Effect of Microstructure and Crystallographic Texture on Mechanical Properties of Modified 9Cr-1Mo Steel

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by

Arya Chatterjee
(Roll No: 12MT92P02)

Under the supervision of

Dr. Debalay Chakrabarti

and

Prof. Rahul Mitra

Department of Metallurgical and Materials

Engineering Indian Institute of Technology

Kharagpur

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Abstract

A modified 9Cr-1Mo steel received in normalized and tempered condition has been separately subjected to different normalization treatments varying the austenitization temperatures (1100°C / 1025°C / 950°C) and different hot-rolling treatments varying the finish rolling temperatures (1050°C / 1000°C / 950°C / 875°C). A combination of both these processing was also carried out by hot-rolling at different temperatures and normalizing each hot-rolled plate from different temperatures. The amount of deformation applied on each hot-rolled plate was constant having true strain of ~ 0.7. The processed samples were finally tempered at 750°C and tested for tensile and Charpy impact properties following standard procedures. A substantial improvement in upper-shelf energy (USE) by ~20 J and reduction in ductile-to-brittle transition temperature (DBTT) by ~20°C has been noticed in normalized samples, in comparison to the As-received plate, especially for the sample normalized from 1025°C. Although hot-rolling increased the strength significantly (by ~100 MPa), it reduced the ductility by more than 10% and increased the DBTT by more than 25°C. Among the hot-rolled samples, the plates rolled at 1050°C showed the best combination of high USE (comparable to the As-received steel) and low DBTT. The results have been analysed considering the effect of normalization and rolling temperatures on the parameters related to the microstructure and crystallographic texture of the steel, such as, prior-austenite grain size and martensitic packet size, ferrite fraction, effective grain size, fraction of the low-angle boundaries, fraction of {100} cleavage planes parallel to the main fracture plane and the fraction of {110 and 112} slip planes along the 45° to the main fracture plane (i.e. along the maximum shear stress plane). 'Effective grain size' represents the crystallographic unit over which cleavage crack propagates in an uninterrupted fashion. For the study of macro- and micro-texture, X-ray diffraction based texture goniometer and electron back-scattered diffraction (EBSD) technique were used, respectively.

The Impact properties of the investigated samples were represented in terms of USE, DBTT, 28J impact energy transition temperature, general yield temperature (T_{gy}), blunt-notched dynamic fracture toughness (K_{jd}) and reference temperature (T_{0-MSP}^{dy}). K_{jd} was determined following the modified Schindler's procedure for the same strain rate as that of the standard Charpy impact tests. Correlation between different transition temperatures and their conservativeness were analysed in view of the fracture safe design. Finally, microstructural parameters were related to the impact transition temperatures based on the microstructural and fractographic studies.

The effect of hierarchical martensitic microstructure having different structural units of varying length scales (i.e. lath, sub-block, block, packet and prior-austenite grain) on the micro-mechanism of deformation and fracture have been elucidated by studying the propagation of cleavage cracks and the formation of shear cracks within the investigated samples using EBSD technique and visco-plastic self-consistent (VPSC) polycrystalline plasticity model. The study indicates strong influence of certain crystallographic variants on the c leavage crack propagation. The ‘martensitic block’ was found to be the ‘effective grain’ controlling the impact toughness at low temperatures, where cleavage fracture dominates. Dynamic fracture at high temperatures, on the other hand, was found to be dictated by cracking along the shear bands, evolution of which depend on the size and distribution of the prior-austenite grains.

An attempt has also been made to study the effect and evolution of microstructure and texture of the normalized samples during creep deformation at three different temperatures (550°C / 600°C / 650°C). The sample normalized at 1025°C show better creep resistance at the low temperature (550°C) and the high temperature (650°C) creep regimes. The creep properties are correlated with the microstructural parameters and their stability, precipitate-dislocation interaction and crystallographic texture.

Keywords: 9Cr-1Mo Steel, Martensite, Crystallographic texture, Thermomechancial processing, Charpy impact testing, Tensile testing, Creep testing, Effective grain, Adiabatic shear band.