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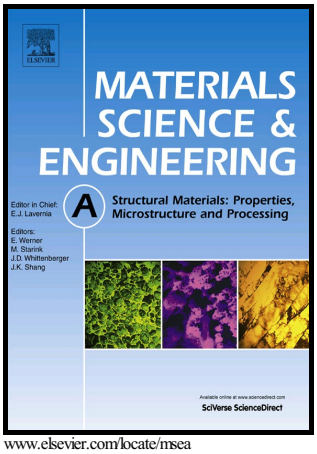

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Microstructure-property relationship in a low carbon Nb-B bearing ultra-high strength steel by direct-quenching and tempering

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Abstract

This work describes here the synergistic effect of niobium micro-alloying in combination with boron addition on the development of a 900 MPa grade ultra-high strength low carbon cost-effective bainitic steel processed by direct-quenching and induction tempering. A mixed microstructure consisting of acicular ferrite and lath bainite associated with high density of high angle grain boundaries was obtained by controlled rolling and direct-quenching. Nano-sized precipitation behavior during controlled rolling and induction tempering was studied by transmission electron microscopy (TEM). A number of nano-sized precipitates were observed in the matrix after controlled rolling and direct-quenching. These precipitates were identified by electron energy loss spectrometry (EELS) in scanning TEM (STEM) to be TiN-Nb(C,N) or TiN-NbC composite precipitates, and were associated with mean austenite grain size of ~34±6 μm in steel before finishing rolling. A finish rolling reduction of 67% below non-austenite recrystallization temperature pancaked the austenite grains to 10-15 μm in thickness. Nano-sized NbC formed during induction tempering at 670°C had an average diameter of ~4.3 nm and 9.5 nm for tempering duration of 5 min and 30 min, respectively. It is noted that while nano-sized NbC precipitates smaller than 5 nm provide significant precipitation hardening effect to increase the mechanical strength, acicular ferrite in the mixed microstructure helps in retaining high elongation of low carbon direct-quenched and tempered steel. Ultra-high yield strength of 944 MPa with high ductility (uniform elongation of 6.3% and total elongation of 20%) was obtained after induction tempering at 670°C for 5 min.

Key words: ultra-high strength; direct quenching and tempering; Nb-B bearing steel; grain refinement; nano-sized NbC precipitate.