STRAIN RATE DEPENDENCE OF FRACTURE TOUGHNESS ($J_{IC}$) AND DUCTILITY

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1. INTRODUCTION

In most cases in engineering practice, fracture initiation in metals and alloys is experimentally determined under slow loading conditions. However for materials with strong temperature and strain rate dependence, the fracture toughness usually decreases with decreasing temperature and increasing loading rates. It is thus important to obtain a quantitative correlation between ductility and fracture toughness of these materials as a function of temperature and through a wide range of loading rates. Experimental data in these ranges reveals a transition region from high to low values of fracture toughness.

A study of the variation of fracture toughness $J_{IC}$ and ductility, measured under both tensile loading and biaxial plane strain (bulge) loading of AISI 1045 steel, in the transition temperature range was carried out [1]. The temperature range used showed changes in behaviour from primarily linear elastic to elastic-plastic for this steel. A model relating fracture toughness, expressed as $J_{IC}$ and bulge ductility for materials exhibiting linear elastic behaviour at low temperature and elastic-plastic at higher temperatures was reported [2], while a model based on ductile fracture mechanisms involving void nucleation followed by cavity growth and void coalescence was developed to relate the fracture toughness parameter $J_{IC}$ with temperature [3].

Determination of the fracture toughness of materials under high loading rates, in the dynamic regime, has received much less attention than in the case of quasi-static loading. Presently, there is an increased interest in dynamic fracture studies motivated in part by problems associated with transport and energy applications. The difficulties in studying dynamic fracture behaviour of materials lies in both analytical and experimental aspects.
In the analysis of dynamic fracture $\dot{K}_I$ defined as
\begin{equation}
\dot{K}_I = \frac{K_{IC}}{t_c},
\end{equation}
where $t_c$ is the time interval from the start of loading to the point where the crack starts to propagate, is frequently used to characterize how fast the crack tip region is loaded. The loading rate parameter $\dot{K}_I$ may be changed over several orders of magnitude, mainly due to changes in the loading time $t_c$.

The most common experimental technique to study dynamic fracture is the Instrumented Charpy test. Difficulties in understanding the inertia forces and the wave mechanics in the Charpy specimen limit the interpretation of the resulting data from this test. Another testing alternative for studying fracture at higher loading rates is based on the Split Hopkinson Pressure Bar system [4,5]. An experimental method was described for measuring the fracture properties of metals and alloys over a wide range of loading rates, which can cover over six orders of magnitude in $\dot{K}_I$ [5]

\[ 1 \text{ MPa\textcdot m}^{-1} \text{s}^{-1} \leq \dot{K}_I \leq 10^6 \text{ MPa\textcdot m}^{-1} \text{s}^{-1}. \]

Studies in dynamic fracture have been limited to analysis based on linear elastic fracture mechanics concepts. In many engineering materials, such as low and medium strength steels, fracture is analyzed in terms of elastic-plastic behaviour using the J-integral. Recently wedge loaded compact tension specimens (WLCT) were adopted for quasi-static and dynamic determination of $J_{IC}$ using a special arrangement of the Split Hopkinson Pressure Bar [6]. The analysis of the results was based on the $J_{IC}$ expression as:

\begin{equation}
J_{IC} = \frac{kA}{Bb},
\end{equation}
where $k$ is a constant which was found to be about equal to 1.0, $A$ is the energy under load-displacement curve up to the point of onset of crack propagation, $b$ is the remaining ligament and $B$ is the specimen thickness. The value of $k$ equal to 1.0 was confirmed using stretch zone measurements [6]. The values of equivalent $K_{IC}$ for both quasi-static and dynamic tests were estimated using the equation

\begin{equation}
K_{IC} = \left[ \frac{E J_{IC}}{(1-\nu^2)} \right]^{1/2},
\end{equation}