Study of Multiple Crack Interaction on the Surface of Solid Shaft Using Ansys Finite Element Analysis

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Abstract

This study uses ANSYS Workbench software to examine the interaction of single and multiple cracks on the surface of a solid shaft under different stress circumstances using the finite element method (FEM). Investigating the effects of various fracture depth ratios, aspect ratios, and placements on the stress intensity factors (SIFs) is the goal of the study. The study guarantees that the results are generally applicable by normalising the SIF values according to the loadings, which include internal pressure, bending moment, tension force, and torsion moment. Validating the data is part of the approach to ensure that the simulation process is accurate. By anticipating probable failure areas and enhancing design tactics to avoid catastrophic failures in mechanical systems, the findings help in the understanding of the structural integrity of shafts with many fractures.

1. Introduction

The term "crack" in mechanical engineering usually denotes a fissure or fracture in a material. It may happen for several reasons, including corrosion, stress, or wear and tear alone or in combination. Engineers frequently research the behaviour and spread of cracks to create materials and structures that can withstand the forces and environments they will be subjected to. Methods like stress analysis and non-destructive testing are used to identify and address cracks before they can result in catastrophic failure. Hence, cracks in engineering are like the weak links that engineers work hard to identify and eliminate to ensure the reliability and safety of structures and components [1]. A solid shaft crack, also called a "shaft crack" is a flaw in a cylindrical component that can seriously affect how well it performs mechanically. Numerous factors, such as material fatigue, excessive stress, or manufacturing defects, can result in this kind of crack. When it comes to solid shaft cracks, the options are to either repair the crack (if it can be done so), change the design to lessen stress concentrations, or, in extreme situations, replace the shaft entirely. The aim is to ensure the mechanical component's continuous, safe, and dependable operation [2].

Numerous investigators have published stress intensity factor (SIF) solutions for a surface crack in a smooth round shaft. Most of the existing solutions are restricted to straightforward loading scenarios, like tension, bending, or torsion stresses [3]. A smooth round shaft's surface crack has also developed fatigue crack growth and shape evolution under such loading [2]. There were drawbacks and restrictions associated with the semi-analytical or experimental approach that was previously used. Therefore, utilising the finite element method to calculate the stress intensity factor in fractured shafts is highly necessary [4].

Cracks in round solid shafts pose a significant risk to rotating mechanical components' structural integrity and reliability. Caused by manufacturing flaws, corrosion, and cyclic loading, these cracks can lead to catastrophic

failures, compromising machinery functionality and safety. Effective early detection, precise characterisation, and appropriate mitigation are essential. This requires advanced non-destructive testing methods, analytical stress distribution modelling, and innovative crack repair and prevention techniques. Addressing this issue is crucial for enhancing the robustness and safety of mechanical systems in automotive, aerospace, and industrial machinery applications.

Analysing multiple crack interactions on solid shafts using ANSYS FEM is crucial for identifying potential failure sites and understanding material behaviour under different loading scenarios. The study examines both single and multiple cracks to predict interactions that could lead to structural defects. Understanding these interactions helps engineers improve shaft design to prevent failures, enhancing the reliability of mechanical systems in various industries, such as aerospace and power generation. The research also emphasises the importance of considering geometrical characteristics like crack position, size, and shape in analysing stress intensity variations, ultimately contributing to more robust engineering applications.

This study aims to investigate how applied stress affects multiple surface cracks on a solid shaft and to examine the stress intensity factor (SIF) along these cracks. The goal is to understand crack interactions under mechanical loading to improve the design and maintenance of solid shafts in engineering applications.

