Yield surface modeling for failure prediction in turbine disk applications

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Abstract

The plasticity criterion has been shown to strongly influence the global behavior of a rotating aeronautical turbine disk and its expected burst speed (1). Moreover, yield surfaces can evolve very rapidly with plastic strain. Their accurate knowledge is thus essential to accurately predict the behavior of a part subjected to multiaxial loading such as the turbine disk. Three characteristics of the yield locus have to be modeled: the center's movement (kinematic hardening), the size change (isotropic hardening) and a modification of its overall shape (distortional hardening). Furthermore, the material's failure is characterized by local ductile fracture and it has been shown previously that the curvature of the yield surface strongly influences the strain localization (2). Thus, this work aims to precisely reproduce the subsequent yield surfaces in order to predict accurately the failure of the turbine disk.

In this study, the shrinkage of the yield surface of a nickel-based superalloy after tensile loading has been demonstrated experimentally. Firstly, loading-unloading experiments with plasticity threshold detection on an axisymmetrical sample were conducted in order to investigate the material's hardening in the tensile direction and fine-tune the plasticity detection technique. Then, the subsequent yield surfaces were obtained through axial-torsional loading on a thin-walled tubular sample for various pre-strains from small to finite deformation. The subsequent yield surfaces exhibits an egg-shaped distortion, strong kinematic hardening and a very fast reduction in size. A cross-effect was also visible with a size reduction in the direction perpendicular to the loading direction.

Two material behavior laws have been identified on test results and used in this study. One model uses Hosford's macroscopic phenomenological plasticity criterion whereas the second model is an homogenized polycrystalline model. The use of polycrystalline plasticity models enables the numerical reproduction of yield surface distortion effects observed experimentally for all loading paths thanks to the model's proximity to the physical mechanisms at the origin of the plasticity. The prediction of the local field's redistribution of these models was then studied through the comparison between experimental fields measured via digital

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image correlation techniques on a flat notched specimen and finite element analysis results carried out with the Zset software.

Finally, the prediction of the strain localization obtained through the application of the loss of ellipticity criterion to finite element simulation results has been compared to experimental failure for both samples and the turbine disk. Special attention was paid to the effect of corner formation on the yield surface.

References :

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