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Analytical and Numerical Investigation of Fatigue Life in Rectangular Plates with Opposite Semicircular Edge Single Notches

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Abstract: This study undertakes an investigation into the fatigue life of carbon steel specimens with opposite semicircular edge notches using a combined approach based on experimental and numerical analysis. The study emphasises the determination of stress concentration factors (SCFs) for these notches based on S-N curves of carbon steel, employing a comprehensive method to evaluate their impacts on fatigue performance. Both experimental and numerical methods are applied to understand the influence of notches on fatigue characteristics, yielding insights into potential failure modes and opportunities for design enhancement. The research deepens our comprehension of fatigue mechanics in carbon steel structures, offering valuable perspectives regarding structural engineering and design refinement. The outcomes highlight the significance of integrating experimental testing and numerical simulations to carry out an exhaustive investigation of fatigue behaviour in notched specimens.

Keywords: stress concentration factors; fatigue life; finite element analysis (FEA); stress analysis; fatigue notch factor; SolidWorks

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1. Introduction

Fatigue failure is a pivotal issue within the realms of structural engineering and materials science, prompting extensive research endeavours aiming to comprehend and forecast materials' responses when subjected to cyclic loads [1].

This study focuses on investigating the fatigue lives of carbon steel specimens with opposite semicircular edge notches using experimental and numerical analyses.

The analysis of semicircular notches' geometries and engineering applications is driven by the urgent need to enhance our understanding of fatigue-induced failures in practical structures. This study focuses on opposite semicircular edge single notches in rectangular plates for several reasons:

Real-world relevance: Such notches are common in engineering structures, like aircraft parts and bridges. Thus, studying their fatigue behaviour provides insights into real-world scenarios [2].

Stress concentration effects: Notches introduce stress concentrations that accelerate crack initiation. Semicircular notches create complex stress patterns, requiring thorough investigation to comprehend their impacts on fatigue life [3].

Design guidelines: This research refines design guidelines by establishing links between notch geometry, loading conditions, and fatigue life. Engineers can make informed decisions and create safer designs.

Method validation: This study validates and improves analytical and numerical methods of fatigue analysis. Comparing models to simulations enhances prediction accuracy for notches of various shapes.

Interdisciplinary insights: beyond structural engineering, this study contributes to materials science, fracture mechanics, and numerical simulations, broadening our understanding of fatigue mechanisms.

In summary, this investigation addresses practical engineering challenges, enhances design practices, and advances analytical methods. Exploring the intricate relationship between semicircular notch geometry, stress concentration, and fatigue behaviour could lead to safer and more efficient engineering designs across diverse applications.

Stress concentration factors are examined to understand notch deformation, and S-N curves are used to quantify stress concentration factors. Experimental testing and numerical simulations are employed to evaluate the impact of notches on carbon steel fatigue performance [4].

Understanding fatigue behaviour and predicting fatigue life are essential for designing reliable structures. This study specifically examines carbon steel structures with opposite semicircular edge notches known to induce stress concentration. Experimental fatigue tests supply data used to construct S-N curves, proving the relationship between stress amplitude and fatigue life. Numerical simulations using advanced finite element analysis (FEA) investigate stress concentration factors at critical locations, confirming experimental observations. The integration of experimental testing and numerical simulations enables a comprehensive understanding of fatigue behaviour in carbon steel specimens with opposite semicircular edge notches. The findings help us to predict fatigue life and optimise designs to mitigate fatigue-related failures [5].

This study enhances our understanding of fatigue life in carbon steel structures with opposite semicircular edge notches and contributes to the field of fatigue mechanics. It serves as a valuable resource for professionals employed in structural engineering, materials science, and design optimisation, leading to safer industrial components. By combining experimental and numerical approaches, this study lays the foundations for further advancements in fatigue life prediction and structural integrity assessment of notched materials and geometries.

