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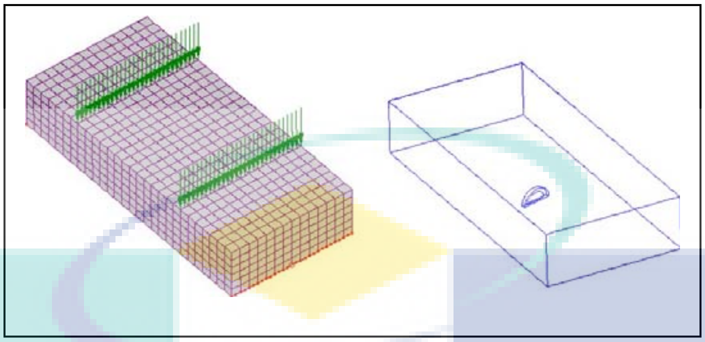

FORMULATION OF INITIAL FLAW SIZE FOR NEW CRACK GROWTH UNDER FATIGUE LOADING

Name of Project Leader: MOHD AKRAMIN BIN MOHD ROMLAY

Name of co-researchers:

1. Ahmad Syahrizan bin Sulaiman
2. Md. Mustafizur Rahman
3. Mohd Ruzaimi Bin Mat Rejab
4. Al Emran Bin Ismail

Fakulti Teknologi Kejuruteraan Mekanikal dan Automotif

Universiti Malaysia Pahang

E-mail: akramin@ump.edu.my

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ABSTRACT (120 words)

Fatigue contributes to approximately 90% of failures for metallic structures. In order to model the behaviour of 3-dimensional fatigue crack growth, initial flaw size needs to be constructed in the finite element model. Small changes in value to the initial flaw size caused a great impact on the residual life of a cracked structure. The unknown initial flaw size is the main problem in analysis process since it will affects the remaining life of structures. Thus, it is essential to model the initial flaw size accurately. The main objective of this research is to formulate the initial flaw size in the structure through the calculation of stress intensity factor, surface crack growth and fatigue life prediction on the surface cracks. The formulation will be introduced in simulation code to model the unknown initial flaw size. The available initial flaw sizes from the experimental works are analysed using a statistical approach. Kolmogorov-Smirnov approach is used to verify the type of distribution. Based on the verified distribution, the initial flaw size is modelled in the numerical calculation. Subsequently, the numerical process produces raw mesh files with different initial flaw size. The finite element models with various initial flaw sizes are constructed and proceed with the calculation of the fatigue crack growth. The correlation and accuracy analysis for the initial flaw size model will be performed by comparing the stress intensity factors, surface crack growth and fatigue life prediction with the experimental results. The expected results of the research are the mathematical model of initial flaw size and a new formulation for fatigue crack growth to specialize for all finite element software and structural integrity assessment. It is

expected to be the first 3D finite element analysis with initial flaw size modelling to be implemented in the oil and gas industries at Malaysia.

1. INTRODUCTION

The mechanical behaviour of cracks in promoting failures is crucial in all modes of failures. Failures can occur in real engineering applications and it starts with crack. Fracture mechanics approach is commonly used to predict the residual life of the cracked structure. The calculation of the residual life is based on the initial flaw size in the structure. The weaker part of fracture mechanics approach is that the time to crack initiation. It is due to the unknown initial flaw size. One practice is to assume the flaw size as 0.25-1 mm for metals. However, the drawback is that the flaw size is a function of material, machining, environment, local stress concentrations and loading history. The initial flaw size will vary over components, batch of manufacturing process and load. Thus by assuming the initial flaw size to a certain value is an unrealistic method. Nondestructive inspection technique is introduced to inspect and determine the initial flaw size in a structure but it is time consuming process. Thus, a new technique based on modelling of initial flaw size incorporating numerical solutions is needed to improve the quality of an analysis. The main problem in simulation process is that the unknown initial flaw size affects the residual life of structures.

