A CRITICAL GRAIN SIZE CONCEPT TO PREDICT THE IMPACT TRANSITION TEMPERATURE OF TI-MICROALLOYED STEELS

A. Ray
Department of Metallurgical and Materials Engineering, Indian Institute of Technology (I.I.T.), Kharagpur, 721 302, India.
arunimray@gmail.com

S. Sivaprasad
Material Science Technology Division, National Metallurgical Laboratory (CSIR-NML), Jamshedpur, 831 007, India.
shiva@nmlindia.org

D. Chakrabarti
Department of Metallurgical and Materials Engineering, Indian Institute of Technology (I.I.T.), Kharagpur, 721 302, India.
debalay@metal.iitkgp.ernet.in, Ph. +91-3222-283282, Fax. +91-3222-282280.

Abstract. Based on the assumption that local principal stress remains the same everywhere within a ferrite grain, a critical value of grain size can be determined for a fixed TiN particle size. When the grain size is smaller than the critical size, grain boundary is expected to resist the propagation of a micro-crack that is initiated from a TiN particle. Using this concept, an attempt has been made to predict the local cleavage fracture stress and 27J impact transition temperature (ITT) of different Ti-microalloyed steels, which were subjected to (instrumented) Charpy impact testing.

Keywords: ductile-to- brittle transition, instrumented impact testing, TiN particle size, critical ferrite-grain size.

1. Introduction. TiN particles prevent the austenite grain growth during soaking or welding treatment of the steel. However, coarse TiN particles can act as the cleavage initiation sites due to their brittle nature and that affect the low temperature toughness of steel [Yan et al. (2006)]. TiN particles in steel can have inherent crack, which starts to propagate as the applied stress increased during the mechanical testing [Fairchild et al. (2000)]. Hence, crack nucleation appears to be an easier process and the crack propagation controls the cleavage fracture, which is a transgranular fracture. Depending on the critical step behind the crack propagation, either the propagation across the particle-matrix (p-m) interface or matrix-matrix (m-m) interface (i.e. the grain boundary), the cleavage fracture stress ($\sigma_f$) can be calculated from the generalised Griffith’s equation as given below [Hahn (1984), Echeverría and Rodriguez-Ibabe (2003)]:

$$\sigma_f = \sigma_{im} = \alpha \sqrt{\frac{2E\gamma_{im}}{(1-\nu^2)d_i}}$$

(1)
where, \( i \) can be either particle (\( p \)) or matrix (\( m \)), \( d_i \) is either the particle size (\( d_p \)) or the grain size (\( d_m \)) and \( \gamma_{pm} \) and \( \gamma_{mm} \) are the corresponding ‘effective surface energies’ for the crack propagation across \( p-m \) or \( m-m \) interfaces, respectively. Therefore, the cleavage fracture stress can be predicted from eq.(1) either considering the ferrite grain size or the particle size. Experimental studies indicated that the combination of large ferrite grains and coarse TiN particles seriously hamper the toughness of low-carbon steels [Echeverría and Rodriguez-Ibabe (2003)]. There have been very few attempts [Martin-Meizoso et al. (1994), Rodriguez-Ibabe (1998)] to examine the combined role of grains and particles on the resistance of the steel against low-temperature cleavage fracture. Hence, the present study proposed a fracture model that can be able to compare between different steels having different combinations of ferrite grain size and TiN particle size in terms of their resistance to cleavage fracture and predict the cleavage fracture stress and fracture transition temperature for each steels.

\[ \sigma = \frac{1}{2} \sqrt{\gamma_{pm} \gamma_{mm}} \]

**2. Concept of Critical Grain Size.** For the prediction of cleavage fracture stress from eq.(1) usual values of Young’s Modulus (\( E \)) and poisson’s ratio (\( \nu \)) for HSLA steels are 200GPa and 0.3, respectively. Micro-cracks formed in cuboidal TiN particles can be assumed as penny shaped for which, \( \alpha = \sqrt{(\pi/2)} = 1.25 \) [Hahn (1984)]. In order to consider the crack propagation under lowest possible fracture stress, \( \gamma_{pm} \) and \( \gamma_{mm} \) values have been taken from the literature as 7 J/m² and 52 J/m², respectively, and used in the eq.(1) [San Martin and Rodriguez-Ibabe (1999), Wu and Davis (2004), Gerberich and Kurman (1985)]. Thus, for different combination of grain size and particle size, a fracture stress diagram can be constructed as given in Fig. 1. The diagram presents the \( \sigma_{pm} \) values for different particle sizes and the variation of \( \sigma_{mm} \) as a function of grain size. The present study considers a competition between these two values at the local scale. Assuming that local principal stress remains the same everywhere within a ferrite grain, for a fixed particle size, from the intersection point of \( \sigma_{pm} \) and \( \sigma_{mm} \) curve in Fig. 1 (indicated by arrows), a critical value of the grain size (\( d_{crit} \)) can be obtained. When the actual grain size is smaller than \( d_{crit} \), \( \sigma_{mm} > \sigma_{pm} \) and hence, the local fracture stress (\( \sigma_f \)) will be corresponding to \( \sigma_{mm} \) i.e. resistance to crack propagation at