2. Material and Method

This chapter is more focused on the method or process for conducting this work. To ensure the validity of the result analysis, the appropriate step is carried out while an accurate planning schedule is prepared. The procedures involved in finite element simulation that is carried out using ANSYS Workbench Software are discussed clearly in this chapter. The inquiry flow chart in Fig. 1 illustrates the research process. Beginning with the study's objectives, the methodology was developed to address the identified problem and implement all goals. The study's scope was limited to ensure focus and appropriate conduct. A literature review was conducted to gather essential data and references. ANSYS simulations with varying crack positions and loads were then performed, followed by data analysis and discussion. If validation was unsatisfactory, the analysis and discussion were repeated. Finally, the research findings and outcomes were summarised in the conclusion. Fig. 2 displays the thick-wall solid shaft model type, with the length and diameter of the shaft 50mm in diameter and 100mm in length.
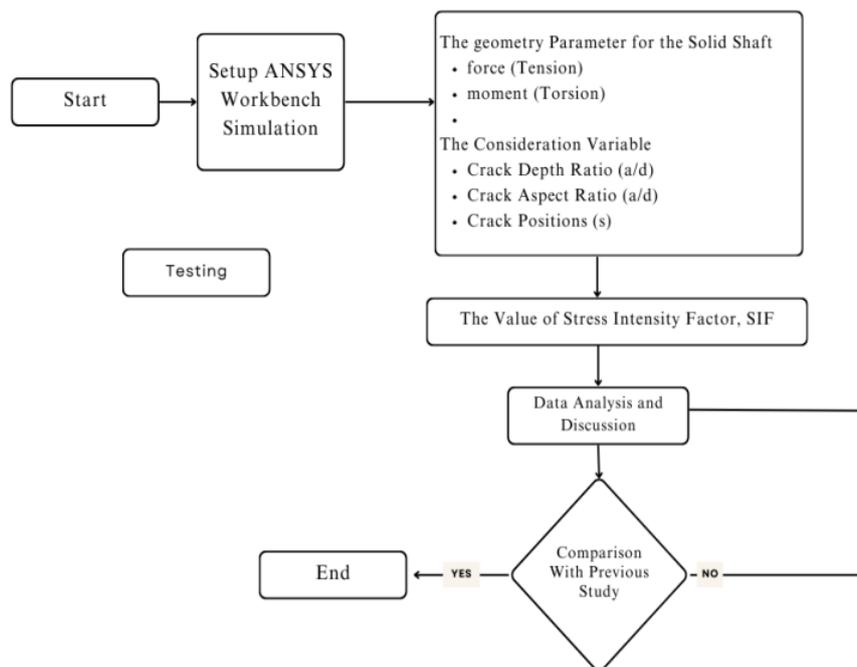

Fig. 1 *General flowchart of the overall work.*

The study aimed to determine how a shaft breaks under internal pressure, tension, bending, and torsion moments. The approach involved changing only the selected load and applying all other loads using the same technique, with internal pressure illustrated in the phases. Internal pressure (or tension, torsion, or moment) was applied to the shaft, and cracks were introduced on its surface using STATIC STRUCTURAL methods. Geometry and model systems were used to reach the final findings. The process for constructing the system analysis using ANSYS software involved several steps.

i.   Launched ANSYS Workbench 16.1 and STATIC STRUCTURAL under Analysis System was selected.
ii.   Design shaft geometry by using ANSYS Design Modeler.
iii.   Prepare and display the analysis in Mechanical Application.
iv.   Mesh the geometry in the ANSYS meshing application.
v.   Create a new coordinate system.
vi.   Insert and define the crack.
vii.   Apply the loads.
viii.   Solve the crack analysis using ANSYS.
ix.   Define the results obtained.
x.   View the results.
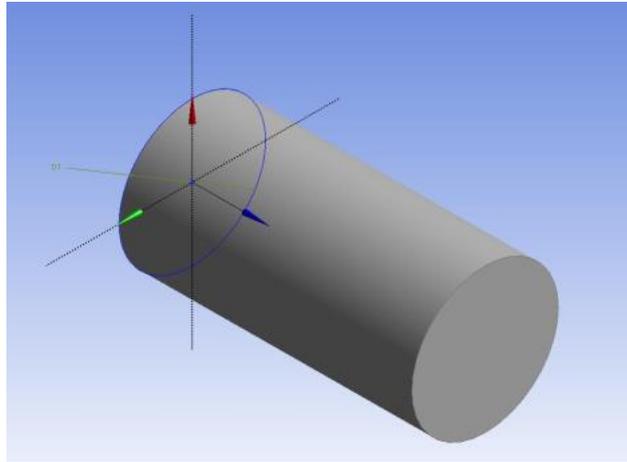
Fig. 2 *Round bar under in this work*

3. Results and Discussion

A comparison between the suggested model and a specific model found in the literature is necessary to create an appropriate finite element model [3]. To verify the already collected data, the data was compared. The findings of comparison SIFs under tension force loadings for mode I are displayed in Fig. 3. Four relative fracture depth ratios, a/t, were employed for validation. It has been shown that the results of this study are consistent with those of earlier models, in which the graph's pattern is nearly identical, but the SIF values varied somewhat. For the four crack aspect ratios, a/t = 0.1, 0.2, 0.3, and 0.4, respectively, this illustrates the variance of Fs along the crack under tension force. Otherwise, the comparison was made again with another previous study [3], using the normalised coordinate as the range subject as in Figure 3. This also compares under tension force loadings. It has been discovered that the pattern of the graph obtained was not so identical at the beginning of the graph, but it became identical and closer in the middle. Therefore, these two models can be assumed that the present model is suitable enough to analyse the SIFS. A comparison was made between the previous studies to get a suitable finite element model under the end-free axial tension conditions [3]. Fig. 4 shows a comparison of the SIFs under torsion loadings. Crack aspect ratio, a/b and relative crack depth ratio, a/t, were used for validation purposes. After all, the findings of this model pattern have been found to meet those determined by the previous models, where the curves are a little bit like each other.

