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# A study on crack propagation and life expectancy

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## ABSTRACT

***Cracks are the most common flaws that are usually observed occurring on metallic surfaces, however, the existence of a crack on any material deteriorates the overall strength of the component and in turn, becomes the prominent reason for the failure of the component. The purpose of this research is to find out the behavior of a crack when the component is put to undergo cyclic loading. The study of cracks comes under the section of the vast concept of 'Fracture Mechanics'. The concept gives detailed information about the formation and expansion of cracks and also contributes largely in determining the probable failure time of a component under cyclic or fatigue loads. It's important to know the life of a component keeping the existence of a crack of even the smallest size under consideration. The project uses concepts and information from fracture mechanics and forecasts the process of propagation of cracks on metal and determines its life under a given loaded condition. To determine the life of the component pre-established relations and formulae are used and results are obtained using a numeric and graphical approach.***

***Keywords***— *Cracks, Fracture mechanics, Crack propagation, Expected life, cyclic loading, failure of a component.*

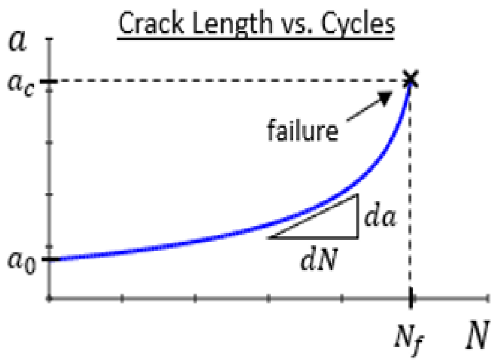
## 1. INTRODUCTION

Cracks are the most commonly occurring flaws in engineered parts and they can reduce the ability of the material to withstand the load significantly. Cracks usually form around pre-existing surface flaws in a part. They start small and then grow during operational use. The propagation of cracks can be divided into 3 stages namely,

(a) Crack initiation stage
(b) Crack expansion stage
(c) Rupture/failure stage

When the material undergoes work under the given condition considering it already has a crack which is known, this initial state marks the first stage which is 'Crack Initiation' where the given crack opens up but the growth/ expansion rate is minimum or tremendously low. The material can work without any issue for a certain period. The expansion rate of the crack keeps on increasing subsequently with the increase in the no. of cycles. At a certain point, the crack growth rate gets enough higher to start doing some considerable damage to the material. This is the beginning of the second stage which is the 'Crack expansion stage' which is also known as the 'tearing stage'. As the name suggests, at this stage due to continuous rise in expansion rate, the crack starts to penetrate deeper in the material by tearing through cross-section deeper and deeper with the rise in no. of cycles.

It is concluded that the increase in crack expansion rate and the No. of cycles are proportional. we could easily plot a graph based on the increase in the crack length vs. the no. of cycles of cyclic loading as shown in Fig. the following graph also indicated the point of failure.




The third and final stage is when the crack length increases so much that the material becomes unsafe for further usage and its life is nearly over. It could be observed that the existence of a crack and its propagation decreases the overall expectancy of the material exponentially.

The main objective of the research is to put a component having a predefined crack in the form of a notch on its surface, which would in turn help in the expansion of the crack, and find out how many cycles of loading can the component withstand before failing in the strength criteria or factor of safety FOS. As discussed above, the whole objective of the study lies in the second stage of crack propagation. Here, the initial crack size is intentionally taken large and it is expected that the component would hence fail at a much earlier stage or would withstand a smaller number of cycles.

## 2. METHODOLOGY

There were various factors which were needed to be considered while carrying out detailed research. the basic theoretical data from the research papers based on fracture mechanics and crack propagation were taken under observation. Along with the theoretical data, for carrying out a detailed calculation for knowing the crack expansion rate and the life expectancy of the component some already derived or existing formulae and factors were used. After completing a detailed literature review and studying pre-existing available research papers, the necessary data required for our study were collected. This data included both the selection of material and also a selection of the relations and factors to be taken under consideration for completion of the calculation of the Final crack length and the life expectancy of the component. The Calculation of the crack length went in the following order;

- Selection of materials
- Selecting loading magnitude and point of action for force.
- Selecting initial crack length (notch size) and initial No. of cycles for loading.
- As discussed earlier, the crack propagation is divided into 3 stages and the study mainly focuses on studying the behavior of cracks in the second stage, the initial parameters like initial crack size and No. of cycles are kept intentionally for obtaining quick results.
- Calculation of stress intensity factor.
- Calculation of crack growth rate or expansion/propagation rate using Paris equation.
- Checking crack growth rate by comparing results from both graphical and numeric method
- Calculating crack size prediction ($\Delta a$)
- Calculating the final No. of sizes that the Component can withstand before failure. ($N_f$).

