Burnishing technology mitigates stress corrosion cracking in weldment areas

The low plasticity burnishing process uses a hydrostatic tool that continuously "floats" the burnishing ball in fluid during operation, enabling the tool to apply the correct amount of pressure to surfaces with varying topography. Photo courtesy of Lambda Technologies.

Recent research performed by engineers at Lambda Technologies (Cincinnati, Ohio) demonstrates that stress corrosion cracking (SCC) can be mitigated in areas near weldments like those found in nuclear power plants and oil and gas pipelines by employing a unique, low cold work burnishing technology. The process, called low plasticity burnishing (LPB†), uses a novel, fluid-suspended burnishing ball that imparts a minimal amount of cold work (plastic deformation) to compress the surfaces of metal components and render them more resistant to SCC and other metal fatigue-related failures. Tensile residual stresses, which can develop during manufacturing processes such as grinding, turning, or welding, are known to increase a metal component's sensitivity to corrosion fatigue and can accelerate SCC.

According to the researchers, SCC is a primary maintenance concern for many components in nuclear power plants for both pressurized water reactors (PWRs) and boiling water reactors (BWRs). It has been observed for years in austenitic alloy weldments such as Type 304 stainless steel (SS) (UNS S30400) as well as in Ni-based alloy weldments including Alloy 600 and 690.[1]

"SCC is understood to be the result of a combination of three conditions—a material that is susceptible to SCC, tensile stress above a threshold, and exposure to a corrosive environment," says Jeremy Scheel, NACE International member and senior research engineer with Lambda Technologies. "Remove any one element and SCC initiation is impossible." It's well known that applying selected residual compression to a metal surface reduces the tensile stress and enhances the fatigue properties of the metal—how well it holds up to fatigue damage over the lifespan of the part—and reduces its susceptibility to corrosion fatigue and SCC, Scheel says, adding that a surface treatment that can reliably produce deep compressive residual stresses in austenitic and Ni-based alloy weldments will prevent SCC. The low plasticity burnishing process as well as technologies such as shot peening, laser shock peening, and roller burnishing are used to induce compressive residual stress in metal components.

Applying a force to make an irreversible impression on a metal surface (which is done at room temperature) is called plastic deformation or cold work. Basically, cold work compresses the surface by pushing together the crystal lattices that form the metal structure at the atomic level. Creating a deep compressive residual stress field on a metal surface can be accomplished through Hertzian stresses produced by a ball with a force sufficient to plastically deform the surface of the material. When a crack is initiated on the surface of a metal part with compressive residual stress, the compressed crystal lattices close the pathways that would allow the crack to grow, and prohibit the crack from propagating.

During plastic deformation, the crystal structure accumulates irregularities or defects, called dislocations. As the amount of cold working increases, the dislocation density (number of dislocations per unit area) increases proportionally. The high dislocation density creates a thermomechanically unstable stress state. At high temperatures—for example, typical operating temperatures of nuclear reactors—a highly cold-worked surface will thermally relax, resulting in loss of the imparted residual compression along with the protection afforded by the compressive stress field. When this happens, the advantages of the residual compression are diminished, resulting in reduced performance and shortened component life.

A key benefit of the low plasticity burnishing technology is that it uses a mini-

†Trade name.

mal amount of cold work to induce a deep, engineered compressive residual stress field, Scheel explains. The process compresses the metal directly under a ball as it travels, while the surrounding material constrains the deformation to allow maximum depth of compression to be reached in only one pass of the tool. Compared to other surface enhancement methods, this results in fewer dislocations and less cold working, and relaxation is minimal when the burnished component is heated—even to very high temperatures. While conducting studies on the effect of temperature on samples treated with various compressive residual stress technologies, the Lambda researchers found that crystal lattice relaxation increased dramatically at higher temperatures (200 to 400 °C) in metals with