      The tension force is the axial force that passes through a shaft when it is pulled taut by forces operating from opposing ends, and there is a surface fracture. Under tension stress, the changes in Fs along the crack front are displayed in Fig. 3 for three relative crack ratios, a/t = 0.1, 0.2, 0.3, and 0.4, respectively. The normalised SIF, Fs utilised with the x/h=0 was chosen in every Fs. The Fs is shown to have grown initially as the relative crack ratio rose, but it then fluctuated until it reached the a/b = 0.8. The curve at a/t = 0.1 was positioned higher than the others based on the four relative crack ratios, whereas the curve at a/t = 0.4 was at the lowest point on the graph.
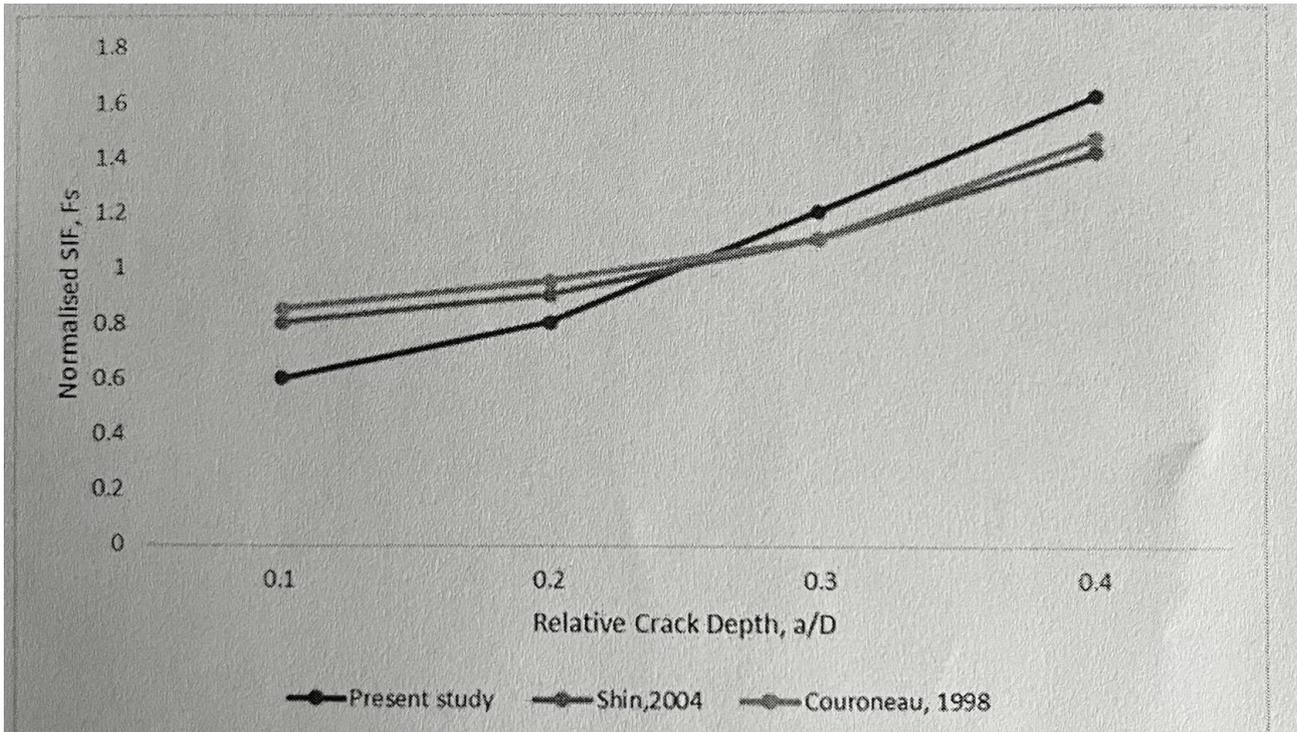
Fig. 3 *Validation of stress intensity factors*
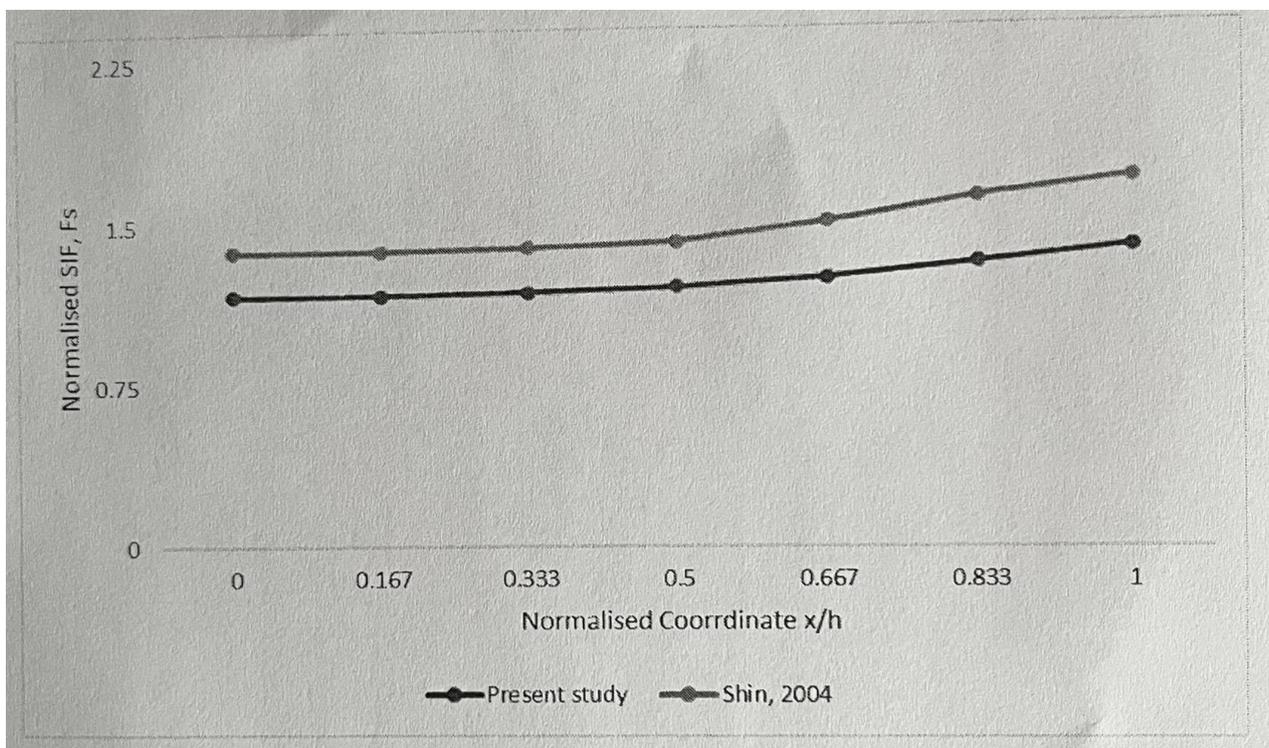
Fig. 4 *Comparison between SIFs under tension force using different relative crack depth*

