M. E. Williams and Associates, Inc.

"Excellence in Metallurgical Engineering"

12825 385th Avenue
Waseca, MN 56093

Case Study: Failure of a Repair Weld in Aluminum

By

Merlin E. Williams, P.E.

Subject

An aluminum tank trailer panel blew out of the top of the trailer while unloading dry cement at a ready mix facility. The panel, which was large enough to kill a child or an adult, landed in the empty school grounds next to the ready mix plant.The unloading process involved pressurizing the tank to aid in removing the dry cement powder. The panel that blew out of the top of the trailer was a replacement, and had been repaired several times prior to being purchased by the ready mix plant. The trailer was examined and samples were removed for further evaluation. The samples were examined by visual examination, scanning electron microscopic examination, and metallographic examination to determine the cause of damage.

Visual Examination

Trailer

Figure 1 shows the trailer's left side. The valves for unloading the trailer are located on this side of the trailer. The pressure relief valve, that was set at 16 psi, is indicated.

Figure 1 – Trailer and Pressure Relief Valve

The damage on the top of the trailer is shown in Figure 2. The panel that was blown from the trailer is shown in Figure 3. This was apparently a replacement panel that was welded into the top center of the trailer. The locations of the three samples removed for further examination are indicated on the panel. The inside and outside of this panel was covered with hardened cement.

Figure 2 – Damage to Top of Trailer

Figure 3 – Panel Blown from Top of Trailer

Samples

Sample 1, shown in Figure 4, had been welded twice. The original weld was a full penetration weld that appears to have broken. The tan and gray materials are cement. The metallographic cross section is shown in Figure 5. The two welds are evident, with the original weld being a full penetration butt weld. It had been repaired with a non-penetrating cover pass which was significantly weaker than the original weld.

