CASE STUDY 1

PROBLEM

Overview

After operating satisfactorily for about a year, the outer insulation on a series of large pressure vessels was discovered to be leaking. The vessels were used for hydrogenation and desulfurization of petroleum crude oils at a pressure of about 3000 psi at 315°C or higher. The vessel was approximately 10 ft in diameter, and the walls ranged from 4 to 9 in. in thickness. The vessels were fabricated of quenched and tempered plates of 2.25Cr-0.5Mo steel, rolled and welded vertically with electroslag welding. The welds in these sections were quenched and tempered before vessel final assembly girth welding with a submerged arc process. The girth welds were then stress relieved to a final hardness of Rockwell C 28 to 32.

Investigation

The outer insulation was stripped, which exposed perforations through the vessel walls. Examination of the vessel interiors revealed numerous cracks in the welds, some of which were transverse to the welds but did not penetrate the heat-affected zone on either side.

An effort was made to halt the cracking by stress relieving the pressure vessel in place and decreasing the hardness to Rockwell C 22, but the stress relief was not effective.
CASE STUDY 2

PROBLEM

Overview

Several fractures occurred in flange studs used for remote handling of radioactive equipment. The studs, of quenched and tempered type 414 stainless steel, fractured in the heat-affected zones produced in the studs during the circumferential welding that joined the studs to the flange as shown. The weld deposits were of type 347 stainless steel and the flanges were type 304 stainless steel.

Investigation

Metallographic examination showed that the HAZ contained intergranular cracks which initiated at the stud surface and propagated in a manner indicated on the figure into the stud about 3/16 in. and about 100 degrees around the circumference before turning up to the final fracture contour noted. No preheat or post heat was performed on these parts. The studs fractured under service loads.
CASE STUDY 3

PROBLEM

Overview

An air bottle, machined from a solid block of aluminum alloy 2219-T852, displayed liquid-penetrant crack indications after assembly welding (see figure). The air bottle was machined to rough shape, which consisted of a 0.15 in.-wall cylindrical cup with a 3/4 in. wall integral boss on one side, and was annealed at 413 C. The lip of the cup was then hot spun to a dome shape, the metal being preheated to 204 C with a torch. After a second anneal, a port fitting for the dome opening was attached by four tack welds. The assembly was torch preheated to 121 to 149 C, using a contact pyrometer to check the temperature. The port fitting was then GTA welded in place. Final full heat treatment to the T62 temper was followed by machining, pressure testing, and radiographic and liquid penetrant inspection.

Investigation

The crack indications were found only on one side of the boss and on the lower portion of the hot-spun dome region, as indicated. Sections were cut from both the boss and the tank wall for Metallographic examination. Other cracks were broken open and studied fractographically.

The metallographic sections revealed triangular voids and sever intergranular cracks. When the cracks were opened up they displayed a very glossy surface. At regions away from the crack the metallurgical structure was found to be sound.
(a) Machined air bottle showing hot-spun region, circumferential butt weld made in assembly, and location of crack indications. (b) Micrograph showing longitudinal intergranular crack and triangular void (at arrows) typical of those at the failed areas of the boss and tank. (Etched in Keller’s reagent; 250×.) (c) Fractograph, at 10×, of the fracture surface of one of the tank-wall cracks, showing typical glossy surfaces.
CASE STUDY 4

PROBLEM

Overview

A braze welded joint between lengths of 4 in. OD by 0.092 in. wall copper pipe failed by cracking around more than one-third of the pipe circumference, as shown in figure a. The pipe had served as part of a cold-water main. The filler metal used for braze welding was 60-40 alpha-beta brass corresponding approximately to AWS RBCuZn-A.