Fig. 5 displays three figures illustrating the stress intensity factors for various crack configurations on a solid shaft, using simulations performed with ANSYS software. It is focused on a single crack on the surface of a solid shaft. The colour contour map highlights the stress distribution around the crack, with darker colours indicating higher stress concentrations and lighter colours showing lower stress levels. Fig. 6 expands the analysis to two cracks on the surface of the shaft. This figure reveals the interaction between the two cracks, resulting in different stress patterns compared to the single-crack scenario. The stress intensity factors, in this case, will reflect the combined effect of both cracks on the overall stress distribution. Fig. 7 further extends the study to multiple cracks on the surface of the solid shaft. The stress distribution contour map in this figure shows how stress is concentrated

around each crack, and the presence of multiple cracks influences the overall stress intensity factor in a unique way, different from the single or double crack configurations.

Fig. 7 illustrates the correlation for three distinct fracture configurations in a solid shaft: single, double, and numerous cracks, between normalized Stress Intensity Factors (SIFs) and normalized crack lengths (x/h) with different size of crack. The y-axis displays the normalized SIF values (Fs), and the x-axis the normalized crack length (x/h). The single crack's curve, which is shown by grey markers, has the greatest SIF values across all normalized crack lengths, indicating a considerable concentration of stress around the fracture tip. Orange-marked multiple crack scenarios exhibit moderate SIF values, which are greater than those of double crack configurations but lower than those of single cracks.
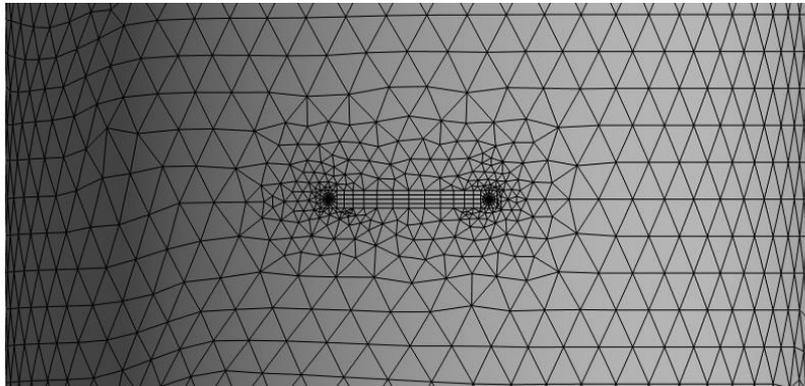
Fig. 5 *Single crack exerted on surface solid shaft*
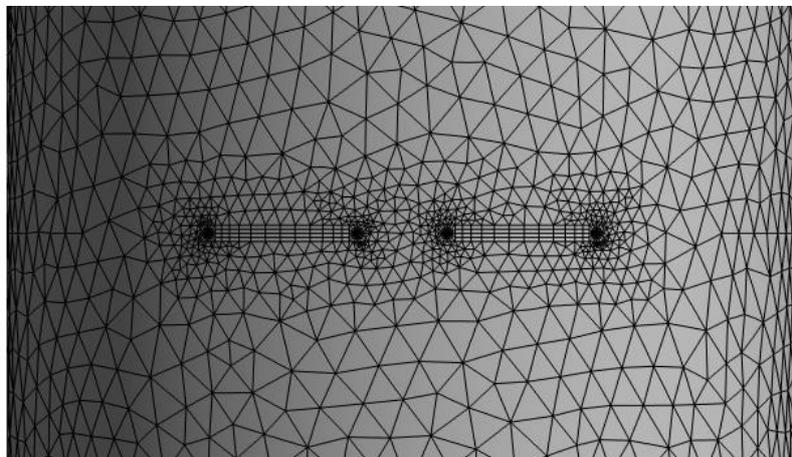
Fig. 6 *Two cracks exerted on surface solid shaft*
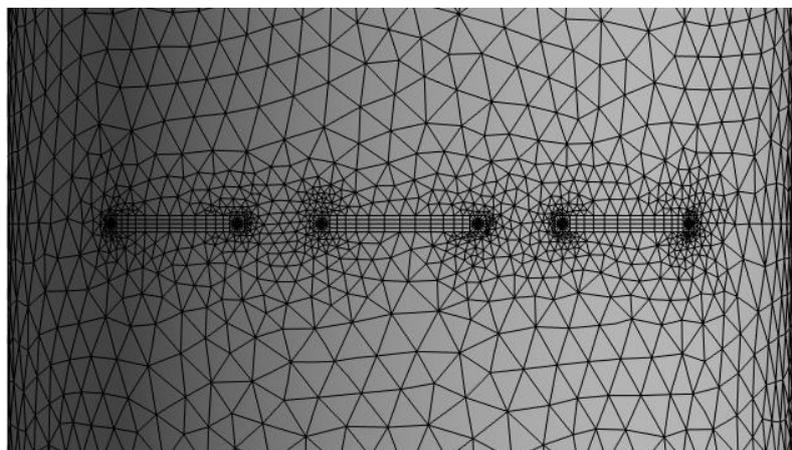
Fig. 7 *Three cracks exerted on surface solid shaft*

Finally, the double crack scenario, represented by blue markers, shows the lowest SIF values among the three scenarios, suggesting that the interaction between the two cracks reduces the overall stress intensity at each crack tip. The graph effectively illustrates how the presence and interaction of multiple cracks influence SIF values, with single cracks showing the highest stress intensities, followed by multiple cracks, and then double cracks.The single crack design as in Fig 8, represented by the blue curve, shows the least amount of stress concentration near the crack tip in comparison to the other scenarios, with the lowest SIF values throughout all normalised crack lengths. It is possible that the interaction between the two cracks somewhat enhances the stress intensity since the double crack configuration, shown by the orange curve, has moderate SIF values that are greater than those of the single crack but lower than those of the multiple crack configuration. The grey curve, which represents the multiple crack configuration, has the greatest SIF values, showing a considerable concentration of stress brought on by the interplay of several fractures. The blue curve in Fig. 10 represents the single crack configuration and shows the lowest SIF values for all normalised crack lengths. This implies that, in contrast to the other designs, the stress concentration around the fracture tip is low.

The orange curve shows the double crack arrangement with intermediate SIF values. The two cracks' interaction has resulted in a mild rise in stress intensity, as indicated by these numbers, which are greater than those for the single-crack configuration but lower than those for the multiple-crack design. The multiple crack configuration, depicted by the grey curve, shows the highest SIF values. This indicates a significant increase in stress concentration resulting from the interaction of multiple cracks. The curves for all three configurations exhibit a generally convex shape, with SIF values peaking at an intermediate normalised crack length and decreasing towards the ends of the range.The single crack configuration as in Fig. 11 depicted with a blue curve, which demonstrates the lowest SIF values, remaining relatively constant around 1.2 to 1.4 across the entire range of normalised crack lengths.