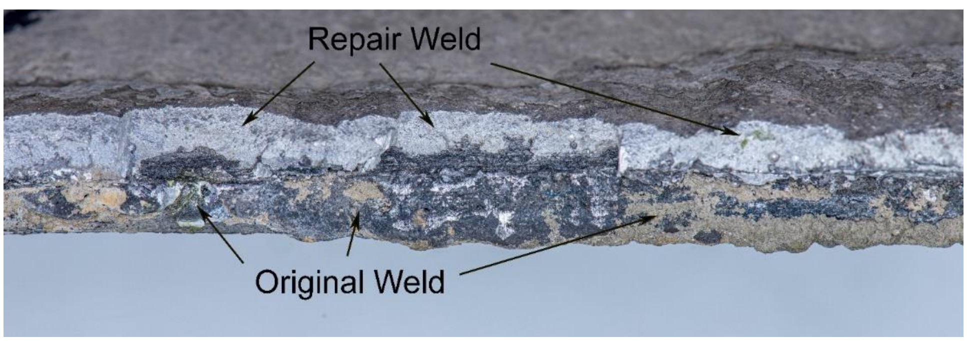

Figure 4 – Sample 1 Welds

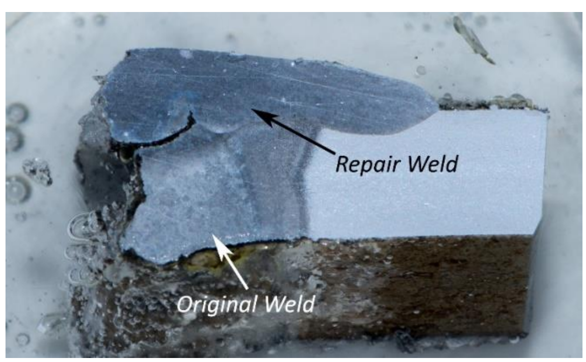

Figure 5 – Metallographic Cross Section of Sample 1

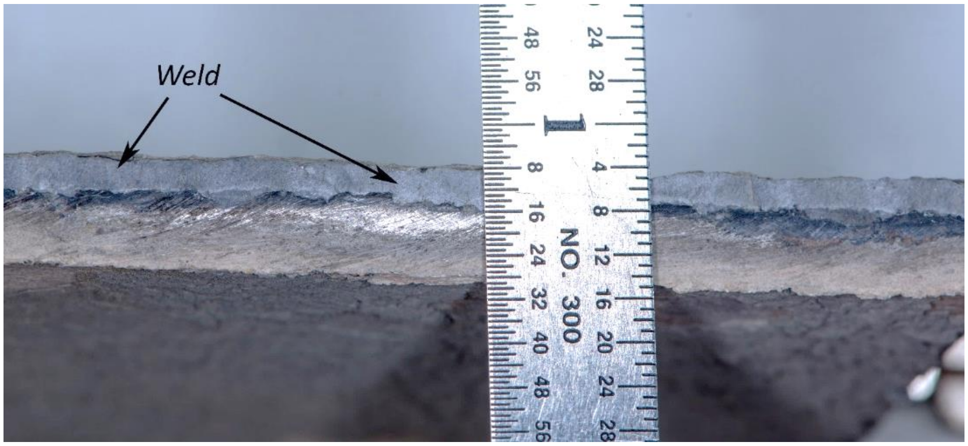

Figure 6 – Sample 2 Weld

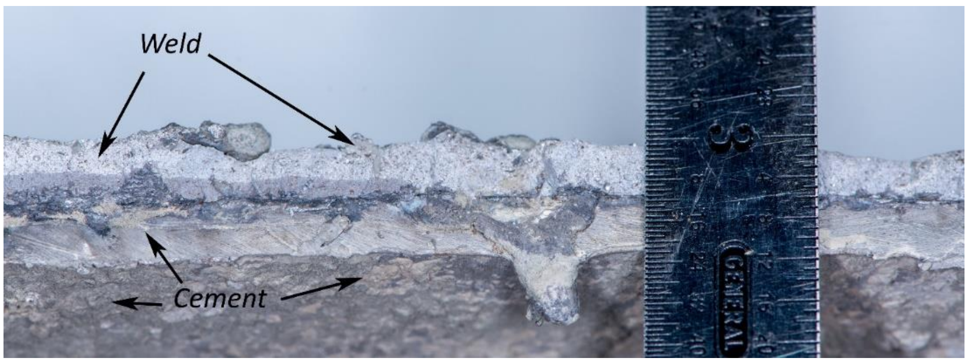

Figure 7 – Sample 3 Weld

The weld in Sample 2, Figure 6, was a partial penetration weld, with a throat depth of about 1/8 inch. This was a potential problem when the trailer tank was pressurized during unloading. The unwelded section in the plate thickness can act as a stress riser.

The Sample 3 weld is shown in Figure 7. The weld thickness for this sample in the area shown was about 5/32 of an inch, somewhat better than Sample 2, but still not a full penetration weld. At the location of the two cross sections made through this sample, the welds were full penetration welds.

The samples showed that there were problems with both the original welds, and the repair welds, and that the original welds had been repaired at least once.

Scanning Electron Microscopic Examination

Many of the very fine surface details were obscured by corrosion. Corrosion would have covered or removed any indications of high cycle fatigue.

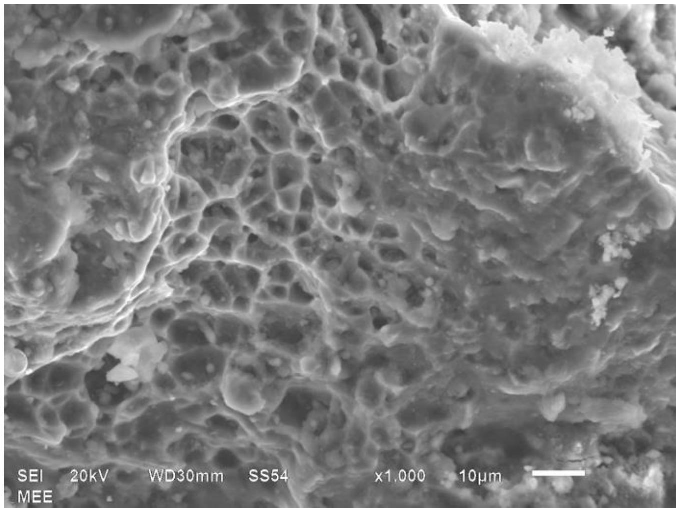

Figure 8 – 1000X Sample 1, Ductile Rupture and Corrosion near Outer Surface of Weld

