Finite Element Modeling of Pit Growth on Stainless Steel Materials

Syifaul Huzni[1,*], Haris[2] dan S. Fonna[1], A.K. Ariffin[3]

[1]Department of Mechanical Engineering, Faculty of Engineering, University of Syiah Kuala, Darussalam, Banda Aceh 23111

[2]Undergraduate Program, Department of Mechanical Engineering, Faculty of Engineering, University of Syiah Kuala, Darussalam, Banda Aceh 23111

[3]2Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia 43600 Bangi Selangor

*Corresponding author: syifaul@unsyiah.ac.id

Abstract. Corrosion pit is one of the factors that cause a decrease of metal fatigue strength. Based on previous research, fatigue failure on steel AISI 304 on low cyclic stress is dominated by the growth of pit up to 90%. This research focused on the study of stress distribution on some pit shape and develop pit growth model using finite element method. The shape and geometry of specimen employed in this work referred to ASTM E-466. Stress distribution analysis using finite element software implemented against seven types of pit, i.e. wide shallow, vertical attack, elliptical, narrow-deep, undercutting, horizontal attack, and subsurface. Meanwhile, pit growth model is developed for wide shallow pit type only. Some previous experimental data related to pit growth also applied in this development. Finite element analysis results shows that stress distribution much depend on shape and geometry of pit. Relation between stress distribution and pit geometry could be studied by employing pit growth model developed in this work. This model can facilitate the study of pit growth in the future studies.

Abstrak. Korosi sumuran merupakan satu diantara penyebab kekuatan fatik suatu bahan menurun. Kajian sebelumnya menunjukkan bahwa 90 % kegagalan fatik baja AISI 304 pada tegangan siklik rendah di dominasi oleh pertumbuhan pit. Kajian ini difokuskan untuk mempelajari distribusi tegangan di beberapa jenis bentuk pit menggunakan metode elemen hingga. Bentuk dan geometri spesimen dirujuk dari ASTM E-466. Analisis distribusi tegangan dengan menggunakan perangkat lunak berbasis metode elemen hingga dilakukan terhadap tujuh jenis pit yaitu wide shallow, vertical attack, elliptical, narrow-deep, undercutting, horizontal attack, dan subsurface. Sedangkan untuk pemodelan pertumbuhan pit hanya dilakukan pada jenis wide shallow pit. Bebarapa data yang digunakan juga merujuk kepada penelitian sebelumnya. Hasil analisis elemen hingga menunjukkan distribusi tegangan sangat bergantung kepada bentuk dan geometri pit, Hubungan distribusi tegangan dan geometry pit ditunjukkan melalui model yang dikembangkan dalam kajian ini. Model ini dapat menfasilitasi kajian pertumbuhan pit di masa yang akan datang.

Kata kunci: pit growth model, stainless steel, finite element analysis

Introduction

Fatigue loading has dominated up to 80% causes of structural failures, particularly those made of metal [1]. This phenomenon has certainly happened a lot in the area where the environment conditions are corrosive, and even more if subjected to loads and repetitive stress [2]. Material that is often experienced this kind of failure is stainless steel that is widely used in the petrochemical industry, structural construction, and transportation. Stainless steel, such as AISI 304, has good mechanical and physical properties and as well as having excellent corrosion resistance [3].

The previous researcher has previously studied experimentally the behavior of steel AISI 304 in 3.5% NaCl solutions and showed that at low stress, fatigue failure dominated by pit growth up to 90% [4]. So far, the relationship between the stress, shape and size of the pit could not be explained properly, so further study about this need to be done.

Generally, there are two approaching methods that could be used to study the fatigue corrosion, i.e. experimentally and numerically. In a certain case where the geometry of structure is complex and difficult to observe, experimental work is very difficult to perform. In such conditions, numerical approach is an option. The phenomenon of fatigue failure that dominated by pit growth is an example of this problem.

In this paper, the relationship between the pit shape and stress distribution in some pit types is shown. Furthermore, the result of pit growth model development is discussed.

