Controlled shotpeening prevents stress-corrosion cracking

Peening of a metal surface with fine shot can turn tensile stresses in the metal surface into compressive stresses.

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Many corrosion failures of equipment and components can be traced to residual surface tensile stresses that cannot, in any practical manner, be quantitatively allowed for in original design.

These are stresses induced during manufacture of the equipment, regardless of the metal or alloy, although some materials are less susceptible than others. Welding, drilling, threading, grinding, shrinkfitting, bending, and wrapping without preforming are examples of manufacturing operations that create residual surface tensile stresses. These stresses, in effect, reduce the surface intergranular cohesiveness.

Where corrosion starts

Since corrosion begins at places where the corrosive agent can most readily penetrate the surface (exemplified in pit-type corrosion), the phenomenon of stress-corrosion cracking originates at the grain boundaries of the tensile-stressed surface layer. The cracks propagate inward until failure of the equipment results. The process occurs more readily and rapidly in corrosive atmospheres but is quite evident in typical industrial environments.

Original equipment (or components or replacement parts) in which the inherent, residual, surface tensile stresses have not been eliminated can be subject to corrosion cracking literally from the moment it is manufactured (even before being placed in actual service). Reserve items kept in inventory, for example, will exhibit surface cracking if the heretofore mentioned conditions are present. It is not uncommon that, by the time a new facility's valves, piping, pumps, vessels and towers are hooked up and the process is on stream, stress-corrosion cracking is well underway. Subsequent dynamic stressing of the equipment—subjecting it to weight or pressure and to cyclic loading—increases the total surface stress, and speeds corrosion and premature failure.
Controlled shotpeening of bottom of copper-silicon-alloy sulfuric acid tank

Table II Effect of heat on stress-corrosion resistance of shotpeened type 304 stainless

<table>
<thead>
<tr>
<th>Specimen*</th>
<th>Heated to,°F</th>
<th>Time held at temp.,h</th>
<th>Time to stress-corrosion cracking in 42% aqueous MgCl₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unopened</td>
<td>1,000</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Peened</td>
<td>1,000</td>
<td>16</td>
<td>103 NF†</td>
</tr>
<tr>
<td>Unpeened</td>
<td>1,050</td>
<td>144</td>
<td>10</td>
</tr>
<tr>
<td>Peened</td>
<td>1,050</td>
<td>144</td>
<td>202 NF†</td>
</tr>
</tbody>
</table>

* Standard U-bent specimens
† NF—No failure—test terminated

Approaches to the stress-corrosion problem

Since stress-corrosion cracking originates in the tensile-stressed surface layer in contact with a corrosive atmosphere, preventing it involves removal of its prerequisites, and may be accomplished through one or more of the following: (1) redesigning and/or choosing a new material of construction that, by virtue of its constituency and grain structure, is less susceptible to crack propagation; (2) preventing contact between metal and atmosphere through use of an inert, impenetrable coating; (3) converting the residual surface tensile stress to surface compressive stress through controlled shotpeening. Number 3 is usually the least costly by far, and in most cases it can alleviate the problem by itself. Numbers 1 and 2 do not remove the major cause of stress-corrosion cracking, namely residual surface tensile stress. Combinations of 1 and 3, or 2 and 3, offer some interesting possibilities.

What is controlled shotpeening?

Controlled shotpeening describes those exacting procedures that involve the uniform impacting of a metal surface—with either fine steel shot or glass beads—to induce surface compressive stress to the required depth. It may be likened to the effect produced by hundreds of thousands of tiny peening hammers striking with blows of equal intensity. The resulting layer, several thousandths of an inch in depth, is compressively stressed—and stress cracks, the precursor of the type of corrosion discussed here, will not occur, even in a corrosive environment. The maximum residual compressive stress that can be produced in a surface layer through controlled shotpeening and the stress that effectively retards corrosion cracking is equal, at least, to half the yield strength of the metal.