Investigation

Metallographic sections from a region of the joint near the end of a crack in figure b showed a region around the crack low in zinc, some pores were evident at higher magnification in the beta matrix phase shown in figure d. Figure c shows the side opposite the crack and the area of lower zinc was much less extensive (see arrow).
(a) View of crack (arrow) in braze welded joint, which extended around one-third of pipe circumference. (b) Macrograph, at 10×, of a section through the joint, showing a crack partly penetrating the braze metal (arrow), and dezincification surrounding crack. (c) Macrograph, at 10×, of a section from side of pipe opposite that in (b), where pipe ends were more closely butted, showing a much smaller region of dezincification (arrow). (d) Micrograph, at 150×, showing attacked zone (at right) and unattacked zone (at left) of the braze-metal structure.
CASE STUDY 5

PROBLEM

Overview

A welded Aluminum Wheel Rim for a Specialty Race Car failed in an explosive manner in the "Race Pit". A tire was being replaces with a new one and the pressure was being applied. In this process, a slight pressure above the run pressure is applied to be certain the tire seats properly and then the pressure is reduced to the running pressure. The rim failed through the fillet weld as shown in the illustration. (Not shown in the diagram is an outer ring which is mechanically fastened to the tire to hold it on to the rim). The rim was made from 6061-T6 material and welded with 5356 wire.

Investigation

When the fractured weld was examined, it was obvious that the weld failed along the centerline of the weld with 1/2 of the weld present on the outer flange (portions of the frayed tire still attached) and 1/2 remaining on the spider. The concave surface of the weld had a coating of silicon rubber on it.

A scanning electron micograph of the fracute surface is presented at 20X in the picture above. Note the silicon film on the far right of the photograph, and the weld metal fracture surface.
After cleaning the silicon rubber residue from the surface, a scanning electron micrograph below was taken showing the top portion of the fractured weld metal and the top surface of the weld. An additional picture of the top surface of the weld without the silicon is also presented.
CASE STUDY 6

PROBLEM

Overview

Rolls used to roll hot rolled steel sheet wear with continued use and either need to be "built" back up to their original diameter or scrapped. One process of roll reclamation is to stand the roll on end, place a donut shaped copper "shoe" around the roll with the inside diameter of the Taurus equal to the original diameter of the roll, and electroslag weld a build-up coating on the roll. This was done for a series of rolls. After welding, the repaired rolls were ultrasonically inspected and indications were obtained at the weld-haz interface. The inspection was made with contact transducers using glycerol for couplant. No indications were found while using either 1.6 MHz or 2.25 MHz transducers, but some were found at 5.0 MHz when an extremely high sensitivity was used. Because of this, the whole batch of rolls is about to be rejected, resulting in a considerable loss.

Investigation

Two slices were cut out of the roll showing the largest indications at the point of the indications and the center portion of the roll was milled out (i.e. producing rings) to give access to the fusion line from both the base roll and the weld overlay (see figure). The rings were again ultrasonically tested to locate the indications, and then radiographed. No radiographic indications were seen. Chemistry samples from the roll mandrel and the weld fusion zone were taken, tensile samples, and Metallographic samples were also taken. What is going on here? What would you recommend?
### TABLE I

WELDING VARIABLES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number of Filler Wires</td>
<td>15</td>
</tr>
<tr>
<td>Size</td>
<td>5/32&quot;</td>
</tr>
<tr>
<td>Wire Spacing</td>
<td>4-3/4&quot; - 5&quot;</td>
</tr>
<tr>
<td>Power Supplies and Controls</td>
<td>15</td>
</tr>
<tr>
<td>Amperage</td>
<td>460 AC</td>
</tr>
<tr>
<td>Voltage</td>
<td>41</td>
</tr>
<tr>
<td>Slag Temperature</td>
<td>3150 F</td>
</tr>
<tr>
<td>Flux Consumed</td>
<td>40 pounds</td>
</tr>
<tr>
<td>Slag Depth</td>
<td>1-1/2&quot; - 2&quot;</td>
</tr>
<tr>
<td>Starting Diameter</td>
<td>21&quot;</td>
</tr>
<tr>
<td>Finish Diameter</td>
<td>24&quot;</td>
</tr>
<tr>
<td>Arc Time</td>
<td>5 hours</td>
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<tr>
<td>Deposition Rate</td>
<td>530 pounds per hour</td>
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</tbody>
</table>