Methods

Shape and stress distribution study. The shape and geometry of finite element model employed in this work is referring to ASTM E-466. The model is considered as linear elastic and meshed with tetrahedron type using refinement feature in ANSYS R14. Material properties and fatigue characteristic of AISI 304 is referred to Julie [5]. The boundary condition is modeled as close as possible to experiment condition that have carried out by previous researcher [4], as can be seen in Figure 1. A single pit is introduced in the central part of the finite element model. Seven types of pit shape employed in the shape and stress distribution study is referred to Pierre R Roberge [6], i.e. wide shallow, vertical attack, elliptical, narrow-deep, undercutting, horizontal attack, and subsurface. Pit dimension (width and depth) is determined using pit ratio developed by Cerit [7]. In this part, the analysis was conducted only to study the effect of pit shape on stress distribution on each pit types.

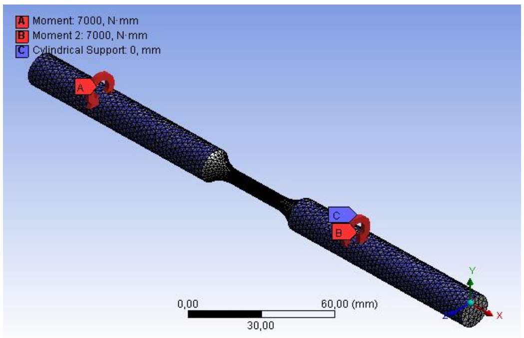

Figure 1 Geometry and boundary condition of finite element model

Pit Growth Modeling. The size of pit width applied in the pith growth analysis is based on data provided by previous researcher [4], as shown in Table 1. The depth of pit is determined using pit ratio developed by Cerit [7].

Results and Discussion.

Shape and stress distribution. The stress distribution on 7 types of the pit shape was simulated is wide shallow, vertical grain attack, elliptical, narrow-deep, undercutting, horizontal grain attack, and subsurface. The Equivalent stress distribution (von Misses), maximum shear, and maximum principal stress was obtained on those several pit shapes and the relationship curve between the specimen without pit and specimens with different types of pit shape was presented in this section.

Tabel 1. Pit growth dimension

Siklus	Pit Width (µm)
4200	58
5200	79,5
6200	135,64
7200	208,8
8200	298
9200	403
10200	645

The highest equivalent stress distribution and maximum shear occurs in the bottom of the pit as shown in figure 4, the equivalent stress (von Misses), maximum shear stress, and max principal stress of wide shallow pit are 345.33 MPa, 199.38 MPa and 212.69 MPa, respectively. While the maximum principal stress occurs in the bottom of the pit and some walls of the pit.

On the vertical attack pit, the highest equivalent stress (von mises) is 410 MPa, maximum shear stress is 230.34 MPa, and maximum principal stress is 427.3 MPa as shown in figure 5. Moreover, the equivalent stress (von mises) and maximum shear stress took place in the bottom of the pit and the maximum principal stress goes on the pit wall.

The bottom of elliptical pit occurring the equivalent (von mises) and maximum shear stress. Meanwhile, on the pit wall follow the maximum principal stress. The elliptical pit reaches 480 MPa equivalent stress(von mises), 277,1 MPa maximum shear stress and 355,4 MPa maximum principal stress as pictured in figure 6.

The stress distribution of narrow-deep pit as shown in figure 7, showing the equivalent stress (von mises), maximum shear stress, and maximum principal stress that occurs on pits is 483,6 MPa, 248,6 MPa, dan 505,8 MPa, respectively. In contrast, the equivalent stress (von mises) and maximum shear stress, which obtained the highest stress distribution occurs at the walls of the pit and maximum principal stress occurs on most walls of the pit.

Results of the equivalents stress (von mises), maximum shear stress and maximum principal stress on the elliptical motion pit obtained respectively the maximum stress value reaches 595.14 MPa, 327.31 MPa, 595.14 MPA, as shown in figure 8. Which the equivalent stress (von mises) and maximum shear stress occur in the same parts namely upper wall undercut pit. Then, maximum principal stress takes place on the portion of pit's mouth main wall.

