Abstract

The thesis delves into the in-depth comprehension of the influence of localized microstructures, specifically within or in proximity to the failure-prone regions, on determining the global mechanical properties of low-carbon ferritic steel. The microstructures around two selected failure-prone areas—the crack-tip and the surface—of an in-service structural component were selectively tailored at a local scale (up to a specific area or distance) by the process of tensile pre-straining followed by annealing and plunge surface grinding. Gradient ferrite grains were developed around the notch-root via pre-straining and annealing, while surface grinding induced an ultrafine ferrite grain on the ground surface.

At the notch-tip, pre-straining induced heterogeneous plastic deformation, forming a kidney-shaped plastic zone (r_p^*) with sharply declining strain (ε_{yy}), which expanded with increased pre-strain level and reduced thickness. Subsequent annealing led to the formation of gradient ferrite grains at the notch-root through recrystallization and strain-induced boundary migration (SIBM). At low pre-strain (6%), a steep grain size (GS) gradient (22 μm to 180 μm) was observed over a small area. At high pre-strain (12%), a gradual transition in ferrite GS (16 μm to 217 μm) extended over a larger area (close to ~ r_p^*). Additionally, thin specimens led to more gradual gradient ferrite grains than thicker ones. The gradient was observed in all directions, creating a layered structure pattern. Strain above a critical threshold induced complete recrystallization, forming fine, strain-free ferrite grains near the notch-root, while strain below this level caused structural restoration via grain coarsening by SIBM. Nanoindentation-derived dislocation density aligns well with trends from EBSD analysis. Statistical analysis revealed a power relation between ferrite GS and ε_{yy} within the modified zone upon annealing at 650 °C for 3 hours. Superior impact toughness (DBTT ~-32.4°, USE ~128 J) resulted from a gradual ferrite grain gradient, owing to fine GS resisting crack

propagation. Poor impact toughness (DBTT ~2.6°, USE ~97 J) arose from a steep gradient due to coarse ferrite grains within the active zone facilitating cleavage crack initiation. Meanwhile, at the surface, surface grinding produced ground layers of variable thickness, ranging from approximately 5.0 - 10.4 μm, using different combinations of grinding parameters. The characterization of the ground layer reveals the presence of ultrafine grains (average grain size ≤ 1 μm), sub-grains, along with some elongated deformed grains. Furthermore, a high fraction of low-angle boundaries (LAGBs), hardness, and dislocation density are identified in the ground layer. In contrast to ferrite deformation texture (γ-fiber and ε-fiber) at high grinding parameters, ferrite recrystallization texture (cube fiber) was found at low grinding parameters. Severe plastic deformation generating heat during grinding caused rapid dynamic recovery and, to a certain extent, continuous dynamic recrystallization, which resulted in the formation of sub-grains and ultrafine grains. The fatigue ductility exponent (c) from the indentation fatigue test fell within the expected range of -0.5 to -0.7. A sample with high tensile residual stress and roughness displayed inferior fatigue performance, as anticipated, compared to cases with low roughness and compressive residual stress.

In conclusion, the study introduces novel approaches to locally tailor microstructures within or in close proximity to identified failure-prone regions. It demonstrates that surface grinding can be an effective method for grain refinement to an ultrafine level on the surface, which enhances overall surface integrity and consequently extends the component's service life. Later, upon continuous service, if a crack is generated, which was detected using non-destructive testing, the application of appropriate heat treatment, as per the current approach, can be employed to tailor the crack-tip microstructure using a laser gun or induction heating arrangements, locally, and further prolong the lifespan of the entire component.

Keywords: Localized microstructure; Tensile pre-straining; Annealing; Surface grinding; Crack-tip microstructure; Gradient ferrite grains; Ultrafine ferrite grains; Recrystallization; Strain-induced boundary migration; Impact toughness; Nanoindentation fatigue test.