LAMBDA
Technologies Group

Diffraction Notes

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Issue No. 54 | Improving Component Life and Performance | 2025

BALANCING COMPRESSIVE RESIDUAL STRESS AND COLD WORK: EFFECTS ON CORROSION FATIGUE, STRESS CORROSION CRACKING, AND POLARIZATION BEHAVIOR IN ENGINEERING ALLOYS

INTRODUCTION

Surface treatments that introduce residual compression, such as shot peening and low plasticity burnishing (LPB®), play a crucial role in enhancing fatigue performance and stress corrosion cracking (SCC) resistance across an array of industries and components. These treatments reduce the likelihood of crack initiation and propagation, significantly enhancing material durability in harsh environments.

Plastic deformation, or cold work, is the mechanism by which these surface treatments induce beneficial compressive stress. Cold working can differ significantly between different surface treatments. The effects of surface cold work can be either beneficial or harmful, depending on the application. This article examines the effect of cold work on corrosion susceptibility and discusses the challenges of balancing cold work with the compressive stress requirements for improved fatigue performance. Residual stress and polarization data are presented.

SURFACE TREATMENTS & COLD WORK

Surface treatments like shot peening utilize cold work to introduce residual compressive stresses. This process can significantly enhance material properties, but it also comes with potential trade-offs that must be considered. Cold working levels vary depending on the treatment parameters; however, the magnitude of compressive residual stress is not necessarily proportional to the degree of plastic strain. While these residual stresses improve fatigue resistance, high levels of cold work can increase susceptibility to stress relaxation due to thermal exposure or cyclic loading.

Cold work can improve material characteristics beyond just introducing compressive residual stresses. Strain hardening, for example, enhances fatigue strength, while increased hardness improves wear resistance and performance in contact applications. However, excessive cold work can reduce ductility and increase the risk of cracking. Additionally, while surface treatments can enhance mechanical performance, they may negatively affect corrosion resistance, especially in environments where stress corrosion cracking is a concern. Therefore, careful consideration of the specific application and potential downsides is essential when implementing cold working techniques.

COLD WORK EFFECT ON CORROSION

Cold work affects electrochemical properties, increasing susceptibility to localized corrosion (e.g., pitting, crevice corrosion) and galvanic effects, as revealed by polarization testing. Polarization testing shows shifts in both the corrosion potential and the passive current density of some cold worked metals including stainless steels and aluminum alloys. High levels of cold work often result in more negative (less noble) corrosion potentials and higher passive current densities. These shifts are indicative of a passive layer that is less stable and more prone to localized breakdown in aggressive environments. This means that components subjected to high cold-work levels can exhibit accelerated corrosion initiation and faster propagation rates in aggressive environments.

Additionally, a more negative corrosion potential can create a galvanic situation, where the cold worked region of the material becomes anodic relative to other, less cold worked (more noble), areas. In such a scenario, the cold worked region will corrode preferentially, similar to how a sacrificial anode behaves in galvanic corrosion. This galvanic effect can lead to increased localized corrosion in the shot peened or otherwise processed areas, exacerbating corrosion attack.

An example of potentiodynamic polarization responses showing the degree to which cold work can shift potential towards more active (corrosive) states is shown in Figure 1. The plot shows results for shot peened aluminum alloy 7075-T6 containing varying levels of surface cold work. The surface cold work was determined using x-ray diffraction line broadening results. A potential shift of 0.24 volts was observed between the 0% and 30.4% cold work samples. Consulting a typical galvanic series chart would illustrate the significance of 0.24 volts.

MANAGING COLD WORK

For critical applications requiring compressive residual stress with minimal corrosion risk, several options exist to reduce cold work while maintaining beneficial stress levels. For example, shot peening process parameters can be adjusted to minimize cold work while also optimizing compressive stress. Figure 2 shows residual stress and corresponding cold work data for shot peened 7075-T6 aluminum samples. Shot peen coverage was adjusted to find the optimal balance of minimizing cold work while maintaining a level of compressive residual stress necessary to achieve the required fatigue life improvements.

Alternative surface treatments like LPB induce beneficial compressive residual stress while imparting significantly less cold work than traditional methods like shot peening. LPB achieves compressive stress via CNC-controlled processing, limiting deformation to a single pass per region and preventing excessive cold work accumulation. Figure 3 shows residual stress and cold work for LPB treated 7075-T6 compared to traditional shot peening. Depth and magnitude of compression is improved while cold work is minimized.

CONCLUSION

Surface treatment processes like shot peening offer substantial benefits in mitigating corrosion fatigue and stress corrosion cracking through the introduction of compressive residual stress. However, the associated cold work can degrade corrosion resistance in certain alloys by altering the electrochemical properties and creating galvanic interactions. Balancing mechanical performance and corrosion resistance is crucial, especially for stainless steels and aluminum alloys, where cold work can shift polarization behavior and increase susceptibility to localized corrosion.

