Case Study: Aluminum Sand Casting Failure

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Subject

A clamp made from an aluminum sand casting was examined to determine the cause of breakage. These castings failed shortly after the equipment on which they were installed was put into service. The sand castings were produced by a new supplier and were put into service without undergoing rigorous inspection. They were only inspected for dimensional tolerances.

The sand casting was examined by visual examination, chemical analysis, scanning electron microscopic examination, and metallographic examination to determine the cause of the casting failure.

Visual Examination

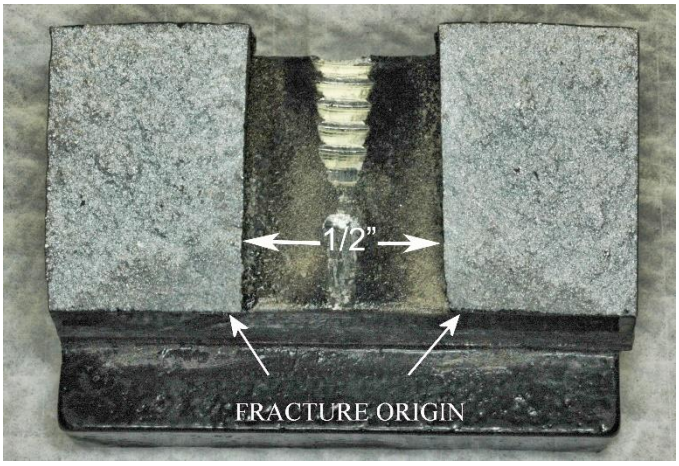

Figure 1 – Fractures in Sand Casting

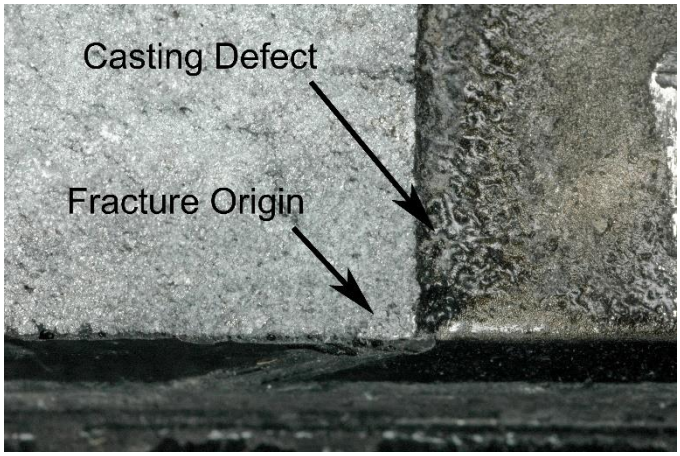

Figure 2 – Fracture Origin in Sand Casting

Figures 1 shows the fractures in the clamp sand casting and the fracture origins. The fracture origin is shown at higher magnification in Figure 2. There was a pre-existing crack at the fracture origin of this sand casting, Figure 2. Figure 2 also shows a casting defect that was caused by the sand mold being broken while the aluminum was still liquid.

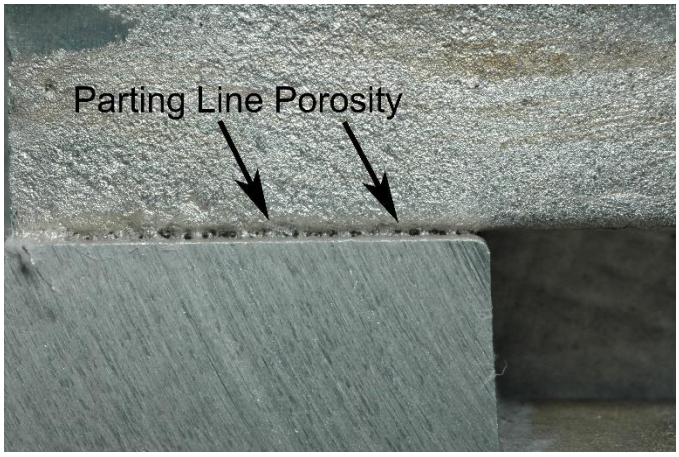

Figure 3 – Internal Parting Line Porosity

The parting line on all the castings were very poor due to the presence of porosity, shown in Figure 3. Parting lines are supposed to be free of porosity.

Chemical Analysis

The chemical analysis was done according to ASTM Specification E227. The casting was supposed to have been sand-cast from aluminum alloy 713. The chemical analysis of the casting and the specification for aluminum alloy 713 are given in Table 1.

