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Evaluation of fracture toughness and its scatter in the DBTT region of different types of pressure vessel steels

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ABSTRACT

Safety analysis of critical components and the overall plant is a major and important task in the field of mechanical engineering. Therefore, it is essential to know the allowable loads and the corresponding failure behaviour (e.g., crack initiation, growth and instability) of the component. Most of the safety critical components, such as pressure vessels of nuclear reactors, are made of ferritic grade low-alloy steels. When these components operate in the ductile-to-brittle transition (DBTT) regime of the material (due to irradiation embrittlement and other material aging and degradation mechanisms taking place), the two mechanisms that compete with each other in the failure process are: ductile and cleavage fracture. From fracture mechanics point of view, fracture toughness of the material must be adequate to prevent the failure. However, there is considerable scatter observed in the fracture toughness data and the analyst must account for this in the safety analysis. Master curve approach according to ASTM E-1921 standard is popularly employed for this purpose. However, it requires the data for transition temperature T_0, which is dependent upon the specimen geometry and loading configurations employed in the laboratory tests. Its transferability to safety analysis of components is questionable. In this work, a combined model for ductile and cleavage fracture is used to predict the fracture toughness scatter and its variation with temperature in the DBTT range. It is demonstrated that the above data for fracture toughness can be predicted once we know the material stress–strain data at different temperatures and a single set of Weibull statistics parameters for cleavage fracture. Extensive experimental investigations have been carried out on two types of pressure vessel steels in the DBTT region using different kinds of specimens to validate the predictions of the model.

1. Introduction and motivation for current research

Prevention of failure of pressurized and high-energy components and systems has been an important issue in the design of all types of power and process plants. Instead of the traditional fracture mechanics based approaches, it is now possible to go for the detailed modelling of different fracture or material degradation processes using local approaches [1–3]. There are two classes of local approaches, i.e., uncoupled and coupled types. In the uncoupled type of models for ductile fracture (e.g., Rice and Tracey's model [1]), the material damage is evaluated from the local stress and strain fields in a post-processing

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