Alternative methods like LPB offer the advantages of compressive stress with minimal cold work, providing a more corrosion-resistant solution for alloys used in aggressive environments. The strategic use of differential cold work to create sacrificial regions may also offer unique opportunities to optimize component lifespan in demanding operating conditions.

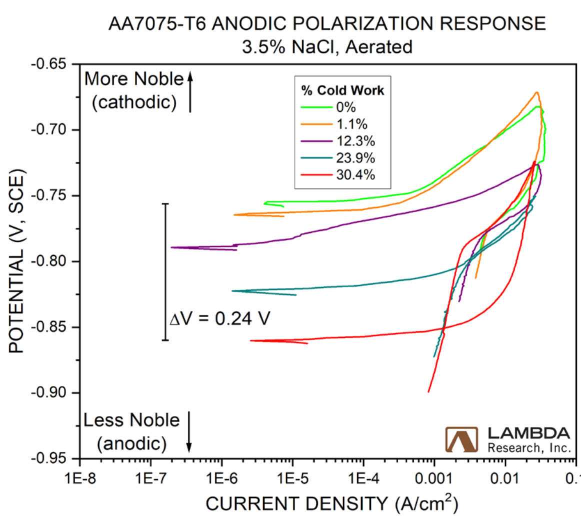

Figure 1 – Potentiodynamic Polarization Responses for Varying Levels of Cold Worked 7075-T6

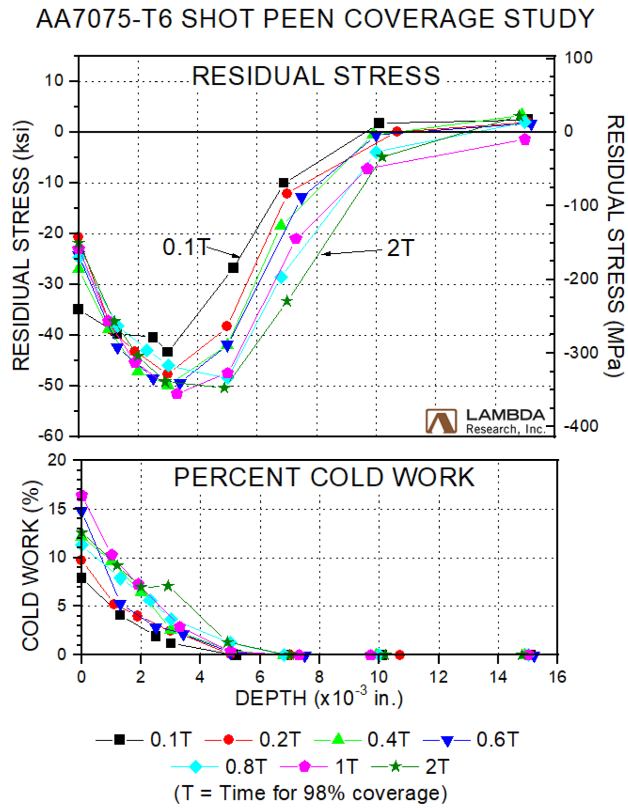

Figure 2 – Residual Stress and Cold Work Distributions for Varying Shot Peen Coverage of 7075-T6 Aluminum

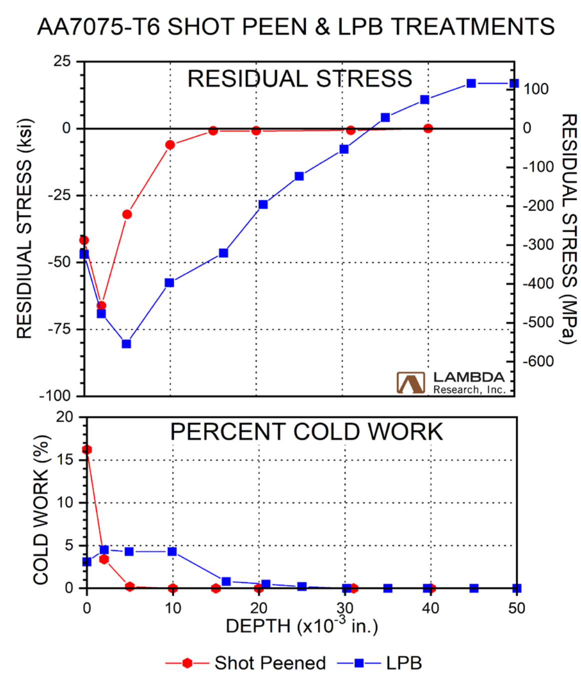

Figure 3 – Residual Stress and Cold Work Distributions in Shot Peened and LPB-Treated 7075-T6 Aluminum