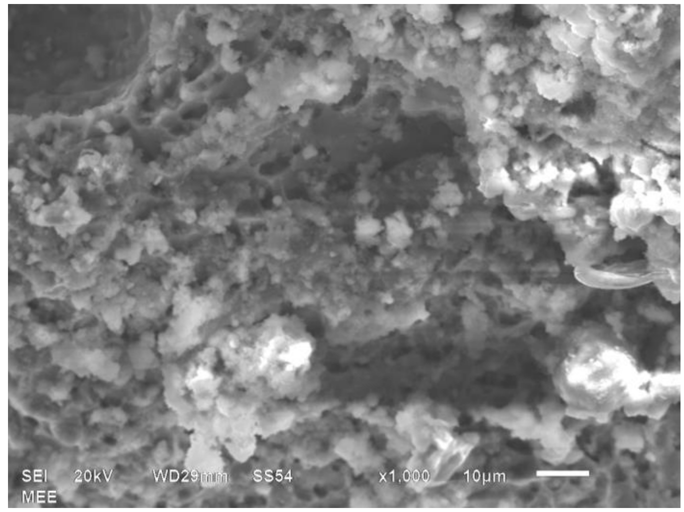

Figure 9 – 1000X Sample 1, Corrosion and Ductile Rupture near Weld Root

Figure 8 shows the fracture surface of the weld just below its outer surface. The fracture mode was ductile rupture. The fracture was formed at the time of failure. There was also extensive corrosion present, indicating that corrosion had penetrated the thickness of the weld. The location of Figure 9 was near the root of the repair weld. This area was heavily corroded, but some evidence of ductile rupture remained. The presence of ductile rupture near the weld root, and corrosion near the surface, indicated that this weld was broken most of the way through prior to the trailer failure.

Figure 10, Sample 2, shows another location near the surface. The fracture mode at this location was very low cycle fatigue. The weld root showed evidence of intergranular corrosion, Figure 14. Intergranular corrosion is often found with fatigue in aluminum alloys when both fatigue and corrosion are present.