Table 1
Chemical Analysis of Sand Casting
(Percent by Weight)

Element	Sand Casting	Specification
Silicon	2.89	0.25 Max.
Copper	1.49	0.40 – 1.00
Magnesium	0.20	0.20 – 0.50
Iron	0.40	1.10 Max.
Titanium	0.13	0.25 Max.
Zinc	4.55	7.0 – 8.0
Manganese	0.19	0.60 Max.
Lead	<0.05	0.10 Max.
Tin	0.07	0.10 Max.
Nickel	<0.05	0.15 Max.
Chromium	<0.05	0.35 Max.
Others Each	<0.05	0.10 Max.
Others Total	<0.15	0.25 Max.

The chemical analysis showed that the casting was not aluminum alloy 713. The amount of silicon and copper was too high for this alloy, and the amount of zinc is much too low. The chemical composition of the sand casting does not conform to any known standard alloy.

Scanning Electron Microscopic Examination

The dominant fracture mode of the sand casting was brittle fracture. Typically, an aluminum sand casting would have failed by a ductile fracture mode, such as ductile rupture or fatigue.

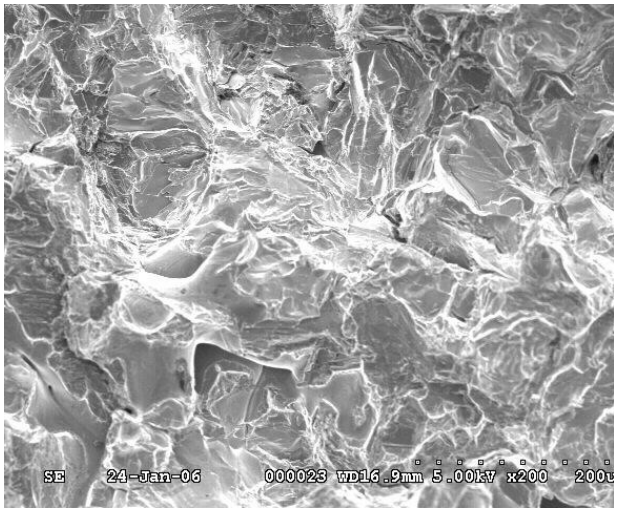

Figure 4 – 200X Brittle Fracture, Cleavage, near Fracture Origin

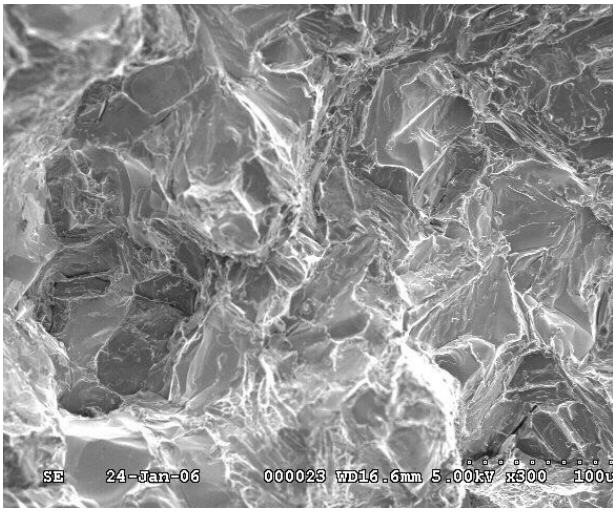

Figure 5 – 200X Brittle Fracture, Intergranular

Figure 4 shows cleavage fracture near the fracture origin. Throughout the rest of the fracture surface the brittle fracture was a mixed mode of cleavage and intergranular, Figure 5. The sand casting had no ductility. The elongation for 713 alloy is 4%, which is enough to show ductile fracture characteristics.

