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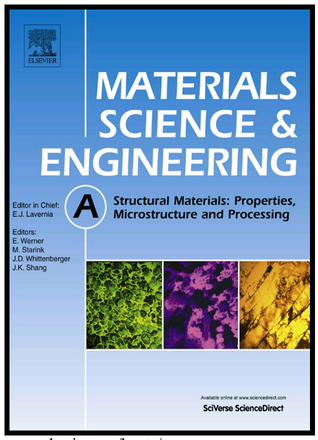

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EFFECT OF IMPURITY LEVEL AND INCLUSIONS ON THE DUCTILITY AND TOUGHNESS OF AN ULTRA-HIGH-STRENGTH STEEL

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ABSTRACT

The effect of composition, size and number density of inclusions on the ductility of an experimental direct quenched ultra-high-strength low-alloy steel with a minimum specified tensile strength of 1300 MPa has been investigated. Two steels with impurity levels, i.e. total O + N + S contents, of 55 and 91 mass ppm have been studied. Both steels were Al-killed and Ca-treated, and had a martensitic microstructure after hot rolling and direct quenching. Ductility was characterized using tensile and Charpy V-notch testing. The number, size and composition of the inclusions were characterized using field emission scanning electron microscope with energy dispersive spectrometer (FESEM-EDS). At the higher impurity level of 91 ppm, the inclusion structure consisted of titanium nitrides, spherical calcium aluminates and elongated manganese sulphides, whereas at the lower impurity level of 55 ppm, the inclusion structure consisted of mainly fine spherical calcium aluminates with sulphide shells. The impurity level did not have a significant effect on the number density of inclusions, as with higher and lower impurity level the number of inclusions mm^{-2} was 80.5 and 73.8, respectively. However, the impurity level affected somewhat more the size distribution of the inclusions, as well as the composition of coarse inclusions with their longest length more than 8 μm. The number density of coarse inclusions mm^{-2} rose from 0.7 to 1.2 with increasing impurity level, and with the higher impurity level of 91 ppm, 72% of the coarse inclusions were titanium nitrides or manganese sulphides, whereas with the lower impurity level of 55 ppm, only 14% of the coarse inclusions were titanium nitrides while no manganese sulphides were detected. Coarse titanium nitrides were especially detrimental to the impact toughness. The number density of them should be below 0.4 mm^{-2} in order to guarantee the best possible toughness in the steel in question.

Keywords: electron microscopy, inclusion, martensite, mechanical characterization, failure, fracture

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