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Eliminating Stress Corrosion Cracking: A Study on the Effects of Designed Compression

POWER PRODUCERS spend nearly $10 billion a year fighting corrosion, and that is only covering the United States. Stress Corrosion Cracking (SCC) can cause sudden, catastrophic and costly failures. Power facilities attempt to prevent SCC by using materials that are generally thought of as SCC resistant, like austenitic stainless steels and nickel-based alloys. Despite the general corrosion resistance, even some conditions of austenitic stainless steels and Ni-based alloys are susceptible to SCC. High-strength ferritic alloys can be susceptible to sulfide stress cracking. Many alloys are subject to other types of environmentally assisted cracking under the right conditions, namely a corrosive environment and tensile stress above a certain threshold.

In fact, stress corrosion cracking is one of the most serious metallurgical problems facing the power industry today. Because it can initiate slowly and progress undetected at stresses well within engineering design limits and typical operating conditions, the threat of SCC requires frequent costly inspections. If damage is found, as is common in high-stress areas, repair or replacement is in order, costing even more in parts, labor and downtime.

In another arena, sulfide stress cracking, along with hydrogen embrittlement, prevents the use of less-expensive high-strength carbon steel alloys in oil and gas recovery efforts of the petrochemical industry. Compounds like hydrogen sulfide and sodium chloride are commonly encountered downhole, creating sour environments that are the perfect breeding ground for corrosion. If any of these types of damage are not identified prior to cracks propagating to failure, they have the potential to cause oil spills and other environmental catastrophes, costing millions or even billions. Even with regular precautionary measures, the unpredictability of these damage mechanisms warrants a reliable, and preferably cost-effective, means of mitigation.

Traditionally, methods for mitigating these types of damage have been limited to applying coatings or expensive alternate alloys. While coatings certainly help, they can degrade over time, and remanufacturing a part using a different alloy is time-consuming and costly. Either method may only lead to a small improvement. Shot and needle peening have also been used, but with limited success due to the shallow depth of compression and the fact that a highly cold-worked surface is actually more susceptible to corrosion damage.

More recently, designed compression has been employed to completely eliminate SCC without changing the material or design. Applied using highly controlled surface treatments such as low plasticity burnishing (LPB®), engineers design a deep, stable layer of compression and apply it to the susceptible area(s) of a component. By putting the surface in high residual compression far below the tensile threshold for cracking, the potential for fracture from fatigue, stress corrosion or sulfide stress cracking is eliminated. As an added bonus, LPB in particular greatly enhances the surface finish of processed components, speeding up inspections when they are needed due to the ease of identifying damage.

Lambda Technologies, a company established as a leader in life extension technology and specializing in the understanding, measurement and control of residual stresses, initiated a study to evaluate the effects of LPB on mitigating SCC in welded stainless steel components. Type 304L and 316L stainless steel were chosen for the study due to their widespread application. Plate material conforming to ASME SA240 was machined and welded into test plates of approximately 4" x 4" x 0.5". Each specimen was welded and then subsequently LPB processed on half of the face. Welding was performed by a certified nuclear repair facility using a shielded metal arc welding (SMAW) process and weld filler metal E308 and 152 for the 304L and 316L plates, respectively.

X-ray diffraction residual stress measurements were made on the specimens to characterize the effect from welding and LPB processing as functions of both depth and distance across the welds. Figure 1 (page 20) shows the residual stress distribution as a function of distance and depth for a 304L sample in both the LPB treated and untreated regions. Tensile residual stresses on the as-welded side of the sample approach +100 ksi (+689 MPa). The LPB treatment produced deep compression with a magnitude of greater than –120 ksi (-827 MPa). These results confirm that the LPB treated halves of the specimens are in a state of deep residual compression, while the untreated sides are in tension and remain susceptible to SCC.

To explore the effects of LPB on SCC, the samples were exposed to boiling magnesium chloride above 120˚C in accordance with ASTM standards. After 100 hours of exposure, the untreated sides of all specimens exhibited severe hoop and radial SCC, in some cases completely penetrating through the half-inch thickness. The LPB treated