2. RESEARCH METHODOLOGY

Phase 1.

Activity 1: The available initial flaw shapes from the experimental works were analysed using a statistical approach. Then, the initial flaw size was formulated based on its distribution. Kolmogorov-Smirnov method was used for the modeling of initial flaw size distribution. Once the mathematical model of initial flaw size was developed, then the model was introduced in the numerical calculation by analysing a cracked component structure.

Activity 2: The geometry of the cracked component was modelled in the open source preprocessing software. The mesh was generated in the preprocessing software and produce a raw mesh file. The raw mesh file was amended to characterize the initial flaw sizes. Since the initial flaw sizes were vary, a number of mesh file were needed to represent all sizes of initial flaw. The initial flaw size model that develops in Phase 1 Activity 1 was embedded in the S-version Finite Element Model (S-FEM) via a programming language.

The objective (i) was archived.

Phase 2.

Activity 1: The raw mesh files was supplied to the S-FEM for analysis purpose. The S-FEM was analysed the raw mesh files one by one. It requires a high computation memory and specification to completely analyse all of the initial flaw sizes. Average specification of a computer will lead to the insufficient random-access memory and it will interrupt the numerical calculation of initial flaw sizes model. Each analysis provided results such as crack growth, fatigue life and stress intensity factor. Compilation of all results were needed at the end of the numerical calculation.

Activity 2: The results of the initial flaw size analysis such as stress intensity factor, surface crack growth, and fatigue life were compared with experimental. Then, the developed model was improved for better prediction. A new source code with the embedded initial flaw size was developed at this stage.

The objective (ii) was archived.

3. LITERATURE REVIEW

The fatigue life of a structure is typically initiated by a crack. Once the crack starts to grow, the failure could occur in the certain structural part. Fracture mechanics approach is commonly used to predict the residual life of the cracked structure [1]. The calculation of the residual life is based on the initial flaw size in the structure. One practice is to assume the flaw size such as 0.25-1 mm for metals [2]. However, the downside is that the flaw size is a function of material, machining, environment, local stress concentrations and loading history [3]. Therefore by assuming the initial flaw size to a certain value is an unrealistic method. Thus, a new technique based on modelling of initial flaw size incorporating numerical solutions is developed to improve the quality of an analysis. The main problem in simulation process is that the unknown initial flaw size affects the residual life of structures. The residual life is necessary for planning future maintenance and the structural integrity of an-service component that may contain a flaw. The residual life can be used for run-repair-replace decisions to help determine if equipment containing flaws that have been identified by inspection can continue to operate safely for some period of time [4].

Based on the majority of works published, the initial flaw size can be determined via non-destructive inspection [5]. However, the initial flaw size can be below the current detection capability of the non-destructive inspection technique [6]. As a result, the detection limit is used as the initial flaw size. This would lead to the conservative design [7]. Alternatively, the initial flaw size and shape are measured experimentally [8]. However, experimental measurement is a tedious process when associated with the development of numerical calculation. It is due to the repetition of measurement for different materials to be modelled in the numerical calculation. Then, the equivalent initial flaw size concept is introduced to determine the initial crack size for fatigue life prediction [9, 10]. The calculation of equivalent initial flaw size is computed using back-extrapolation method. Nonetheless, the back-extrapolation method is too dependent on the stress level [11]. The equivalent initial flaw size is measured when connected to the applied stress level. Then, the initial flaw size that obtained from back-extrapolation method [12] is not indicating the initial quality of material. In addition, the back-extrapolation method is more suitable to long crack growth rather than short crack growth modelling [13]. When uncertainties need to be accounted for the modelling process, computation of fatigue life become more expensive. It is due to the coupling of probabilistic analysis with fatigue crack growth analysis [14, 15]. Hence, more efficient formulation to model the initial flaw size is needed.