## 3. RESEARCH COMPONENT

The component selected for the study is the M.S block of Dimension 50x50x10 mm. the block has an external. surface notch created intentionally for the crack to be initiated and expand. The external surface notch is located on the center of the face, having a length and depth of 5 mm. The block diagram and the detailed 3D solid works fig. of the component are shown below,

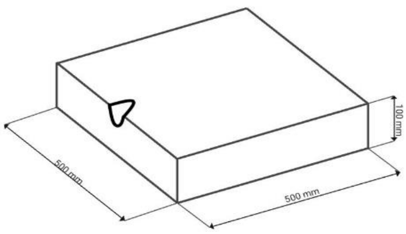



**Fig (a): Simple block diagram**

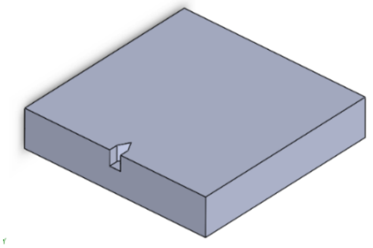


**Fig. (b): Solidworks 3D model**

A cyclic load of 25 N is applied on the component for 2000 cycles initially. It is assumed that the block would fail under cyclic loading at a much earlier stage as the study focuses to study the behavior under the second stage of expansion.

## 4. CALCULATION AND ANALYSIS

After following the initial steps as stated in methodology including the selection of material, forces, and point of action of the forces with the No. of cycles (initially high) and its magnitude. The next step in determining the crack growth rate or expansion/propagation rate is to carry out a calculation process by substituting values and data available into pre-established relations and formulae. The used formulae are stated in the next section along with the numeric and graphical results obtained.
The major relations used for carrying out the calculations were the Paris equation and the relation for obtaining the stress intensity factor.

### 4.1 Formulae used in calculation precess

- **For Calculating the Stress Intensity Factor (K),**

$$K = Y * \sigma * \sqrt{\pi * ao}$$

- **For Calculating crack growth rate using Graphical approach,**

$$\Delta a = (da/dN) * \Delta N$$

- **Crack size prediction,**

$$\Delta a = a_i - a_o$$

- **For calculating crack growth rate by using Paris Equation,**

$$(da/dN) = C * (\Delta K)^m$$

- **For calculating the final No. of cycles that the component can withstand before failing ($N_f$),**

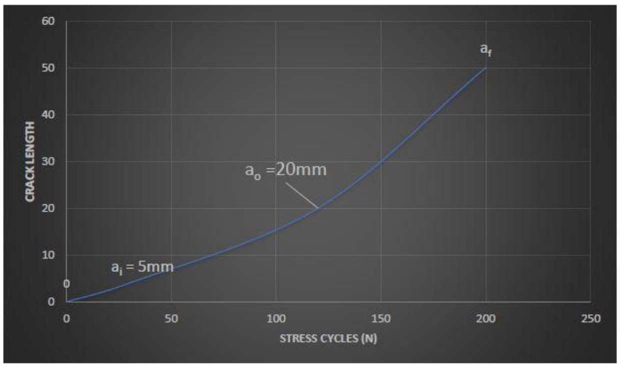
$$Nf = \int_{a0}^{af} \left\{ \frac{1}{C\,(Y\,\sigma\,\sqrt{a})\hat{}n} \right\} da$$

### 4.2 Results obtained in the calculation

The stress intensity factor obtained in the first step is compared to $K_c$ to see if the obtained value is in range and safe.

**K = 99.08 Mpa ; approximately 100 Mpa * $mm^{1/2}$**

Now, for determining the Crack growth rate through a graphical approach, it is first necessary to calculate the factor for crack size prediction i.e., $\Delta a$. The value for $\Delta a$ is obtained as 15mm, therefore **$\Delta a$ = 15 mm.**
The smooth rising graphical curve obtained in the process is shown below,




Graphical representation of the Curve

The graph indicates the stress cycles on the X-axis and the length of crack on the Y axis, the result is a smooth rising curve.
The crack growth rate obtained in the Graphical method is,

**(da/dN) = 0.075**

Another method used for calculating the same rate is the Numerical method, Using the Paris equation and sloes obtained from the graphs, the crack growth rate is found again to match with the earlier value, to see if both rates are in close range.