This indicates minimal stress concentration around the single crack tip. The double crack configuration is shown with an orange curve, exhibiting moderate SIF values ranging from approximately 2.4 to 2.8. The SIF values for the double crack configuration remain relatively stable across most of the normalised crack length range, with slight increases at the beginning and end. The multiple crack configuration, represented by a grey curve, shows the highest SIF values, fluctuating between 3.6 and 4.2. The SIF values for multiple cracks display a slight dip at the beginning, followed by a stable region, and then an increase towards the end of the normalised crack length range.
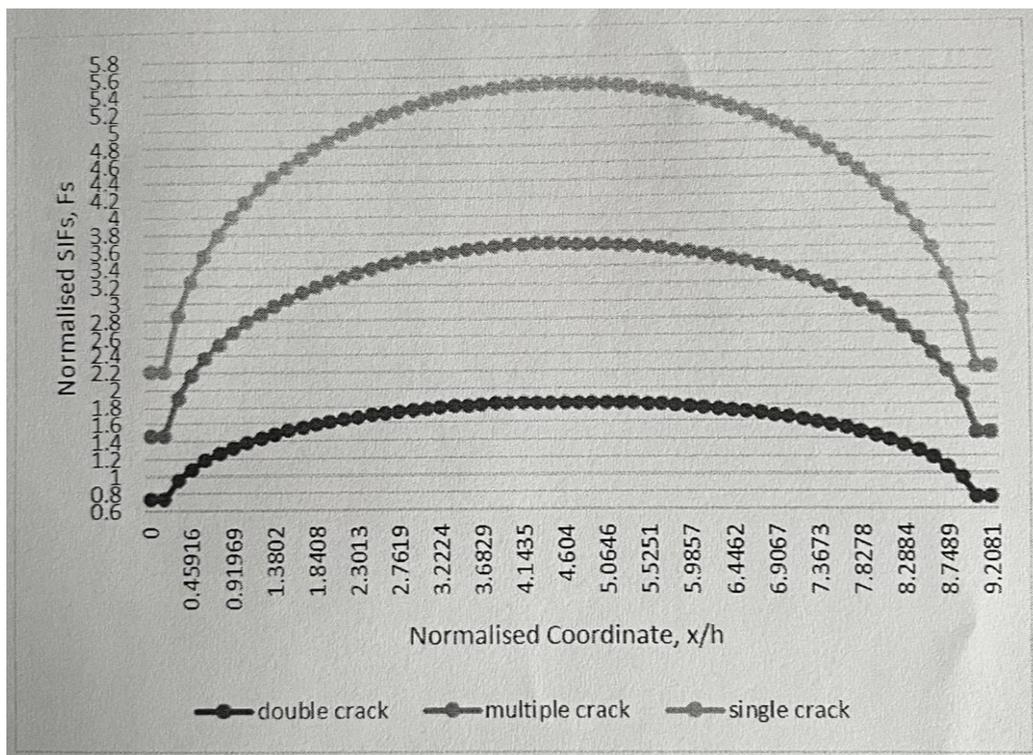