Stress concentration is a crucial factor involved in the design of engineering structures, machinery, and equipment, as it can lead to the fracture and failure of mechanical components. The presence of holes and notches in rectangular plates is common in various industries, including automobile, mechanical, aerospace, and marine manufacturing applications. However, these holes and notches can significantly reduce the mechanical strength of the components due to the high stress concentration they induce [6].

This stress concentration increases the likelihood of fracture under operational loads, compromising the functionality and reliability of the designed structure. The study and analysis of stress distribution around holes and notches, as well as the determination of the load-bearing capacity, are crucial to achieving an optimum design and ensuring the safe lifespan of structures and machine components [7].

Stress concentration refers to the occurrence of highly localised or accumulated stress in the vicinity of a change in cross-section or at a point of structural discontinuity. It is characterised by the clustering of stress lines, leading to elevated stress levels in specific areas [8].

Stress raisers, such as holes and notches, are primarily caused by the presence of concentrated stresses that exceed the theoretical cohesive strength. As a result, these high stresses tend to induce local plastic deformation and lead to the redistribution of stress in the affected area [9]. Various methods, including experimental, numerical, and analytical approaches, are employed to find the stress concentration factor in flat plates. These techniques enable the evaluation of stress concentration factors by examining factors such as physical tests, computational simulations, and theoretical calculations [10].

Extensive research has been conducted into the significance of stress concentration factors (SCF) in isotropic plates. Previous studies have provided a comprehensive understanding of stress concentration by offering a series solution that describes the stress field surrounding circular holes in plates of varying thickness [11]. The stress concentration factor of a plate with a triangular cut-out at its centre has been analysed, considering a diverse set of hole diameters in relation to the plate's thickness [8,12].

The numerical outcomes obtained through the generalised work–energy method have been identified for rectangular plates with circular cut-outs, as well as circular plates with rectangular cut-outs [13]. An examination was conducted to investigate the ultimate strength of metallic plates with central circular cut-outs under shear loading [14]. The stress concentration in finite composite laminates with elliptical holes, as well as multiple elliptical holes, has been analysed using the classical laminated plate theory [15]. A mathematical investigation has been conducted into isotropic plates experiencing in-plane loading in order to determine stress concentration factors [16].

The stress concentration factor for U notches subjected to mixed loads is examined, following past authors by utilising a criterion based on the deformation of the average energy density concept [17]. An analysis of stress concentration is performed on a round bar subjected to bending load, tensile load, and torsional load, considering the presence of a circular arc or V-shaped notch [18]. A comparative investigation has been conducted to analyse stress distribution in various types of notched plates [19].

Babulal et al. [20] conducted a study of the impact of widening an isotropic plate with a centrally located circular hole under a constant tensile load. The plate dimensions were 500 mm × 300 mm × 25 mm, and it was composed of AISI 4340 steel. The study utilised SolidWorks to model and perform a static analysis to find the stresses induced in the plate.

Mekalke et al. [21] conducted research to investigate the effects of an initial widening of a rectangular plate with a cylindrical hole on the stress and displacement distribution around the hole. The finite element method (FEM) was employed in this study. The primary focus was on examining the stresses that developed in the plate during the first stages due to forces applied on both ends. The aim of the research was to analyse the uniform stresses that occurred in the plate with a circular hole and notice any variations in the results obtained using different mesh configurations.

Pawar et al. [22] discussed the impact of geometrical irregularities and their influence on stress distribution within a plate. These irregularities cause disruptions in stress scattering. The study focused on analysing stress distribution in a plate with a circular hole. Two varied materials were employed to perform the analysis, and the results were compared to understand stress scattering and deformation. The findings would supply valuable insights regarding the planning of instruments about stress distribution and deformation.