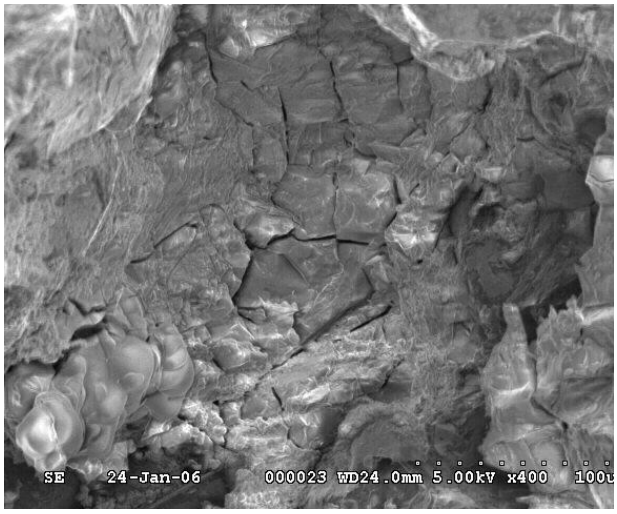

Figure 6 – 400X Intergranular Porosity

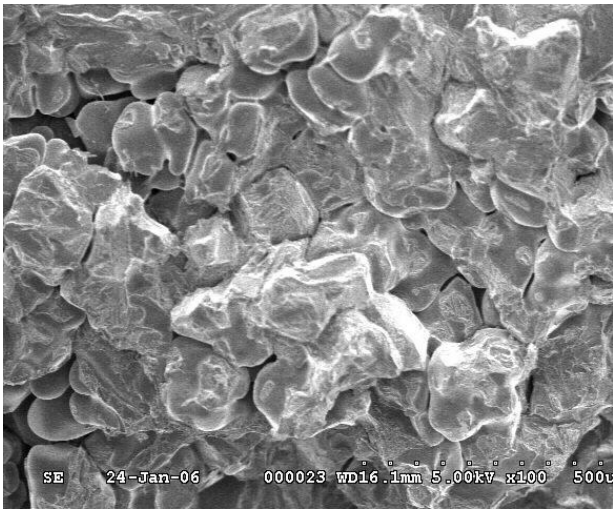

Figure 7 – 100X Intergranular Porosity

The dominant feature of the fracture surface of the sand casting was intergranular porosity, indicated by the angular and nodular features, Figures 6 and 7. Intergranular porosity in sand cast aluminum is due to trapped hydrogen gas, which is the result of not properly fluxing the molten aluminum just prior to casting. The condition shown in this sand casting is a very serious defect.

Metallographic Examination

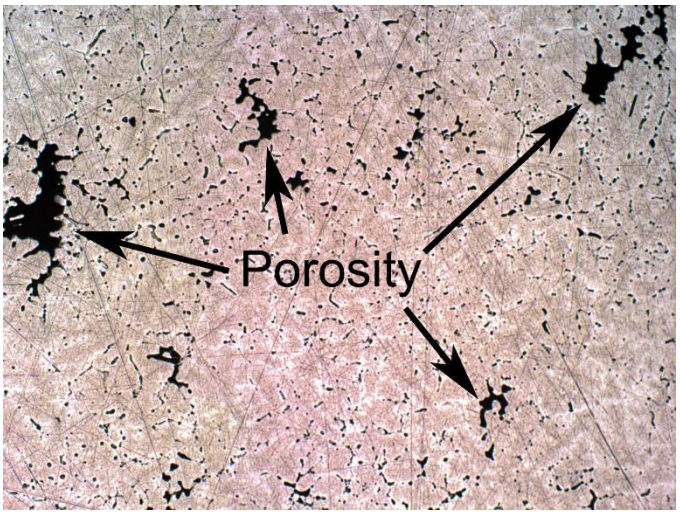

Figure 8 – 25X Porosity in Grain Boundaries

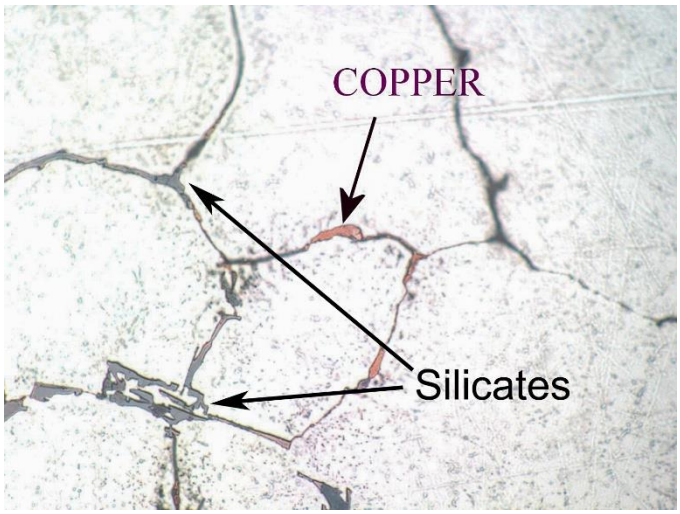

Figure 9 – 400X Copper and Silicate Precipitate in Grain Boundary

Figure 8 shows a cross section through the parting line. There was grain boundary porosity present, as indicated by the black areas within the casting. The presence of porosity to this extent is the result of trapped hydrogen gas. There were copper and silicate precipitates in the grain boundaries, Figure 9. The presence of these precipitates in the grain boundaries is the cause of the intergranular fracture found on this casting. The precipitates are the result of the higher-than-specified concentrations of copper and silicon in the sand casting, and therefore are the cause of brittle failure.

Conclusions

1. The casting was not cast from the specified aluminum casting alloy 713. The composition of the casting material used does not match any known aluminum casting alloy.

2. The sand casting failed because of grain boundary gas porosity and grain boundary copper and silicate precipitates.

3. These castings show a lack of process control by the foundry.

4. This part should be recalled due to the poor overall quality of these castings.

Recommendation

These castings should be recalled and removed from service as soon as possible.