STUDIES ON FATIGUE AND FRACTURE OF NUCLEAR PRESSURE VESSEL STEEL

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IN THE SERVICE
OF
LORD ŚRĪ KṚṢṆA,

THE SUPREME PERSONALITY OF GODHEAD

Śrī-bhagavān uvāca

yat karoṣi yad aśnāsi
yaj juhoṣi dadāsi yat
yat tapasyasi kaunteya
tat kuruṣva mad-arpaṇam

TRANSLATION

Whatever you do, whatever you eat, whatever you offer or give away, and whatever austerities you perform - do that, O son of Kunti, as an offering to Me.

[Srimad Bhagavad Gītā, 9.28]

CERTIFICATE

This is to certify that the Thesis titled **"STUDIES ON FATIGUE AND FRACTURE OF NUCLEAR PRESSURE VESSEL STEEL"** being submitted by **SRIHARSHA H.K.** to the Indian Institute of Technology, Delhi, India, for the award of the degree **of 'DOCTOR OF PHILOSOPHY'** in Applied Mechanics Department is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the standard fulfilling the requirements for the 'DOCTOR OF PHILOSOPHY' degree. The research report and results presented in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Fatigue and fracture properties of structural components play an important role in material selection and subsequently the property degradation during use determines the remaining useful life of the components. These properties are determined by tests carried out following procedures outlined in different standards using standard specimens and the results obtained are extended for actual components. Different types of specimens, both standard and non-standard have been used for this purpose depending on factors like material availability, component geometry, limitations of testing facility etc.

In the present investigation, fatigue studies have been carried out to assess the suitability of small three point bend (TPB) specimens for constant load amplitude testing. A new type of small TPB specimen has been evaluated for this purpose. The specimens have also been tested to study the crack retardation behaviour due to the application of a single overload cycle, the basic building block of variable amplitude cycling.

In fracture toughness testing, fatigue precracking of the test specimens is important in two ways. Firstly, the fracture toughness property being determined can be altered by using high loads for precracking. Secondly, precracking consumes a major part of the time required for fracture toughness testing. In the

present study both these points have been addressed and efforts have directed towards the development of a precracking methodology to determine an optimum crack initiation load as well as the subsequent loads to be used for rapid precracking.

The Thesis is presented in seven chapters.

Chapter I provides an introduction to the present study and defines the objectives of the investigation.

In Chapter II, relevant literature available on areas related to the topic of study is presented. Earlier work on the various factors affecting constant amplitude fatigue crack growth rate (FCGR) and the different parameters used for analysing FCGR has been reviewed. In addition, results of overload retardation studies , different overload retardation models and some aspects of variable amplitude loading available in published literature have been discussed. Finally the fatigue precracking procedure and its effect on fracture toughness properties has been discussed. The scope of the present investigation has also been spelled out in this chapter.

In Chapter III, the details of materials used, experimental procedure, test equipment and techniques employed have been outlined.

Chapter IV presents the results from the constant amplitude experiments. The results have been discussed emphasising the development of a new type of TPB specimen and its standardisation for FCGR studies.

The results from overload studies are detailed in Chapter V. The effect of overload on various aspects of crack growth kinetics and the applicability of different retardation models are brought out in the discussion of the results.

Chapter VI presents the results of the fatigue precracking experiments carried out. It also discusses the development of a computer program to aid in the fatigue precracking of fracture toughness specimens of different geometries.

The conclusions of the investigation are outlined in Chapter VII. Some of the important findings based on the present investigation are summarised as follows:

TPB specimens have been shown to yield reliable FCGR data and a new type of small TPB specimen with a span to width ratio of two has been standardised for FCGR determination. In the range of thickness and width used, FCGR is seen to be independent both.

Delayed retardation was noticed in the three types of TPB specimens used at different values of overload ratios (OLR's) applied. The crack retardation length (a_D) and number of delayed cycles due to overload (N_D) increased with OLR. a_D values were comparable to the monotonic plastic zone size indicating that plasticity induced closure was the main retardation mechanism. The retardation parameter N_D^*/N_{CA} was found to be specimen geometry independent and material specific but constant for a class of alloys like steel or aluminum. Here N_D^* is the number of delayed cycles due to overload as obtained from the plot of crack length versus number of cycles, and N_{CA} is the number of equivalent constant load amplitude cycles required for the crack to advance by an amount equal to the retarded crack length(a_D).

Results from precracking studies have led to the development of a computer program which can be used to generate an optimum precracking schedule satisfying the different ASTM standards for fracture toughness determination. The program output represented graphically as maximum load to be applied versus crack length serves as a sensible guideline for precracking, especially in the absence of a computerised testing facility.

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