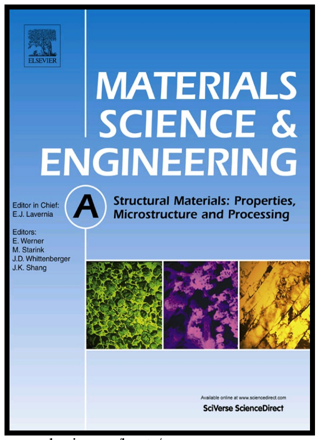

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Evolution of nano-size precipitation and mechanical properties in a high strength-ductility low alloy steel through intercritical treatment

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Abstract

A two-step intercritical heat treatment was designed to obtain a multi-phase microstructure consisting of intercritical ferrite, tempered martensite/bainite and stable retained austenite in a low carbon and copper alloyed steel, characterized by high strength and high ductility combination. The evolution of copper precipitation during intercritical tempering was studied by transmission electron microscopy (TEM). Electron microscopy studies indicated that the precipitation of copper during tempering followed the sequence (as a function of time): twinned 9R-Cu (0.5 h) → de-twinned 9R-Cu (1 h) → ε-Cu (greater than 3 h), which was accompanied by increase in the size of precipitates from ~11 nm to ~30 nm. Considering the cutting mechanism of precipitation strengthening, ε-Cu precipitation contributed to ~248 MPa and ~207 MPa toward yield strength for 3 h and 5 h tempering, respectively. The average size of niobium-containing carbides varied marginally from ~11-16 nm and had a Baker–Nutting (B-N) orientation relationship with the ferrite matrix. The combination of transformation induced plasticity (TRIP) effect and nano-sized precipitation strengthening contributed to excellent mechanical properties (yield strength > 700 MPa, tensile strength > 800 MPa, the uniform elongation > 16% and the total elongation > 30%).

Keywords: high strength steel; intercritical tempering; retained austenite; copper precipitation