### TABLE II

CHEMICAL ANALYSIS OF ROLL SECTIONS

<table>
<thead>
<tr>
<th>Location</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Ni</th>
<th>Cr</th>
<th>Mn</th>
<th>Cu</th>
<th>Co</th>
<th>Sn</th>
<th>Crb</th>
<th>V</th>
<th>Ti</th>
<th>Al</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandrel</td>
<td>0.80</td>
<td>0.29</td>
<td></td>
<td>-</td>
<td>0.26</td>
<td>0.30</td>
<td>2.4</td>
<td>0.17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Weld Overlay</td>
<td>0.84</td>
<td>0.30</td>
<td>&lt; 0.008</td>
<td>0.008</td>
<td>0.30</td>
<td>0.26</td>
<td>2.2</td>
<td>0.33</td>
<td>0.05</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>0.10</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

### TABLE III

MECHANICAL PROPERTIES OF SELECTED AREAS OF THE ROLLS

<table>
<thead>
<tr>
<th>Location</th>
<th>0.2% Offset Yield Strength, ksi</th>
<th>Tensile Strength, ksi</th>
<th>Percent Elongation in 1&quot;</th>
<th>Percent Reduction in Area</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Weld Ring A</td>
<td>114.5</td>
<td>156.6</td>
<td>13.0</td>
<td>34.9</td>
<td>Failure in HAZ</td>
</tr>
<tr>
<td>Cross Weld Ring A</td>
<td>114.1</td>
<td>157.0</td>
<td>14.0</td>
<td>34.9</td>
<td>Failure in HAZ</td>
</tr>
<tr>
<td>Cross Weld Ring B</td>
<td>115.5</td>
<td>161.0</td>
<td>9.0</td>
<td>26.1</td>
<td>Failure in HAZ</td>
</tr>
<tr>
<td>Cross Weld Ring B</td>
<td>113.5</td>
<td>160.4</td>
<td>N.D.</td>
<td>42.2</td>
<td>Failure in HAZ</td>
</tr>
<tr>
<td>Mandrel Ring B</td>
<td>85.3</td>
<td>148.0</td>
<td>17.5</td>
<td>42.2</td>
<td>-</td>
</tr>
<tr>
<td>Mandrel Ring B</td>
<td>84.3</td>
<td>147.0</td>
<td>17.0</td>
<td>40.2</td>
<td>-</td>
</tr>
<tr>
<td>All Weld Metal Ring B</td>
<td>130.3</td>
<td>164.3</td>
<td>11.5</td>
<td>26.1</td>
<td>-</td>
</tr>
<tr>
<td>All Weld Metal Ring B</td>
<td>128.1</td>
<td>162.2</td>
<td>11.5</td>
<td>18.7</td>
<td>-</td>
</tr>
</tbody>
</table>
Weld on left, roll mandrel on right
A=Roll Mandrel Material Heat Affected Zone; B=Electroslag build-up (both 400X)
CASE STUDY 7

PROBLEM

Overview

A leaf spring on a full size farm tractor failed during plowing a field on the side of a hill which had a slope considered to be near the maximum slope for effective farm management by most farmers. When the spring failed, the 14 year old farm hand lost control and the tractor rolled over upon him. At the time of the accident, the tractor was 15 years old. During its service a number of repairs and modifications had been made on the tractor, some by welding. The closest weld to the leaf spring, however, was about a foot away.

Investigation

In checking with the tractor manufacturer, it was determined that most of the leaf springs for tractors made in this period were from AISI 8660 steel, the nominal composition of which is presented below. In the manufacture, the springs are heated, bent to this required shape, quenched and lightly tempered to give properties of high elastic yield strength. The fracture surface of the spring is presented below. Why did this failure occur and who is liable? Any recommendations?

