Investigation of the effect of SMAT on IN718 mechanical behavior using in situ SEM micromechanical testing

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Abstract

Mechanical surface treatments are widely used in the aeronautical industry with the dual objective of enhancing the surface properties of crucial components and delaying fatigue crack initiation. Indeed, fatigue damage was identified as the primary mechanism of failure for turbine disks, with crack initiation predominantly occurring on the surface.
Surface Mechanical Attrition Treatment (SMAT) is a process that creates a nanocrystalline layer on the surface of treated mechanical parts in addition to superficial compressive residual stress and strain hardening. Previous studies have shown that SMAT can increase the yield strength, stress at failure, and improve the fatigue life of metal parts by inducing severe plastic deformations at the surface of the material without altering its chemical composition or core microstructure. Given the thermal and mechanical loads experienced by aeronautical components during service, it is important to investigate the relaxation of residual stresses introduced by SMAT and the associated changes in material properties. Such an understanding is vital for accurately assessing the real impact of SMAT on the longevity and reliability of these components.

This study aims to investigate the effect of SMAT on the mechanical properties of a nickel-based superalloy, Inconel 718. This material, especially in its Direct Aged (DA) condition, is commonly used in aeronautical applications due to its good mechanical properties and corrosion resistance. Existing literature and measurements indicate that the microstructural changes induced by SMAT are localized within the first few hundred of micrometers of the sample surface and may impact the mechanical properties of the material under thermomechanical loading. In order to capture these evolutions at the appropriate scale, innovative characterization techniques, such as *in situ* SEM testing, seemed an appropriate choice. *In situ* SEM four-point bending tests were performed at 20◦C and 450◦C on both untreated and SMAT-treated samples, with two different sets of SMAT parameters. Combined with Digital Image Correlation (DIC), this technique allows access to the local strain fields of the specimen by calculating the displacements of each pixel between the reference image and the images of the deformed material taken during the test. Local changes in microstructure and mechanical parameters can be monitored using this experimental protocol, especially as these tests are coupled with EBSD analysis.

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Initially, a broad zone was examined to determine the strain across the full depth of the specimen, using the inherent microstructure of the material as a speckle pattern for pixel identification. First results show a delayed onset of plasticity at $20\circ$C and $450\circ$C for the SMAT-treated material, compared with the untreated material, in both the compression and tension solicited zones. The observation of similar results in the compression and tension zones is noteworthy, particularly in light of the significant compressive residual stresses that were measured. This suggests that SMAT may induce a work hardening effect, which compensates the influence of compressive residual stresses.

This broader approach offers an overview of macroscopic specimen behavior; however, it lacks the resolution to capture strain localization and slip bands. Therefore, the sample was also studied at more refined scale, with a speckle pattern created through electron-beam lithography, to observe strain localization and plasticity mechanisms. EBSD maps were also acquired during the tests, to visualize the evolution of strain hardening in the sample via Kernel Average Misorientation (KAM) measurements.
In parallel, simulations of the bending tests were conducted, incorporating the surface residual stress gradient obtained from XRD profiles and considering the work hardening. Comparison of these simulations with experimental results enables the dissociation of the contributions from residual stresses, work hardening and grain refinement, thereby providing a deeper understanding of the experimental observations. This work also supports the development of a model that captures the cyclic non-linear behavior of the material, providing a basis for more accurate fatigue life estimations for the SMAT-treated material.