Numerical Prediction of Yield Surface Evolution in LENS-Manufactured Inconel 625 under Sequential Multiaxial Probing: A UMAT-Based Approach

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Numerical modelling of yield surface evolution under non-proportional multiaxial loading is critical for the structural integrity assessment of high-performance engineering components. Nickel-based superalloys such as Inconel 625, fabricated by Laser Engineered Net Shaping (LENS), inherently develop a columnar grain microstructure that introduces pronounced crystallographic anisotropy and direction-dependent plastic flow behaviour [1]. Such orientation-dependent mechanical responses remain beyond the predictive capability of conventional uniaxial characterisation approaches. To capture the anisotropic yielding phenomenon of LENS-fabricated Inconel 625 thin-walled tubular specimens, a dedicated UMAT-subroutine is implemented in ABAQUS, enabling simulation of the initial yield surface under sequential biaxial tension-torsion loading at a 0.01% plastic offset strain criterion. The UMAT integrates the Szczepiński anisotropic yield criterion coupled with the Armstrong-Frederick nonlinear kinematic hardening law to capture path-dependent back-stress evolution. Across all loading paths, the simulation demonstrates excellent agreement with the experimentally fitted yield locus. A mean angular deviation of $|\Delta\alpha| = 0.51°$ with every path within $\pm 1.5°$ confirms directional accuracy, while a mean radial deviation of $|\Delta r| = 2.41\%$ ($< \pm 5\%$) validates magnitude reliability. Additionally, Szczepiński function values are consistent within $f(\sigma, \tau) \in [0.90, 1.10]$ confirms accuracy. The antisymmetric angular deviation pattern of positive back-stress overshoot in 2nd and 4th quadrants constitutes direct numerical validation of kinematic behaviour and the Bauschinger effect under sequential non-proportional loading.

(a) (b)

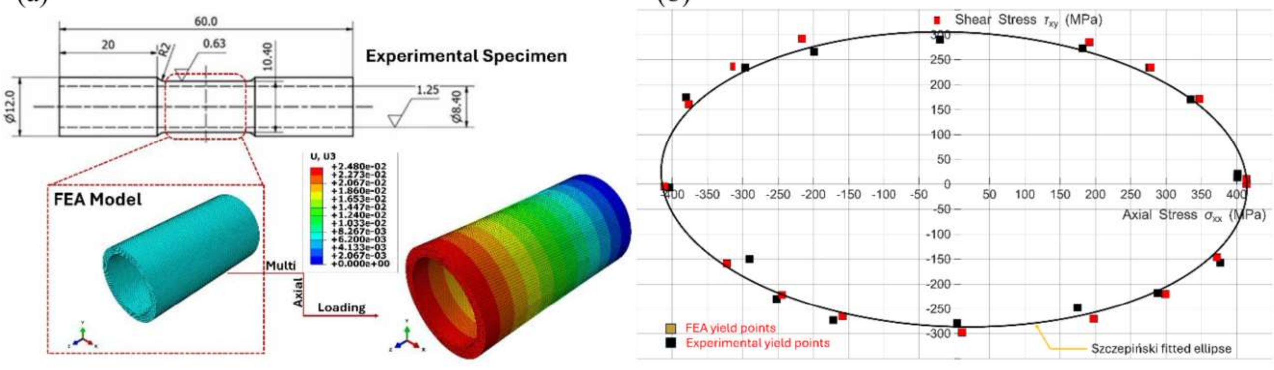

Figure 1. (a) Specimen geometry and discretised computational domain showing contour of deformed model, (b) Experimental and finite element simulated yield points at 0.01% offset strain with fitted Szczepiński ellipse.

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