Fig. 8 *Comparison of stress intensity factors of single, double and three cracks for a/b = 0.2.*
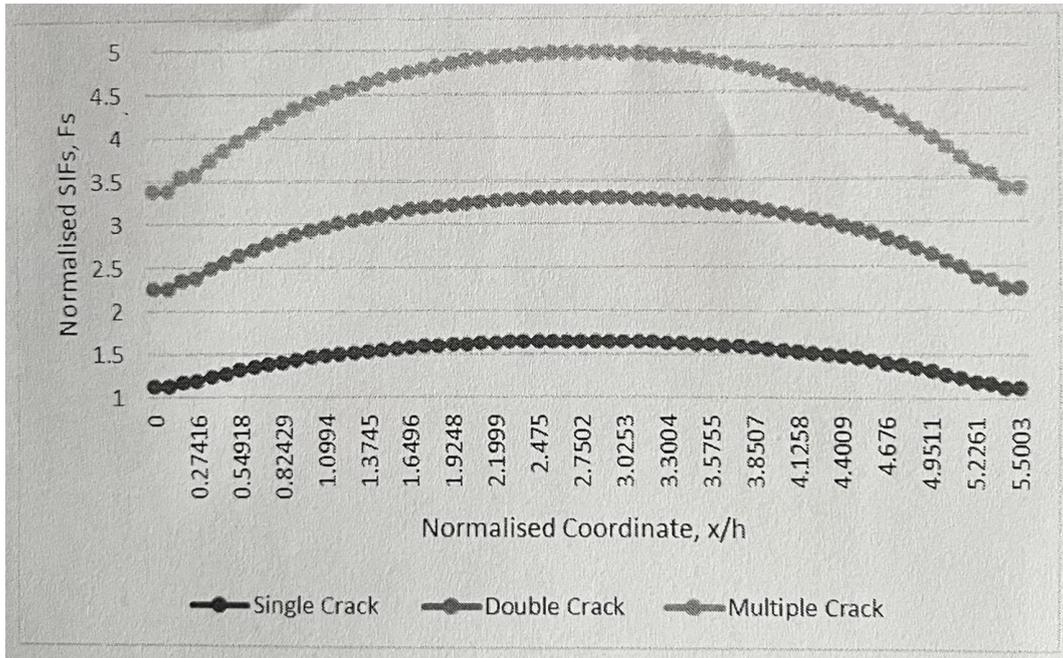
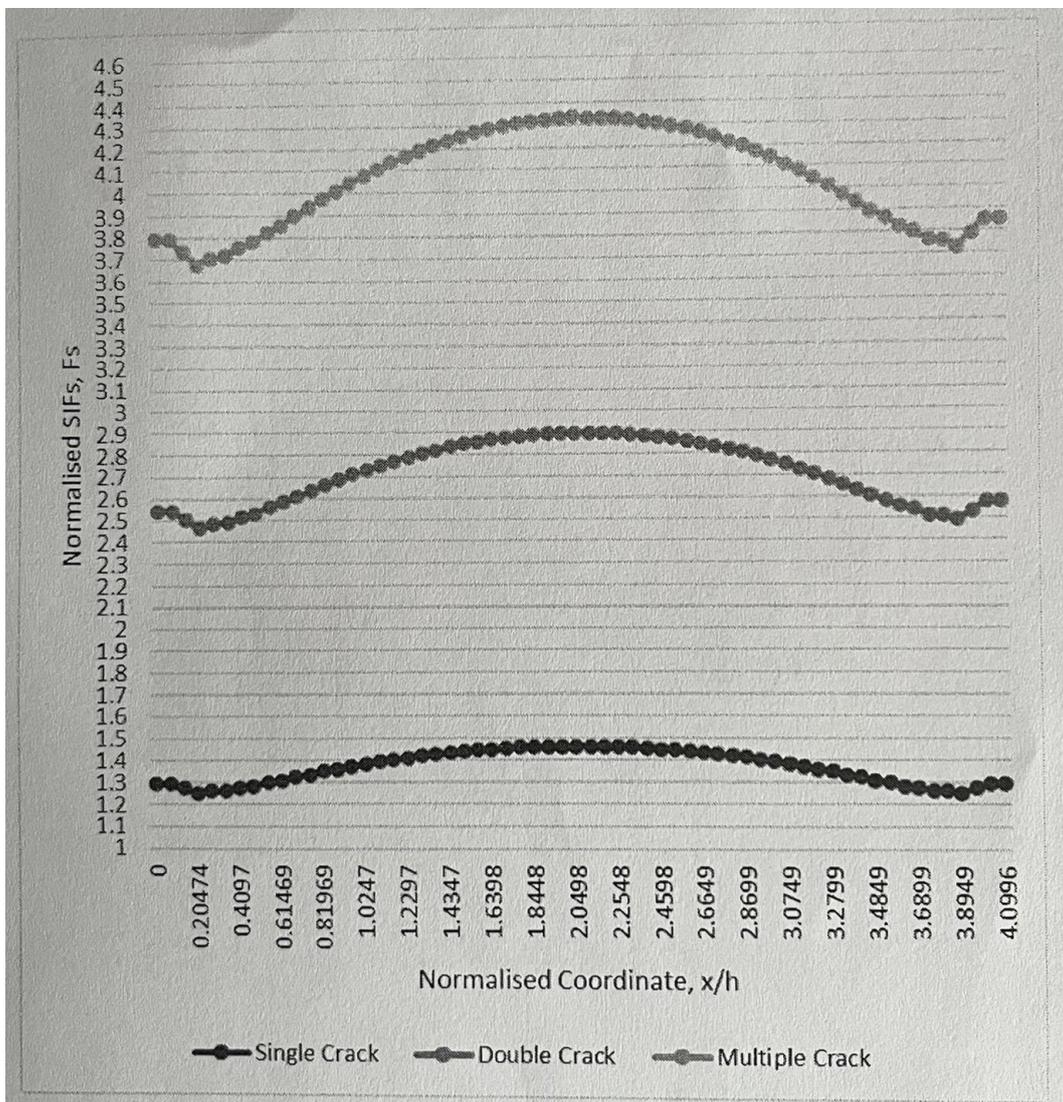**Fig. 9** *Comparison of stress intensity factors of single, double and three cracks for a/b = 0.4*