On the horizontal attack pit, stress distribution results as shown in figure 9, the equivalents stress (von mises), maximum shear, and maximum principal reached 656 MPa, 332.5 MPa, 681.4 MPa, respectively. Which the equivalent stress (von mises) and maximum shear occur on the diagonal direction of the pit wall and maximum principal stress occurs on most of the diagonal direction of the pit wall.

The subsurface pit is the highest stress, which is 723.9 MPa equivalents stress (von mises), 360,1 MPa maximum shear, and 724,8 MPa maximum principal stress as shown in figure 10. The highest equivalent stress (von mises) and maximum shear distribution occur in the upper mouth diagonal direction of the pit wall and the highest maximum principal stress took place on the most diagonal direction of the mouth of the pit wall.

For the simplicity, the influence of the pit shapes compare against the stress distribution were plot in a curve as shown in figure 11 a. and the ratio of the stress increment on each pit shapes can be done by comparing the maximum stress on specimens which have different pit shape and the maximum stress on specimen without pit.

The maximum stress which has occurred on specimens without a pit, then the value of the maximum stress ratio between the maximum stress specimen that has a pit and the specimens without pit can be calculated. The comparison data of the maximum stress ratio was plotted in a curve as presented in figure 11b.

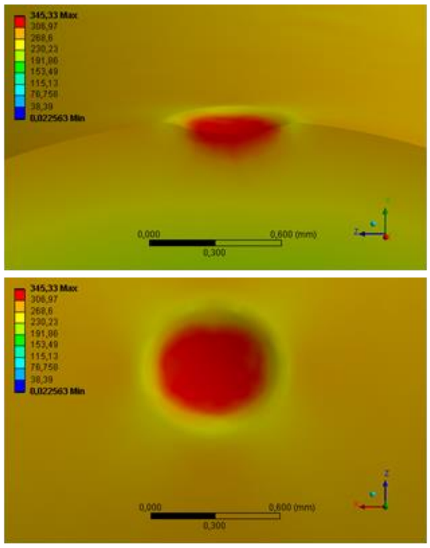

Figure 2 Stress distributions on wide shallow pit (Side and top view)

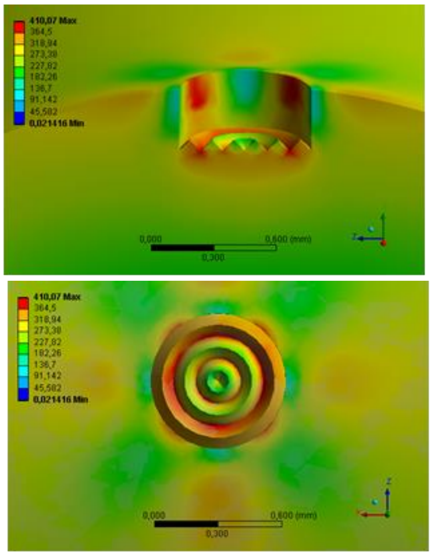

Figure 3 Stress distributions on vertical grain attack pit (side and top view)

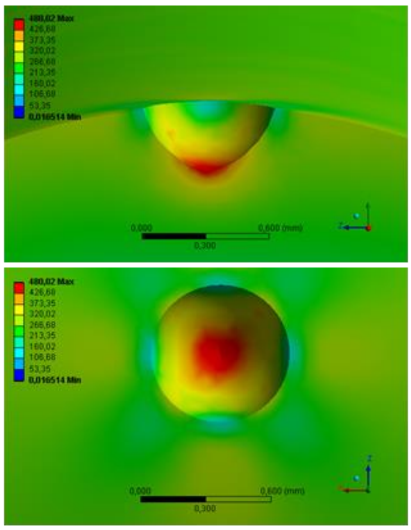

Figure 4 Stress distributions on elliptical pit (side and top view)

