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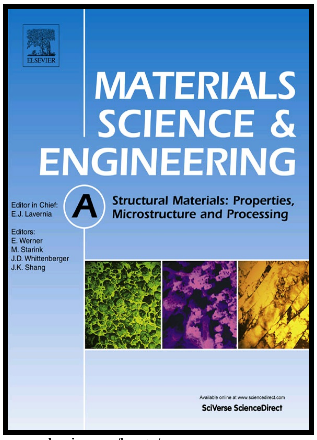

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Interpretation of significant decrease in cryogenic-temperature Charpy impact toughness in a high manganese steel

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Abstract

The grain boundary segregation and precipitation and associated deformed microstructure under cryogenic-temperature and dynamic-loading conditions were systematically investigated by means of high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM), transmission electron microscopy (TEM), high-resolution TEM (HRTEM) and electron back-scattered diffraction (EBSD). The studied steels exhibit equiaxed grains with the similar grain size of 12.0 ~ 13.3 μm. The twinning and dislocation slip were observed as the main deformation modes under cryogenic-temperature and dynamic-loading conditions. However, the secondary twinning system is suppressed and plastic deformation by dislocation slip is small in the steel annealed at 800 ^{o}C for 3 h, leading to a significant decrease in Charpy impact toughness at -196 ^{o}C. The HAADF-STEM results show that there are numerous $(Cr,Mn)_{23}C_6$-type carbides along grain boundaries and the Cr or C peaks have been detected at grain boundaries without $(Cr,Mn)_{23}C_6$-type carbides in the steel annealed at 800 ^{o}C for 3 h, whereas these carbides and Cr or C peaks were not observed in the steel annealed at 300 ^{o}C for 3 h. However, the Mn, P, S, Si and Cu peaks were not observed at grain boundaries in both steels by means of STEM-EDX. The critical shear twinning stress is high in the steel annealed at 800 ^{o}C for 3 h due to heavier grain boundary segregation. Meanwhile, the local stress concentration at grain boundaries may be relaxed because the crack may easily nucleate at grain boundaries whose cohesion is weakened by heavier grain boundary segregation or $(Cr,Mn)_{23}C_6$-type carbides/matrix interfaces whose bonding strength is relatively small. Therefore, the secondary twinning system is relatively hardly activated and plastic deformation by dislocation slip is relatively small for the steel annealed at 800 ^{o}C for 3 h.

Keywords: High manganese steel, carbides, grain boundary segregation, twinning, cryogenic-temperature toughness