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Fatigue resistance of 316L stainless steel cylindrical structures repaired using Cold Spray technology

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Extended Abstract

Abstract

Cold Spray (CS) technology involves projecting unmelted metallic powder particles at high speeds resulting in dense, cohesive coatings due to the shear of the particles and the induced compressive stresses. This makes it an attractive option for repair applications. However, CS is associated with high residual stresses, which can make the repaired zone significantly harder than the substrate, potentially leading to interface delamination under mechanical loading. To address this, post-deposition heat treatments can homogenize the microstructure of the repaired part and the substrate, thereby reducing delamination. In this study, twenty cylindrical 316L specimens were repaired using CS. Following microstructural characterization, the fatigue resistance at 2,000,000 cycles was determined in the as-deposited and heat-treated states using the standard Locati-Staircase procedure. Additionally, this study aims to compare the fatigue limits obtained with those determined using the Self-Heating procedure for fast estimation of fatigue resistance at 2,000,000. CS repairs were conducted using 316L powder with an experimental set up at EDF Les Renardières R&D laboratory. The fatigue specimens were fabricated from wrought 316L, featuring a gauge diameter of 6 mm. The central portion of the gauge section is thinned to a diameter of 5 mm. The repaired specimens were finally machined back to a diameter of 6 mm and polished using a #2000 SiC paper. Ten specimens were retained in their as-built condition, while another ten underwent a heat treatment at 1050 °C for 30 minutes, followed by water quenching. This heat treatment enabled complete recrystallization of the repaired zone, but resulted in grain growth in the substrate. For each sample, a cyclic loading amplitude is applied over 2,000,000 cycles. The applied stress is increased or decreased by ±10 MPa between tests, and unbroken specimens are reused to account for damage accumulation between tests. The fatigue resistance at 2,000,000 cycles and its associated confidence interval are determined by assuming a Weibull statistical distribution. After ten specimens broke and a total of 29 tests, the fatigue limit at 2,000,000 cycles was estimated at 269 ± 17 MPa. Post-mortem characterizations of the fractographies revealed that fatigue cracking initiates near the surface without delamination at the substrate interface. This fatigue limit estimation is significantly higher than that of wrought 316L, around 240 MPa. The much harder repaired zone (420 HV0.5) compared to wrought 316L (260 HV0.5) acts as a protective layer against fatigue cracking as local residual compressive stresses prevent cracks from initiating in the absence of microstructural defects. The staircase tests on heat-treated 316L specimens repaired by CS are currently ongoing. Grain growth and reduced hardness in the substrate were observed for the heat-treated specimens, which might lower their fatigue life. Additionally, the feasibility of localized laser heat treatments is also investigated, as they may enable recrystallization of the repaired zone without affecting the substrate. Finally, in a next step, the fatigue resistance of CS-repaired 316L specimens will be compared to those repaired using the powder-based Directed Energy Deposition process, which conducts to metallic powder fusion and interface dilution.

Keywords:

Repair Cold Spray Stainless steel Fatigue resistance Staircase Procedure Heat Treatments Microstructural characterization