Dhanjal and Arora [23] explored the presence of geometric irregularities, such as holes, notches, keyways, and shoulders, commonly found in machine components. These irregularities often result in stress concentration near the irregularity, causing stress levels higher than the average stress across the entire part. In this study, a plate with a central circular hole was analysed using three-dimensional finite element analysis. The plate was subjected to tensile loading, and the study focused on examining the influence of the plate's thickness-to-hole diameter ratio (T/D) on stresses and displacements. Additionally, the study involved calculating the theoretical stress concentration factor for different T/D ratios and comparing it to the stress concentration factor obtained through ANSYS simulations.

This paper introduces a comprehensive analysis of the elasto-plastic stress concentration factor of a carbon steel material. The material behaviour of the steel is mathematically modelled and analysed using FEA (finite element analysis) and analytical calculations. The focus is on a notched specimen subjected to axial load, aiming to confirm a method for calculating the generalised stress concentration factor in the elasto-plastic stress–strain range. The study supplies insights into the evolution of the plastic zone or front as a function of the load or stress parameter, as well as the calculation of the elasto-plastic stress concentration factor based on this external load parameter. The results aim to supply valuable information for mechanical design purposes, even though the study concentrates on a specific geometry and material. However, the described method lays the foundation for conducting fast and practical calculations via a more comprehensive and parametric design approach, considering input data, such as notch geometry and material properties.

1.1. The Idealised S-N Diagram for Steels

The S-N diagram, which depicts fatigue data, shows a wide range of points due to the inherently unpredictable nature of fatigue. In the context of preliminary and prototype design, as well as certain failure analyses, a simplified and idealised version of the S-N diagram proves to be valuable. Figure 1 presents an idealised S-N diagram specifically tailored for steels, where the median failure curve in the finite-life region is represented by two distinct lines. In the low-cycle region ($N < 1000$ cycles), a line with a gentle slope is positioned between the ultimate strength and a fraction f of the ultimate strength. Typically, f falls within the range of 0.8 to 0.9. Between the 10^3 and 10^6 cycles, a steeper-sloped line represents the median failure curve. At precisely 10^6 cycles, the endurance limit is reached, causing the failure curve to become horizontal. To effectively utilise this idealised S-N diagram, it is necessary to determine two specific points: fS_{ut} at 10^3 cycles and S_e at 10^6 cycles [24].

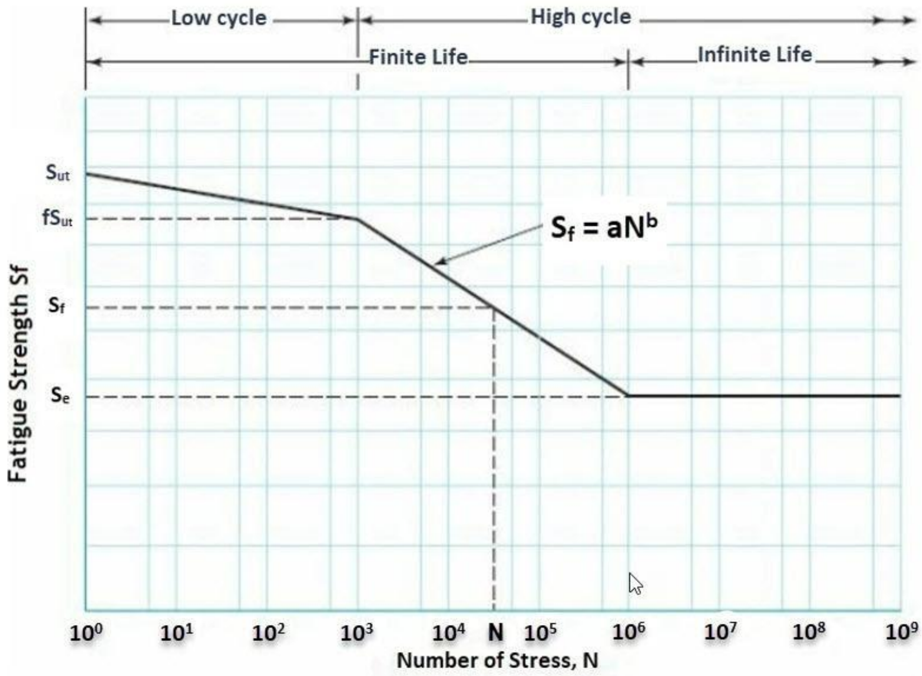

Figure 1. An idealised S-N diagram for steels [24].