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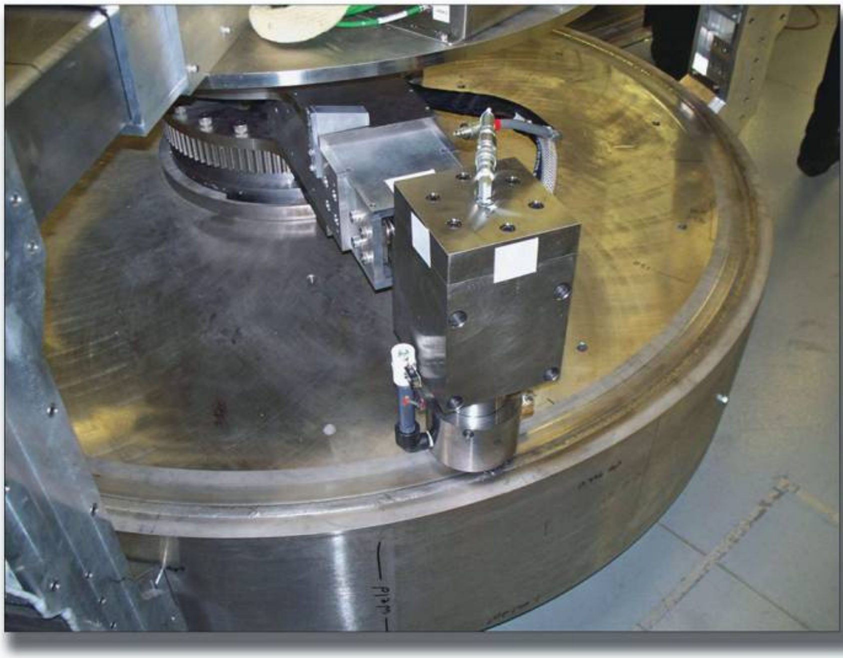

The weld on the top of a nuclear waste container lid, designed for use at a nuclear waste repository, is being treated with low plasticity burnishing to produce residual compression in the fusion weld and heat affected zone. The tool is the device on the top of the lid. Photo courtesy of Lambda Technologies.

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Shown is a photograph of a weld specimen sample of 316L SS with Alloy 52 weld material after exposure to 649 °C for 16 h and immersion in $MgCl_2$ for 100 h at 150 °C. The right half of the sample is processed with low plasticity burnishing. Severe SCC is seen on the unprocessed half of the specimen. Fluorescent dye penetrant and a black light are used to reveal the cracks. Photo courtesy of Lambda Technologies.

compressive residual stress induced by a higher percentage of cold working at the surface. Alternatively, metals with compressive residual stress resulting from a low percentage of cold work at the surface showed no crystal lattice relaxation when exposed to high temperatures and fully retained the beneficial compressive residual stress.

Researchers also tested two sets of weld specimen samples treated with low plasticity burnishing for SCC when exposed to magnesium chloride ($MgCl_2$) for 100 h at 150 °C. One sample set was thermally exposed prior to welding at 649 °C for 16 h to sensitize the specimens; the other set was simply welded. For both sets, one half of the welded sample (Type 316L SS [UNS S31600] substrate with Alloy 52 weld material) was processed with low plasticity burnishing and the other half was left untreated. After exposure, both sample sets showed the same results—severe cracking on the untreated half and no SCC or other damage on the half treated with low plasticity burnishing. X-ray diffraction measurements were performed to confirm the presence of tension in the untreated areas and the compression imparted by the low plasticity burnishing process.

Low plasticity burnishing is able to apply compressive stress with minimal amounts of cold work because of a novel, patented tool design, combined with computer numerical control (CNC), that provides the ability to control the force applied to the metal surface in real time. The hydrostatic tool "floats" the burnishing ball continuously during operation, regardless of the force applied. The smooth, very hard, free-rolling ball is supported in a spherical-socket fluid bearing with sufficient fluid pressure and flow to keep the ball out of contact with the socket. This allows the ball to roll in any direction without resistance; eliminates the possibility of dragging the ball and damaging the surface; and enables the tool to freely apply the specified amount of pressure although the topography of the surface may change. Load is controlled with a hydraulic cylinder contained within the body of the tool. In addition to controlling the force applied to the burnishing ball, the computer also controls the ball's position on the component's surface, and executes a preset burnishing pattern that covers the surface in a series of passes, with no overlap, to obtain maximum compression with minimal cold working.

For each component treated with low plasticity burnishing, the depth of compression necessary to protect the component from fatigue damage is predetermined based on factors such as the thickness and composition of the metal, the maximum yield strength of the metal, the operating conditions the metal will be exposed to, and what type of failure mechanism is a concern (i.e., SCC or foreign object damage). For example, to prevent SCC, the compression depth is engineered to reduce the surface and near surface stresses to well below the SCC threshold. This process can produce a depth of compression from a very shallow depth up to a depth of 12 mm or greater, depending on the application and material used.

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Reference

1 J.E. Scheel, D.J. Hornbach, P.S. Prevey, "Mitigation of Stress Corrosion Cracking in Nuclear Weldments Using Low Plasticity Burnishing," Proc. of the 16th Int. Conf. of Nuclear Engineering, held May 11-15, 2008 (New York, NY: ASME). MP

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