The crack growth rate obtained through Paris equation is,

$$(da/dN) = 0.071$$

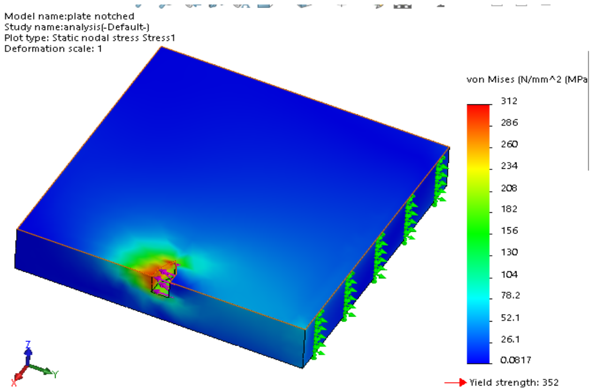
The final step in the study is to calculate the final no. of cycles that the component can withstand before failing, i.e. $N_f$.

For the selected component under the given condition, the value for $N_f$ obtained is,

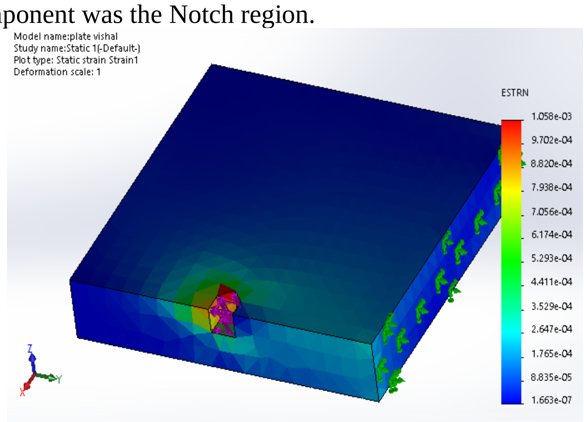
$$N_f = 117 \text{ cycles ; approximately 120 cycles.}$$

so the given component can safely withstand up to 120 cycles of cyclic loading before it fails under the factor of safety.

### 4.3 Analysis of block




When the results for stress concentration on the component were observed, the results matched the earlier assumption. As the stress was acting in one direction and the tearing of metal taking place at the same time, the most affected region on the M.S. component was the Notch region.




Similarly, in the case of analysis for strain as expected the most strain developed was on the end of the notch section. As the tearing of metal took place more and more strain developed in the said area.

## 5. RESULTS

In the study of the behavior of crack under the given condition, it was observed that the crack behaves differently in all 3 phases. When the initial crack is small the expansion rate is extremely low and it is difficult to observe the occurring changes. As the study mainly focuses on 2nd stage expansion, the results of the study were as follows,

- The objective of the study was to calculate the crack growth rate under the given condition, and this task was completed by two methods, graphical and numeric or by Paris equation.
- The crack growth rate obtained by the graphical approach was **0.075**. It was extremely important for the crack growth rate obtained by the second method to fall under a similar range and be extremely close to the previously obtained value, To conclude that the following values are valid, the crack growth rate obtained in the 2nd method by Paris equation was **0.071.**
- The second objective to fulfill was to calculate the Final No. of loading cycles that the component can safely withstand before failing, which was obtained as **120 cycles.**
- The component can however be loaded above the resulting no. of cycles, but it would be unsafe as the component fails under the safety criteria at the resulting no. of cycles. Due to the constantly acting loading cycles, the component would eventually be destroyed and could be termed as un-operational.

## 6. CONCLUSION

According to the research and calculation carried out for the M.S. block, it can be concluded that,

- It was observed in the detailed study conducted that if the initial crack length is very short, then the crack propagation in the 1st phase will occur at a very slow rate, such that it would be difficult to observe the rate of propagation and a micro analysis would be required for the research of 1st phase crack propagation.
- It was observably seen that during the calculation through the graphical method to obtain the rate of propagation (da/DN) the curve would always be smooth, provided that the considered data is valid and accurate or in the acceptance range.
- Results obtained in the study could be varied if few factors are changed such as selection of different material, the magnitude of the force in cyclic loading, and No. of cycles acting on component.
- Through the literature survey and research conducted we can conclude that the rate of propagation acts differently in all 3 phases because it was observed that keeping the initial crack length more, the component tends to fail quickly and withstands less No. of cycles, but in case of 1st phase due to existence of microcrack, the propagation rate is low and crack length increases at a much slower rate.

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