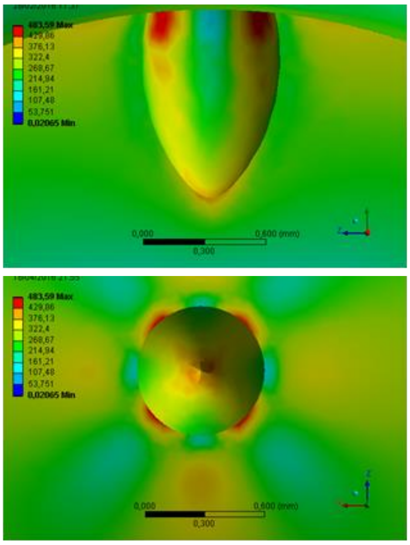

Figure 5 Stress distributions on narrow-deep pit (side and top view)

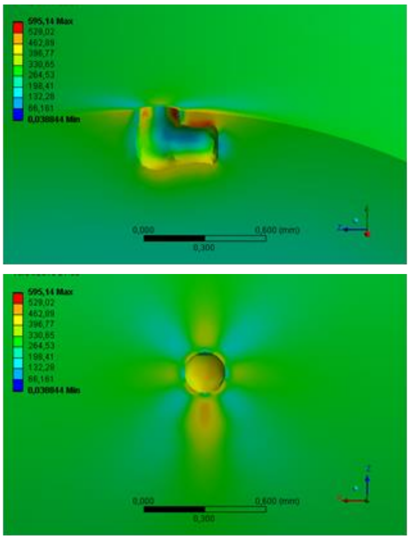

Figure 6 Stress distributions on undercutting pit (side and top view)

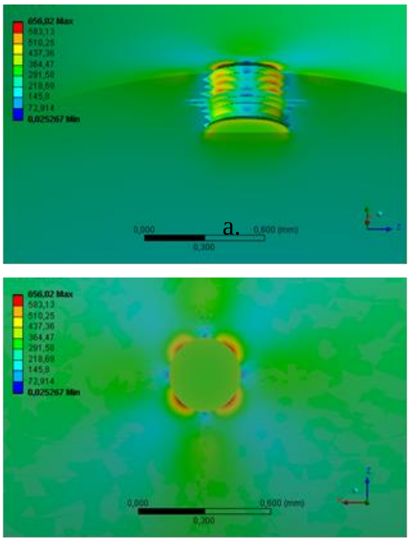

Figure 7 Stress distributions on horizontal grain attack pit (side and top view)

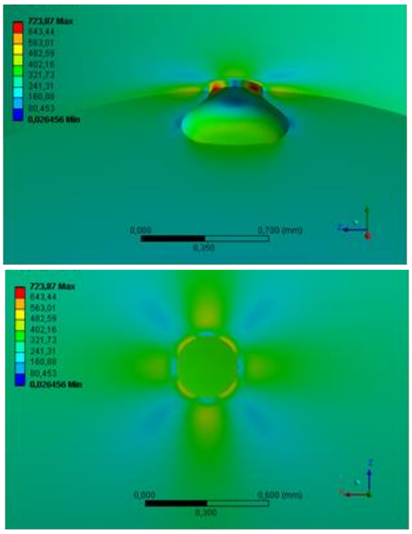

Figure 8 Stress distributions on subsurface pit (side and top view)

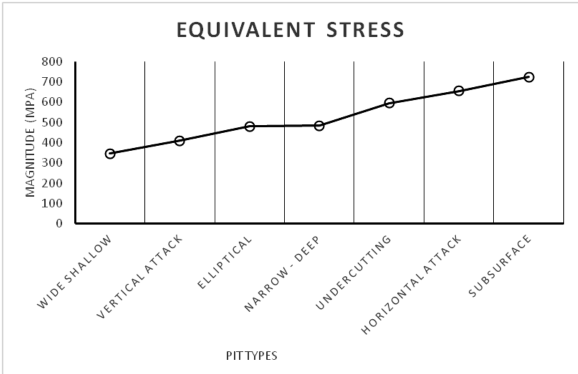

Figure 9 Comparison of equivalent stress magnitude on different types of pit

Pit Growth Analysis. The pit growth assessment is referred to previous experimental research (M Rizky, 2013). The pit depth can be determined by 0,25 pit ratio. With the availability of width and depth of the pit, then the modelling pit can be performed in 2 dimensions as pictured in figure 12. The larger pit size makes the next pit growth larger because with the increasing stress affects on pit growth. Therefore, the stress distribution when the pit growth occurred was analyzed using ANSYS Rel. 14. Based on the result, equivalent stress (von mises) reveals that stress increasing when the pit growth occurred. The maximum stress when pit growth occurred displayed in figure 13.