In the finite life region, there exists an approximate relationship between fatigue strength and the duration of life, enabling the estimation of fatigue behaviour. Furthermore, for stress levels below the endurance limit, it becomes possible to predict infinite life.

1.2. Estimating the Endurance Limit

To find the endurance limit of a specific material, numerous fatigue tests are conducted at progressively lower stress levels. By plotting the obtained endurance limit values against the ultimate strength for a considerable number of ferrous metals, a reasonably strong correlation can be observed, as depicted in Figure 2. The plot proves that the endurance limit typically falls within the range of 40 to 60% of the ultimate strength, particularly up to approximately 1378.95 MPa. Beyond this point, the scatter of data increases, and the slope of the correlation curve becomes less steep. By simplifying the findings presented in Figure 2, an estimation of the endurance limit for steels can be made [24].

$$S'_e = \begin{cases} 0.55 \times \ S_{ut} & S_{ut} < 1400 \text{ MPa} \\ 690 \text{ MPa} \quad S_{ut} > 1379 \text{ MPa} & \\ 700 \text{ MPa} \quad S_{ut} > \ 1400 \text{ MPa} & \end{cases} \tag{1}$$

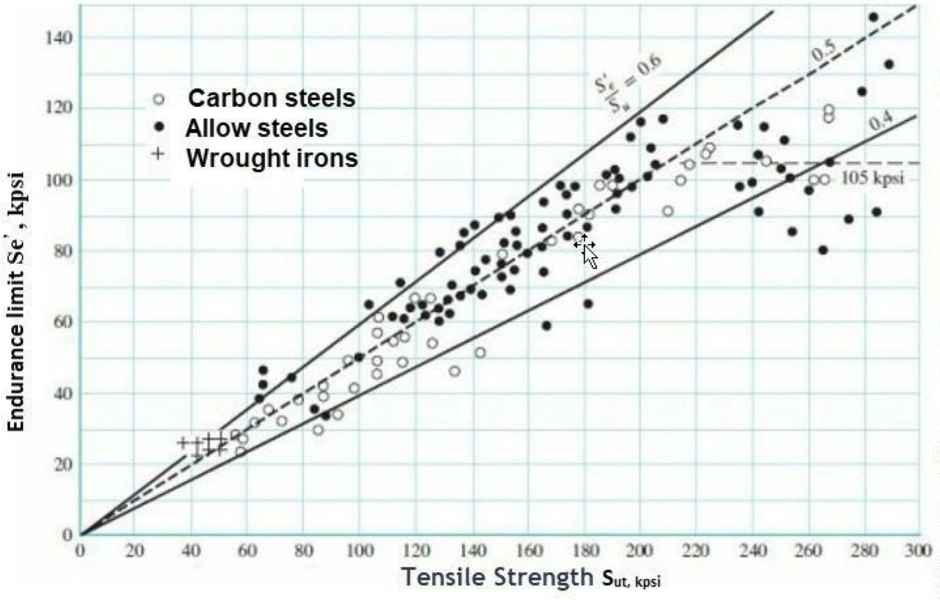

Figure 2. Endurance limits versus tensile strengths [24].

The minimum tensile strength is denoted as *Sut* in this equation. The prime mark on S'_e specifically shows the rotating beam specimen used in testing. The purpose of this notation is to differentiate between it and the unprimed symbol *Se*, which represents the endurance limit of an actual machine element under several types of loading conditions.

The above graph compares the endurance limits to the tensile strengths from actual test results for many wrought iron and steel materials. The ratios of S'_e/Sut of 0.60, 0.50, and 0.40 are represented by the solid and dashed lines. The data illustrate the relationship between endurance limits and tensile strengths, as discussed in their previously published book.