Fig.10 *Comparison of stress intensity factors of single, double and three cracks for a/b = 0.6*
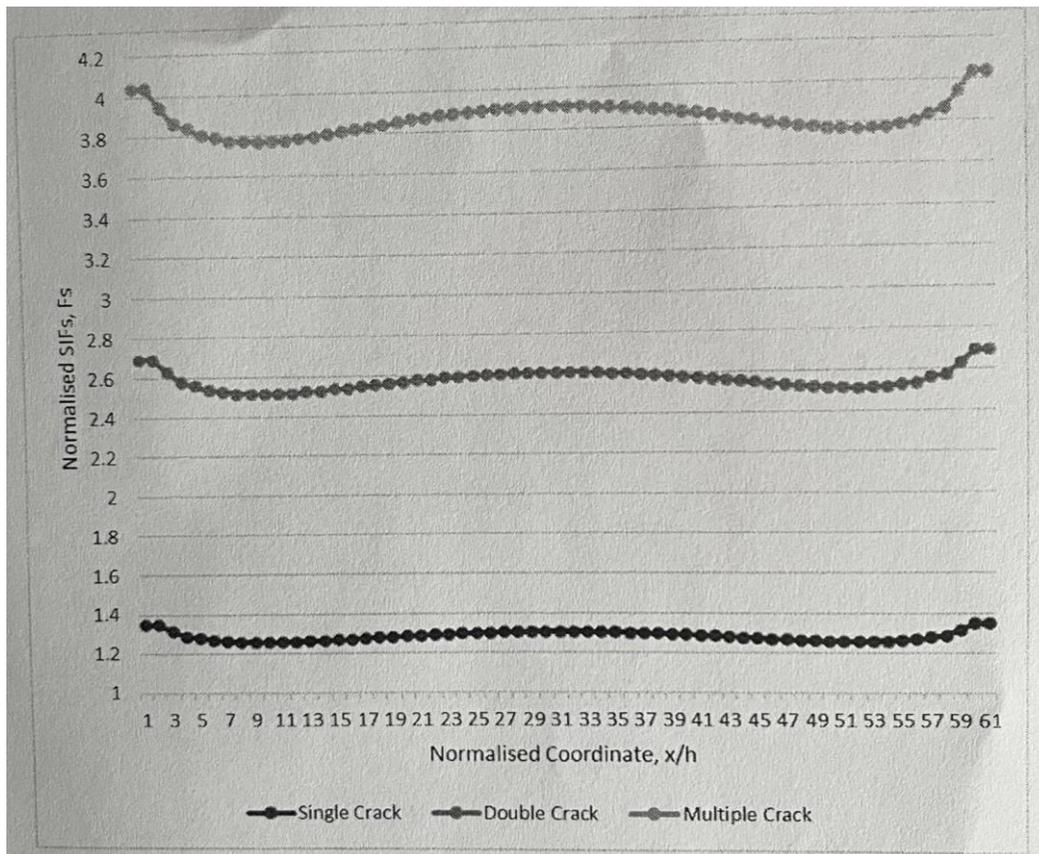
Fig. 11 *Comparison of stress intensity factors of single, double and three cracks for a/b = 0.8*

4. Conclusion

This research studies analysed stress intensity factor (SIF) solutions for semi-elliptical surface cracks on the cross section of a solid shaft under pressure as calculated by finite element modelling (FEM) using ANSYS software. According to the literature reading, no result has been found to calculate and differentiate normalized SIFs between single and multiple cracks interactions. The effect of the interactions on multiple surface cracks on solid shaft has been successfully identified by doing the comparison between the single crack, double crack and multiple cracks. The interaction factor ratio, X was used to investigate the relations between the single and multiple cracks interactions. The result obtained of the interaction factor ratio; X means that the Fd > Fs. From this result, it indicated that the multiple cracks have more impact on the SIFs values compare to the single crack. Thus, the cracks that existed more than one has more SIF interaction with each crack while the single crack has lower SIF interaction on the solid shaft.

Acknowledgement

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Yusoff & Ismail; **data collection:** Yusoff & Ismail; **analysis and interpretation of results:** Yusoff & Ismail; **draft manuscript preparation:** Yusoff & Ismail. All authors reviewed the results and approved the final version of the manuscript.*

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