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Integrated computational materials engineering in quenching and tempering of extra-large rotors

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ABSTRACT

Integrated computational materials engineering approach was applied to study the quenching and tempering of extra-large forgings of 30Cr2Ni4Mo1V steel used for the manufacturing of low pressure rotors of industrial gas turbine engines and generator rotors. Of particular interest were the heat transfer, microstructure evolution, residual stresses, and distortions. Physical and mechanical properties of the material were tested and compared with computed values using JMatPro with general steel database. Property data and property calculation tools were integrated with numerical analyses of spray quenching and subsequent tempering. Thermocouples were mounted in one low pressure rotor to measure the temperature change during spray quenching and tempering. This rotor was sectioned for microstructural examinations and mechanical property tests upon completion of the quenching and tempering heat treatment.

Coupled heat transfer, microstructure evolution, and mechanical analyses were accomplished in temperature–displacement analyses using FEA software ABAQUS with a combination of user material subroutines UMATHT and UMAT, which describe the thermal and mechanical behavior of the material in the heat treatment. An empirical model for convectional heat transfer in spray quenching was implemented in user subroutine FILM to simulate the heat extraction at the surface during spray quenching. Microstructural evolution models were implemented in user subroutine UMATHT. Microstructural state variables were computed and updated in every time increment of the transient heat transfer analyses. Microstructure-dependent mechanical properties and transformation plasticity models were implemented in user subroutine UMAT, which allowed mechanical state variables be computed and updated in each time increment of the static stress analyses.

Numerical simulations indicate that slowest cooling rates in the temperature range of phase transformations during quenching occur in the vicinity of half radius in all sections, which lead to less desirable microstructure and mechanical properties in this region. Upon the completion of quenching and tempering heat treatment, longitudinal extensions occur in large radius sections of forgings, which are attributed to the combination of thermal stresses and transformation plasticity. Predicted results are compared and validated with temperature measurements, microstructure examinations, mechanical property tests, and dimensional measurements.