The main objective of this study is to develop a new formulation for initial flaw size to provide a complete representation of fatigue crack growth and enhance the efficiency of structural integrity assessment. Based on available experimental data, the distribution of initial flaw sizes are analysed and modelled in the pre-processing phase through a programming language. The model of initial flaw size will be developed leading to the prediction of residual life of structure and fatigue crack growth. The validation process will be conducted based on the calculation of stress intensity factor, surface crack growth and fatigue life. Numerical calculation with initial flaw size modelling is expected to produce a new source code for accurate fatigue crack growth simulation especially for oil and gas industry in Malaysia.

4. FINDINGS

1) A mathematical model was introduced to represent the initial flaw size in numerical simulation for fatigue crack propagation.
2) An analysis software was developed for structural integrity assessment through the fatigue crack growth and life prediction.

5. CONCLUSION

A ProbS-FEM source code was developed in this research. Validations of the Prob-SFEM was conducted and showed good agreement with the experimental results. Prob-SFEM was proved to be a useful tool in engineering analysis.

ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

Fatigue crack growth analysis using Bootstrap S-version finite element model. M. N. M. Husnain, M. R. M. Akramin, Z. L. Chuan, Akiyuki Takahashi.
Published online: 20 March 2020
Journal of the Brazilian Society of Mechanical Sciences and Engineering (2020) 42:184. Q3. https://doi.org/10.1007/s40430-020-2268-8

Surface crack growth prediction under fatigue load using probabilistic S-version finite element model. M. R. M. Akramin, A. K. Ariffin, Masanori Kikuchi, M. Beer, M. S. Shaari, M. N. M. Husnain.
Published online: 15 October 2018
Journal of the Brazilian Society of Mechanical Sciences and Engineering (2018) 40:522. Q3. https://doi.org/10.1007/s40430-018-1442-8

ii) Title of Paper presentations (international/ local)

Paper Title	Conference Name	Venue	Organizer	Level
Analysis of Surface Crack using Various Crack Growth Models	1ST INTERNATIONAL CONFERENCE ON COMPUTING, INFORMATION SCIENCE AND ENGINEERING 2020 (ICISE 2020)	Hotel Grand Riverview, Kota Bharu, Kelantan	UniMAP	2019
K-S Test for Crack Increment in Probabilistic Fracture Mechanics Analysis	5TH INTERNATIONAL CONFERENCE ON CIVIL AND ENVIRONMENTAL ENGINEERING FOR SUSTAINABILITY (ICONCEES 2019)	LE GRANDEUR PALM RESORT IN SENAI, JOHOR	UTHM	2019
Modelling of Crack Propagation for Embedded Crack Structure	INTERNATIONAL CONFERENCE OF AEROSPACE & MECHANICAL ENGINEERING	Pulau Pinang	USM	2019
Statistical Distribution for Prediction of Stress Intensity Factor Using Bootstrap S-version Finite Element Model	INTERNATIONAL CONFERENCE ON MECHANICAL ENGINEERING RESEARCH	KUANTAN, PAHANG	FKMP, UMP	2019
Sampling Model in Engineering Analysis Software for Surface Cracked Structure	THE 7TH INTERNATIONAL CONFERENCE ON COMPUTER ENGINEERING AND MATHEMATICAL SCIENCES 2018 (ICCEMS 2018)	Langkawi, Kedah	SCIENCE AND KNOWLEDGE RESEARCH SOCIETY (REGISTERED IN MALAYSIA AS SANDKRS SDN BHD.)	2019
SURFACE CRACK GROWTH PREDICTION UNDER FATIGUE LOAD USING THE S-VERSION FINITE ELEMENT MODEL (S-FEM)	INTERNATIONAL POSTGRADUATE CONFERENCE ON MECHANICAL ENGINEERING (IPCME)	UMP Library, Pekan, Pahang, Malaysia	FKM, UMP	2018

iii) Human Capital Development

-1 master student, 7 undergraduate students

iv) Awards/ Others

v) Others

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APPENDIXES