Individual equipment components and replacement parts, as well as complete assemblies, can be shotpeened to prevent corrosion—if not as a final step before shipment, then upon their arrival in the field, or even after installation as part of an onstream system. The depth of surface compression induced by controlled shotpeening is governed by a number of variables including shot size and quality, peening intensity, and thoroughness of coverage, as well as the hardness and strength of the metal. To be effective, 100% visual coverage is required.

Special machines and procedures are used

Equipment and procedures for controlled peening of components and assemblies to prevent stress corrosion and fatigue failure have been developed. The machines and setups are unlike those of conventional blasting and peening operations. They require skillful engineering planning, much of which is based on past experience.

Attaining uniform depths of compressive stress depends upon uniform and precise control of each of the peening parameters. Usually, many test runs are conducted before the actual peening procedures are final...
TABLE 1. Peened and unpeened specimens used in corrosion tests

<table>
<thead>
<tr>
<th>Stainless Description</th>
<th>steel type</th>
<th>Dimensions, in</th>
<th>How produced</th>
<th>Peened or unpeened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boss-to-pipe weldment</td>
<td>321</td>
<td>3¾-O.D.x ½-wall boss; 7½-O.D.x ½-wall pipe</td>
<td>Fusion weld</td>
<td>Unpeened</td>
</tr>
<tr>
<td>Boss-to-pipe weldment</td>
<td>321</td>
<td>3¾-O.D.x ½-wall boss</td>
<td>Fusion weld</td>
<td>Peened</td>
</tr>
<tr>
<td>Circumferential weldment</td>
<td>347</td>
<td>5½ O.D.x ¼ wall</td>
<td>Uniform 100% weld penetration</td>
<td>Unpeened</td>
</tr>
<tr>
<td>Circumferential weldment</td>
<td>347</td>
<td>5½ O.D.x ¼ wall</td>
<td>Greater than 100% weld penetration</td>
<td>Peened</td>
</tr>
<tr>
<td>Circumferential weldment</td>
<td>347</td>
<td>5½ O.D.x ¼ wall</td>
<td>Uniform 100% weld penetration</td>
<td>¼ Unpeened ¼ Peened</td>
</tr>
<tr>
<td>Hexagonal tube</td>
<td>316</td>
<td>2½ side</td>
<td>Explosion formed; 20% cold worked</td>
<td>¼ Unpeened ¼ Peened</td>
</tr>
</tbody>
</table>

ized for each job. Test strips must be preserved and all procedures documented to assure exact repeatability. Repeatability is extremely important to ensure integrity of the shotpeening process. Therefore, test strips must be processed before, during and after each peening operation.

Where shotpeening is used

Success in preventing stress corrosion and fatigue failure through controlled shotpeening has been achieved with such metals of construction used in the chemical process industries as high-carbon steel, Types 304, 316, 321 and 347 stainless steels, the Inconels, aluminum alloys and copper-silicon alloys. Large tank sections, pump bodies, evaporators, compressors, converters, tower components, assemblies, heat-exchanger tubing and other heat-exchanger surfaces, tubesheets, and simple, as well as complex, steel and nonferrous castings can be treated. Mechanical components such as coil springs, gears, pump shafts, diaphragm couplings, and pressure-switch diaphragms are additional applications where controlled shotpeening has a substantial record of corrosion problem solving.

Fatigue applications are also numerous and include pipeline expansion joints (bellows), and compressor, turbine and pump components such as connecting rods, valves, shafts, impellers, blades, rotors and disks, etc. In a recent development, the problem of intergranular cracking has been attacked successfully in austenitic stainless steels. In sensitized Ni-Cr-Fe alloys, chromium carbides precipitate, with a subsequent depletion of chromium adjacent to the grain boundaries. Reduction of the chromium content leaves the material susceptible to intergranular corrosion.

