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Selection of Hardening Routes for Low-Alloy Spring Steels within a Process–Microstructure–Fatigue Design Space

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Abstract

A data-driven framework is proposed to aid selection of
hardening routes for low-alloy medium-carbon spring
steels. An experimental database comprising multiple
industrial heat treatments—quench–temper, austempering, and hybrid routes—is compiled with microstructural metrics and fatigue properties. Gradient boosting and Gaussian process regression are used to construct surrogate models linking process parameters to performance indicators. The resulting process– microstructure–fatigue maps reveal domains where non-conventional treatments surpass traditional quench– temper in fatigue strength and life. Feature importance analysis highlights the combined effect of retained austenite content and residual stress gradients. The approach builds directly on systematic comparisons of hardening methods for spring steels and demonstrates how machine learning can accelerate heat-treatment design while respecting metallurgical constraints.

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