C: 0.55-0.65%
Mn: 0.75-1.00%
P: 0.040 max
S: 0.040 max
Si: 0.20-0.35
Ni: 0.40-0.70
Cr: 0.40-0.60
Mo: 0.15-0.25
CASE STUDY 8

PROBLEM

Overview

Cracks were found in the welds made in the large dump containers of off highway earth moving vehicles just prior to their being driven to the customer. The material the containers were made from was an abrasion resistant high strength steel with 90-100ksi yield strength. Because of the size of these vehicles, all welding was done outdoors using E6012 electrodes (note that underbead cracks occurred even with this undermatched electrode). The chemistry of the plate material is:

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Nb</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.13</td>
<td>1.40</td>
<td>.013</td>
<td>.017</td>
<td>.21</td>
<td>.74</td>
<td>1.48</td>
<td>1.40</td>
<td>.46</td>
<td>.032</td>
<td>.039</td>
</tr>
</tbody>
</table>

The plate microstructure is presented in the photomicrograph below.

Investigation

A photograph of a portion of the container is presented below. The crack was observed after the vehicle was completely built and painted and awaiting delivery. A 4 inch repair weld was made on the part in an attempt to save the vehicle (note the arrows on the photo). After this repair, numerous other cracks were found, mostly in locations where 3 or more plates intersected. A cross section of this weld and repair weld are also presented. The vehicle was scrapped and inspection of other similar vehicles began immediately. Similar cracks were found in other vehicles, even in some that were produced at the same time but had already been delivered and put into service. What went wrong? Can you repair the existing vehicles? What recommendations would you have for the production of future vehicles?
CASE STUDY 9

Overview

A crack appeared in a fabricated piston after machining off weld reinforcement. The piston was made from 3/4 inch 1025 plate material consisting of two riser plates and one base plate as indicted in the diagram. The plates were saw cut to size and the base plate was bevelled to 30 degree bevel for submerged arc welding. Welding was performed with 900-1000 amps, 35-36 volts and a travel speed of 20 -22 inches/minute. After welding, the welds reinforcements were machined off even with the back of the base plate. Before machining, no cracks were visible, however after this machining, large cracks were found in the weld metal.

Investigation

A cross-section was cut for the area where one of the cracks was observed and the polished and etched section is presented below. Did the machining cause this problem or was there something else happening here? What recommendations can you give?
CASE STUDY 10

PROBLEM

Overview

A 5000 gallon open top hot water holding tank in an automotive manufacturing facility failed after 5 years of service when an irregular shaped fragment 3ft x 1.5 ft broke from near the bottom of the tank. However, cracking and weeping are visible elsewhere on the tank and on three other similar tanks installed at the same time. These other tanks were about ready to fail as well. The tank was made from type 304 stainless steel 0.125 inch thick plate 5 ft x 8ft wrapped around and welded together with the GMAW process making a finished tank size of 8 feet in diameter 13.5 feet high. The hot water inlet is at the top and the outlet is at the bottom. The entire tank is wrapped with 1 inch black insulation foam which is glued onto the OD. Calculation of hydrostatic head at the bottom of the tank is 3.3 psi.

Investigation

The OD of the fractured piece is observed after the insulation is scraped off to be covered with a reddish brown debris resembling hydrous ferric oxide, and brush-like marks are also seen on the OD. The fracture occurred with little or no macroscopic deformation. The ID surface also appeared reddish, but at 1X magnification, a web like pattern was visible all over the surface. The web like structure appeared not to be associated with grain boundaries.
A scanning electron micrograph (1500X) was taken of the fracture surface and energy dispersive spectrographic analysis was performed on the fracture surface and on the insulation to determine the major elemental components of each. The fracture surface appears to have higher than expected levels of Cl and Ca and the insulation which was sputter coated with a layer of gold appears to have high levels of C, O, Zn, Al, and Cl.
An unpolished metallographic cross section (at 25X) of the plate revealed numerous cracks starting at the OD surface and propagating toward the ID. Most cracks started at surface pits. A higher magnification etched cross section (250X) showed these cracks to be transgranular in nature.