8: Vickers hardness measurements of the 5182 alloy. Hardness of the exudation layer is about 10% higher than in the bulk (subsurface).

Rolling Experiments

The control, scored, and fine debris samples displayed no slivering. Coarse debris caused a sliver attached at one end. A light-colored scar, Fig. 9, formed if coarse debris fell off during rolling. The exudation layer at the head of the transverse sample began to crack and separate (Fig. 10).

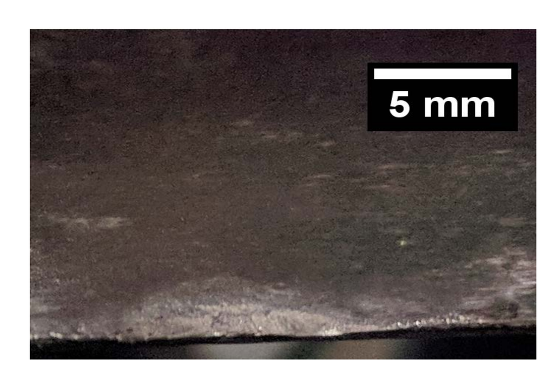

Figure 9: Smeared sliver on sample from coarse debris lost during rolling.

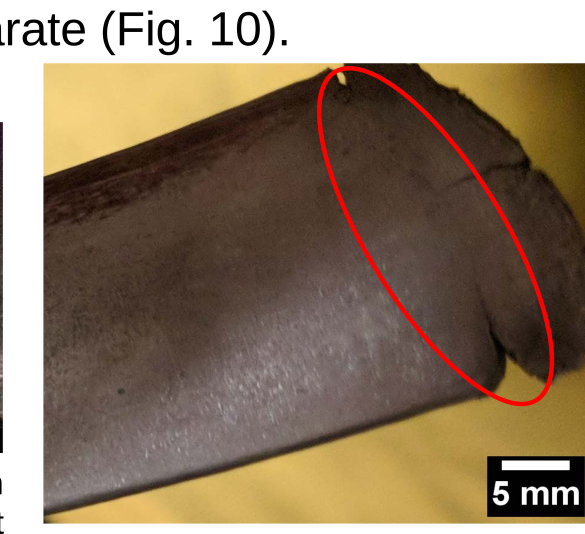

Figure 10: Separation of rolled exudation layer from bulk sample.

Transverse sample defects were constrained to the exudation layer, implying solute enrichment results in defect susceptibility. To confirm this effect, a larger sample was rolled with the exudation layer as one side (edge) and a scalped edge as the other. This sample allowed direct comparison of the effect of ingot side scalping. Shown in Fig. 11, the scalped edge remained smooth and did not crack while the unscalped edge was heavily cracked. The damage on the unscalped side was the same as is seen on edge trim of production sheet (Fig. 12).

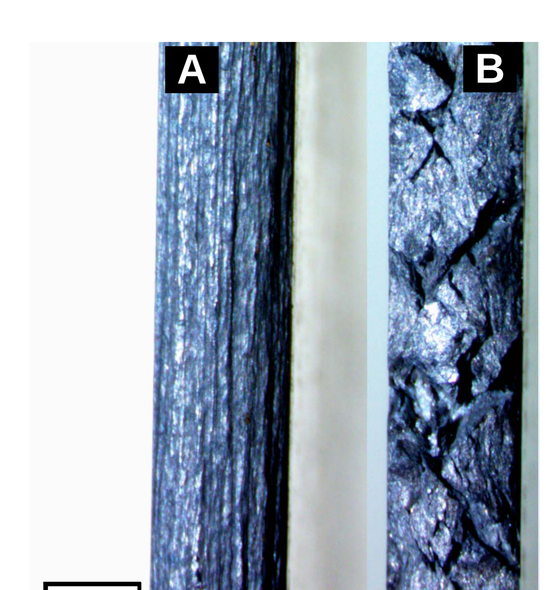

Figure 11: (A) relatively smooth scalped edge (B) extensive cracking on unscalped edge.

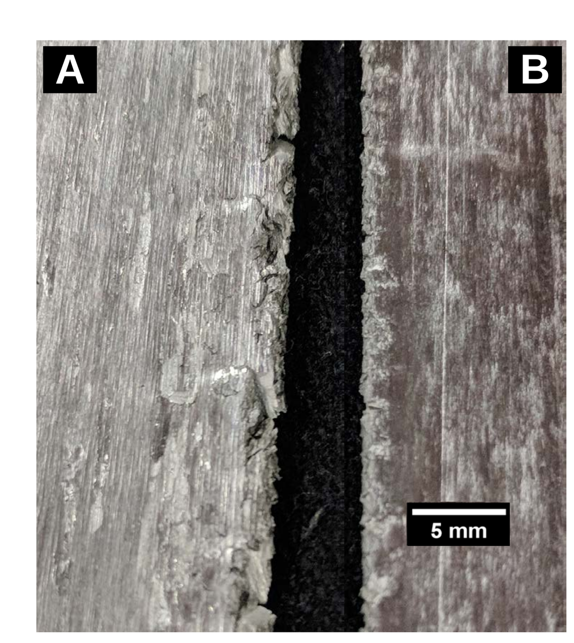

Figure 12: (A) 5182 edge trim from Logan Aluminum compared to (B) the unscalped edge of the transverse sample.

Process Recommendations

Since compositional differences appear to not be the source of slivers, scalping of rolling surfaces should be limited to removing the exudation layer and obtaining a level rolling surface. To reduce mechanical damage and mitigate edge cracking, a potential source of debris, scalping sides before hot rolling is recommended, as it will remove the harder and less ductile exudation layer.