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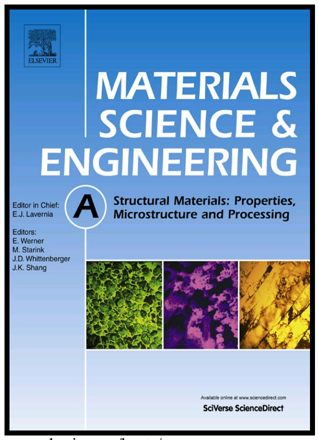

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Fracture toughness of hydrogen charged as-quenched ultra-high-strength steels at low temperatures

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ABSTRACT

The effect of hydrogen on the fracture and impact toughness of ultra-high-strength steels at sub-zero temperatures in the transition temperature region has been investigated with arctic applications in mind. Two types of as-quenched microstructure were studied, i.e. autotempered martensite and a mixture of martensite and bainite, both having yield strengths close to 1000 MPa. These were charged with hydrogen using passive cathodic protection and then tested in both the charged and uncharged condition at sub-zero temperatures. Hydrogen contents were measured with melt-extraction. Fractography, kernel average misorientation measurements and cohesive zone modelling were used to analyse the results considering the degree and the active mechanisms of hydrogen embrittlement. It is shown that hydrogen embrittlement is present at sub-zero temperatures, causing an increase in fracture toughness reference temperature T_0 and a small decrease in deformation capability. The relationship between the T_0 and the impact toughness transition temperature T_{28J}, which, in the case of ultra-high-strength steel, deviates from that observed for lower strength steels, is proposed to be affected by the hydrogen content.

Keywords: Hydrogen embrittlement; Fracture toughness; Martensite; Sub-zero; Cohesive zone modelling; Kernel average misorientation

Nomenclature

δ_c	critical cohesive separation
σ_{11}	opening stress
σ_c	critical cohesive stress
$\sigma_{c,H=0}$	hydrogen free critical cohesive stress
σ_v	viscosity regularized cohesive stress
σ_{YS}	yield strength
σ_{TS}	tensile strength
ζ	viscosity parameter
A	elongation
A_g	uniform elongation
C_I	initial, homogeneous hydrogen concentration
C_L	lattice hydrogen concentration
CZM	cohesive zone modelling