A cold-working process such as shotpeening will break up surface grains and form slip planes and/or dislocations that provide nucleation sites for carbide precipitation. Chromium-depleted grain boundaries are not formed at the surface, and the material is not susceptible to intergranular corrosion.

Shotpeening a sulfuric acid storage tank

Fig. 4 shows the bottom of a 47-ft-dia. copper-silicon-alloy, sulfuric acid storage tank being shotpeened, under controlled conditions. Shotpeening in this case proved to be the answer to an unexpected corrosion problem in which stress cracking was evident after only four months' service. Tanks with shotpeened bottoms have been in service so far for over one year without sign of corrosion cracking. Tank configuration and dimensions are those of the original, and the fabrication procedures are unchanged except for the addition of controlled shotpeening.

Piping system

For a proposed sodium piping system to be fabricated of austenitic stainless steel, accelerated tests were conducted at the manufacturer's plant to evaluate shotpeening. The items tested were similar in dimensions, configuration and methods of manufacture to the probable components of the system. Welding of the boss to the pipe induced the required tensile stress adjacent to the weld area. Stress-corrosion behavior was determined by immersion in boiling (300°F) 42% aqueous magnesium chloride, and then examining for signs of cracking. (This is a standard test for evaluating stress-corrosion resistance of austenitic stainless steels.) Examination was made by unaided eye and with a micro-
Stainless steel boss-to-pipe weldment shows serious cracks after 22-h \( \text{MgCl}_2 \) test (liquid penetrant examination) Fig. 7

Scope. Test items are described in Table I, and the outcome of the tests is given below.

**Results**

**Boss-to-pipe weldments**—The unpeened specimens were severely cracked after only 24 h in the boiling magnesium chloride solution. The photograph shows the condition after 165½ h. At this time, sizable longitudinal cracks had appeared around the circumference of the boss and adjacent to the weld. While none of these appeared to be through-cracks, fine cracks were visible on the inside surface. Through-cracks were present on the 7½-in. O.D. pipe section. As for the peened specimen after 264 h of immersion, at which time the test was terminated, only two small cracks were detected in the boss section, and one in the pipe.

**Circumferential pipe weldments**—The first unpeened specimen, after 47 h of exposure, had developed ½-in-long longitudinal cracks, spaced ½ to 1 in apart on the outside surface adjacent to the weld, as well as cracks on the inside surfaces. The second specimen, which had been peened, developed no cracks after 120 h. On the ½ peened/½ unpeened, welded and machine-finished specimen, after only 22-h exposure, cracks appearing in the unpeened area stopped where the peened surface began.

**Hexagonal tube:** After 24 h, cracking was evident in corners and flat surfaces of the unpeened half, while no cracks appeared in the peened portion.

From the results, we concluded that shotpeening would greatly increase resistance to stress-corrosion cracking but, to achieve the desired degree of success, it must be properly controlled. Monitoring would involve the means and methods to assure complete cold working of the surface by peening to a uniform depth. It is believed, for example, that the two cracks in the boss section resulted from lack of peening coverage in those areas.

**Shotpeening saves redesign**

Faced with a stress-corrosion situation and knowing the reasons for it, one might logically suggest a redesign that minimizes required welding, machining and finishing operations. However, engineering, new material, and time factors can make the cost prohibitive.

Instead, with controlled shotpeening, the original design and basic manufacturing techniques can be retained. The tensile-stressed surface areas need merely be carefully shotpeened to induce a residual compressive stress.

Controlled shotpeening of equipment and component surfaces has, for a number of years, been regarded by the power industry—both nuclear and fossil-fueled—and the builders of its equipment as a practical and relatively inexpensive means of preventing stress corrosion and fatigue failure. Since both the production of power and much of the large spectrum of chemical processing employ many of the same classes of equipment and alloys of construction and often experience similar environmental problems, the chemical process industries might look more seriously at controlled shotpeening for preventing corrosion.

**The author**

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