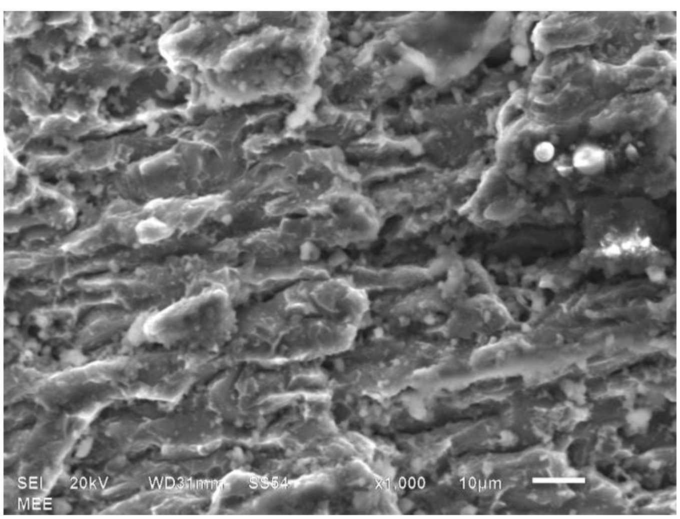

Figure 10 – 1000X Sample 2, Very Low Cycle Fatigue near Outer Surface

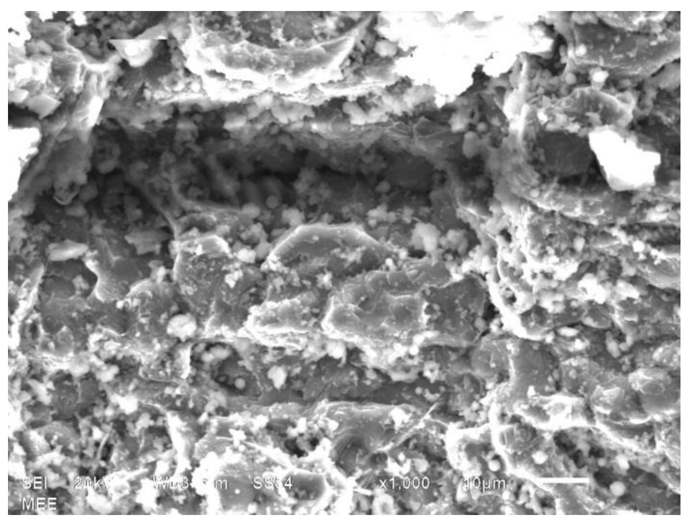

Figure 11 – 1000X Sample 2, Intergranular Corrosion in Weld

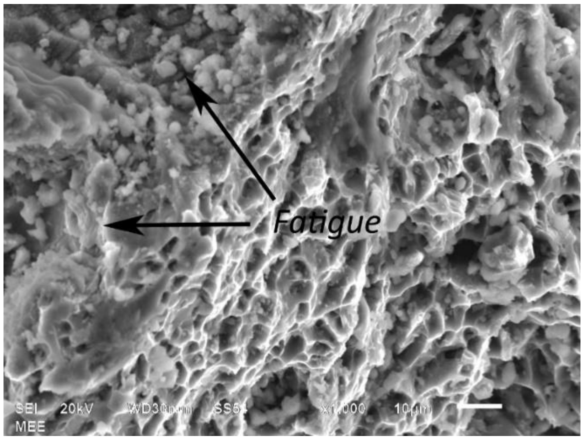

Figure 12 – 1000X Sample 3, Fatigue, Corrosion, and Ductile Rupture near Weld Root

The Sample 3 location, shown in Figure 12, shows ductile rupture fracture, high cycle fatigue. A small amount of corrosion indicated that this location had cracked prior to the accident.

The scanning electron microscope examination showed a variety of failure modes: ductile rupture, corrosion, and high and low cycle fatigue. All of these are typical of a progressive failure involving corrosion and dynamic loading. Over the road, semi-trailers are dynamically loaded pieces of equipment. The source of the corrosion was the cement. Cement contains potassium and sodium oxides which in the presence of water form hydrogen gas, and potassium and sodium hydroxides. Hydroxides are very corrosive to aluminum and aluminum alloys.

Metallographic Examination

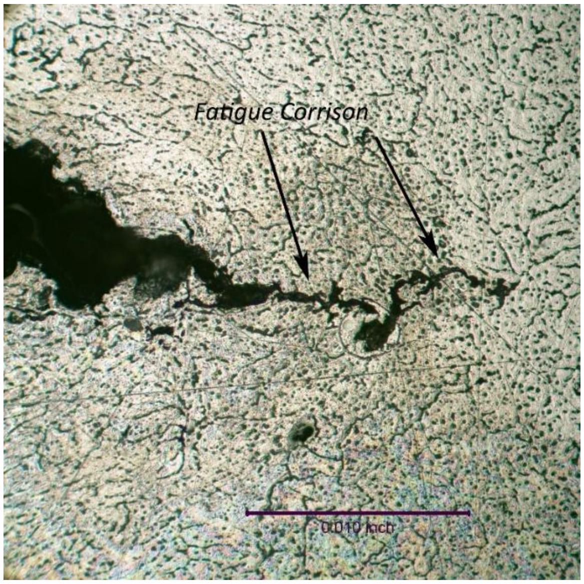

Figure 13 – 200X Sample 1, Fatigue Corrosion between Original and Repair Welds

There was a fatigue corrosion crack between the original weld and the repair weld, Figure 13, Sample 1. The proper procedure for doing a repair effectively is to grind or cut out the broken weld and then reweld.

Welding at the top of a broken weld provides a stress riser for continued crack propagation into the new weld.