Conclusions

From the results of this study, it can be obtained that the simulation to examine the influence of the pit shape and pit growth against the stress distribution has been successfully conducted using

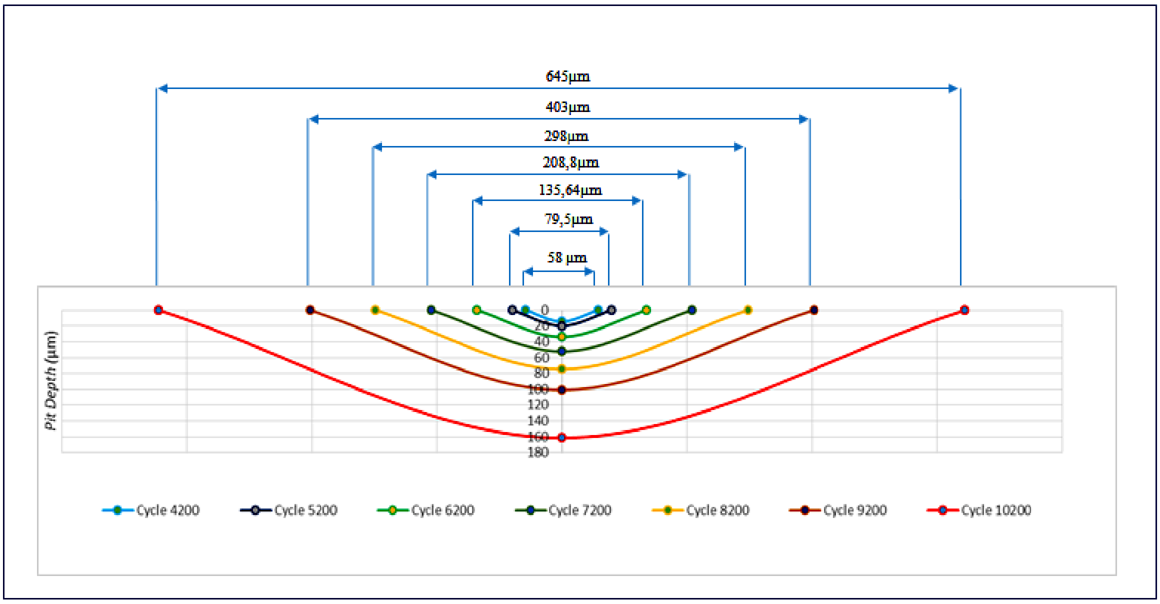

Figure 12 The evolution of pit simulated

ANSYS Workbench Release 14.0. The pit shape affects the stress distribution on the fatigue corrosion specimens. The highest stress occurs at the subsurface pit with the ratio 2.59 times larger than the maximum stress without pit. By using pit ratio (M. Cerit, 2009), pit growth model has been successfully developed and demonstrated the pit growth.

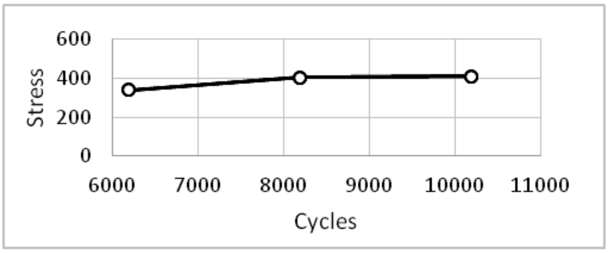

Figure 13. Maximum stress curve when pit growth occurred

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