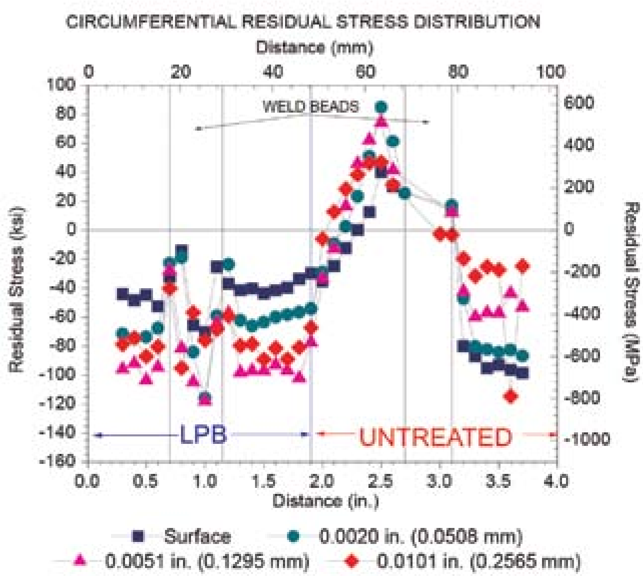

Figure 1: X-ray Diffraction Residual Stress Measurements of 304L Welded Specimen

areas contained no SCC and retained 100% of the initial compression induced by processing. Optical microscopy and fluorescent dye penetrant were used to inspect and confirm that SCC stopped completely at the LPB boundary, as seen in Figure 2.

Designed compression applied with LPB is a valuable tool in both the design and overhaul phases for equipment. As shown in this study, LPB can completely eliminate SCC in stainless steels and shows huge potential to aid in many industries. The work described in this article led to the development of an LPB system for the Department of Energy to process closure welds on nuclear waste containers. The vessels are designed to last thousands of years, but SCC threatened a drastically shorter life. Waste containers are heat-treated to relieve stress before closure, but the final closure welded areas have high tensile stresses, serving as initiation points for SCC. Shown in Figure 3, LPB imparted a 12 mm depth of compression in the weld closure, completely eliminating SCC and ensuring safe usage for the required duration.

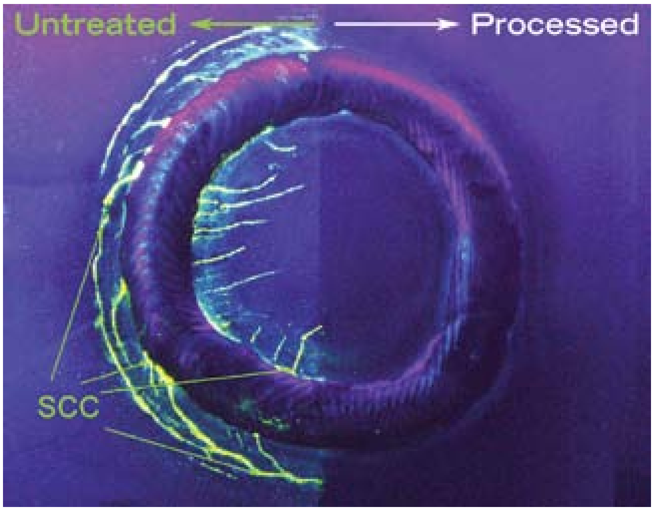

Figure 2: SCC Shown on Untreated and LPB Processed 316L Welded Specimen with Fluorescent Dye Penetrant

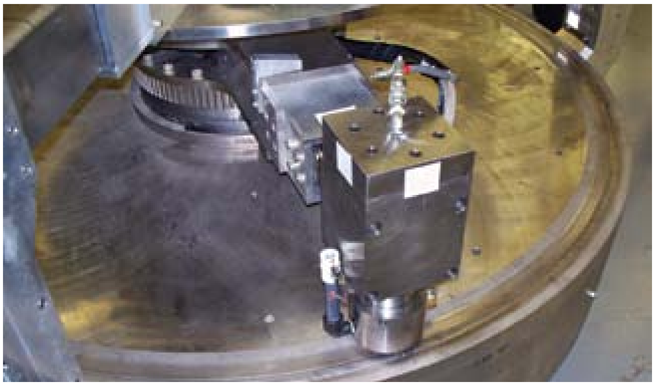

Figure 3: LPB Processing of Nuclear Waste Container Weld

The success of using designed compression to eliminate SCC and other forms of environmentally assisted cracking is not limited to stainless steel alloys. Because LPB drastically increases the damage tolerance of high-strength steels, the use of designed compression has allowed the petrochemical industry to employ materials like P110 steel, which has the strength to last in drilling conditions. Untreated P110 steel can fail from sulfide SCC in just a few hours despite its strength. LPB processed specimens lasted for more than 1,000 hours, when testing was finally discontinued. These results far exceed NACE standards and have allowed petrochemical engineers the ability to use much less expensive material while retaining all the benefits of its strength.

Designed compression applied with LPB is a valuable tool in both the design and overhaul phases for equipment. As a proven method of mitigating both SCC and corrosion fatigue in various components, LPB shows huge potential to aid in the power and petrochemical communities. As more deep wells and offshore resources are developed, and as the world's need for power continues to rise, this cost-effective surface enhancement method will be an invaluable tool to reduce operational costs, extend component life, and improve performance.

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