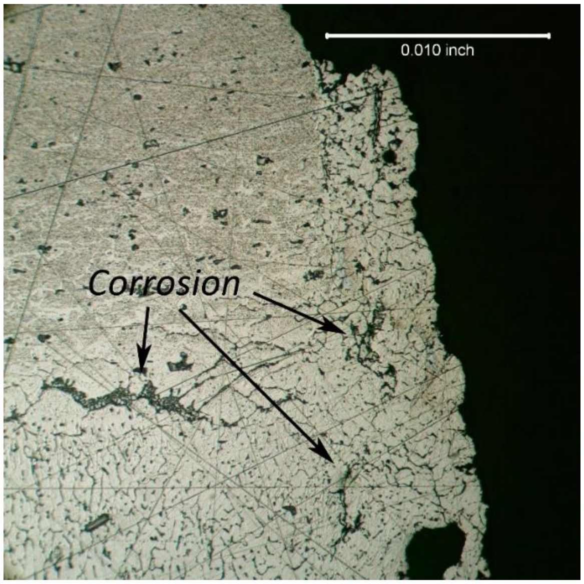

Figure 14 – 200X Sample 2, Corrosion in Weld Metal near Weld Root

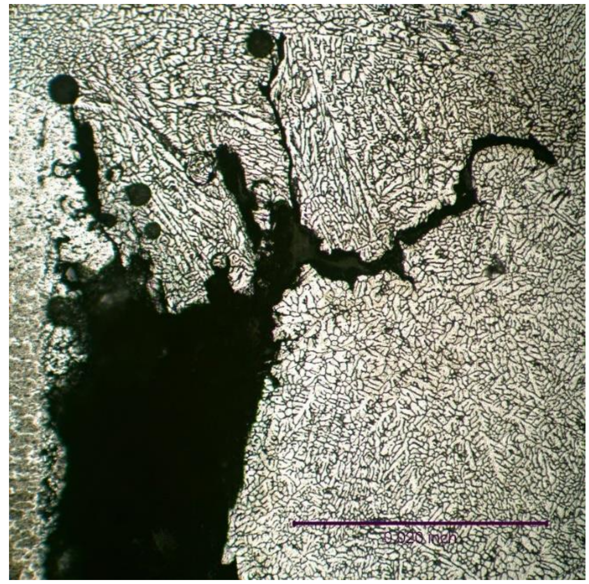

Figure 15 – 100X Sample 3, Fatigue Corrosion in Weld Root

Corrosion is normal for aluminum alloys in the presence of sodium and potassium hydroxides. Figure 14 shows interdendritic corrosion in the weld metal near the root of the Sample 2 weld. The surface on the right side of the photo is a profile of the fracture surface in the weld metal.

Figure 15 shows the profile of the fracture surface near the outer surface of the weld. There was no deformation of the weld metal, indicating that the failure mode was very low cycle fatigue, shown in Figure 10.

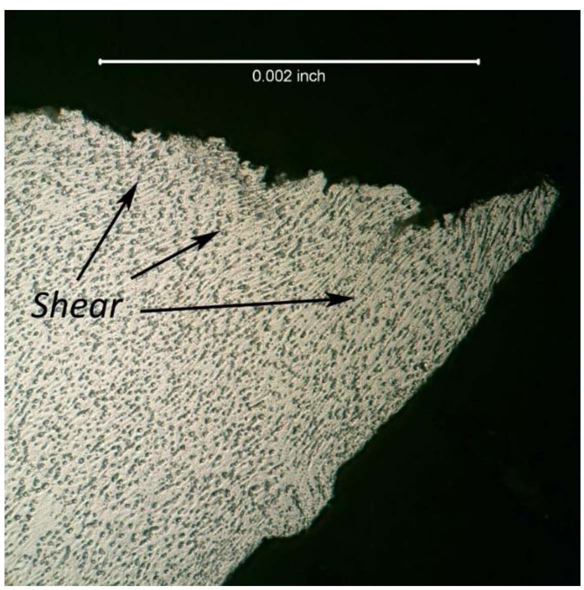

Figure 16 – 1500X Sample 3, Shear Fracture near Outer Surface of Weld

Figure 16, Sample 3, shows approximately 0.002 inch of weld material that failed by shear at the time of the trailer failure.

The metallographic examination verifies the presence of corrosion and shear related to the trailer failure. The metallographic examination also showed the likelihood of fatigue corrosion and fatigue.

Discussion

The panel that blew out of the trailer was a replacement that had been welded into the trailer prior to being owned by the ready mix company. When the panel was welded into the trailer, the weld procedure should have called for a full penetration weld around the perimeter of the panel. It may have, but there were only partial penetration welds along the longitudinal sides of the panel. The welds on both ends of the panel had been repaired after the original panel replacement. The partial penetration welds and the incorrect weld repairs produced stress risers which resulted in fatigue and fatigue corrosion during normal operation of the trailer.

The existence of ductile rupture and shear fracture is expected when material is blown out under pressure. The partially intact welds at the time of the failure indicated that the trailer was not over-pressurized.

The corrosion was caused by a reaction between the cement powder and water. The amount of water needed to cause the observed corrosion was very small. Condensation could easily have caused the corrosion.

Aluminum is very sensitive to fatigue and will eventually fail by fatigue. Welding and weld repairs in aluminum must be done very carefully to minimize the forming of stress risers.

Conclusion

The major cause of failure of this aluminum tanker trailer was defective repair welds. Welding is often thought of as a simple procedure that anyone can do, especially repair welding. In my experience, welding should always be done by a qualified welder.