1.3. Estimating the Fatigue Strength at 10^3 Cycles

The next step in finding the fatigue line in the high-cycle region, which ranges from 10^3 to 10^6 cycles, involves estimating the fatigue strength, which is denoted as fS_{ut}, at 10^3 cycles. Several references have reached a consensus on using a value of f equal to 0.9 [25–28]. However, some researchers, upon considering certain experimental data showing the need for a more cautious approach, opt for a lower value of f, specifically 0.8. Nonetheless, it has been seen that for steels, the value of f tends to be slightly lower for materials with higher strengths. To prove a correlation between f and S_{ut}, a relationship has been developed based on the elastic strain line within the strain–life approach to fatigue analysis. This relationship, which is specific to steels, is graphically illustrated in Figure 3 and expressed through curve fit equations [24].

$$f = 1.06 - 2.8 \times (10^{-3}) \times S_{ut} + 6.9x(10^{-6}) \times S_{ut}^2 \quad 70 < S_{ut} < 1379(MPa) \tag{2}$$

$$f = 1.06 - 4.1 \times (10^{-4}) \times S_{ut} + 1.5x(10^{-7}) \times S_{ut}^2 \quad 500 < S_{ut} < 1400(MPa) \tag{3}$$

Values for f can be estimated using the plot or equations, acknowledging that they lack experimental bases and are merely intended to offer a more correct estimation than offered using a constant value. When dealing with values of S_{ut} below the specified limit, it is advisable to use a recommended f value of 0.9.

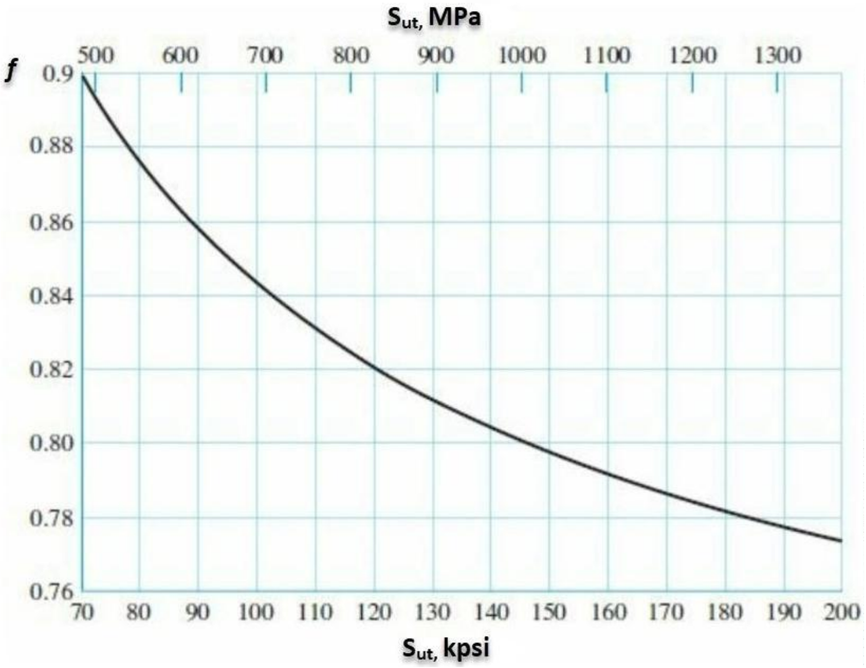

Figure 3. Fatigue strength fraction f of S_{ut} at 10^3 cycles for steels, with $S_e = S'_e = 0.5\ S_{ut}$ at 10^6 cycles [24].

1.4. The High-Cycle S-N Line

The relationship between fatigue strength and life within the high-cycle finite life region, which ranges from 10^3 to 10^6 cycles, shows a near-linear pattern when plotted via a log–log scale. As a result, it can be effectively represented on a normal scale using a power function commonly referred to as Basquin's equation.

$$S_f = a \times N^b \tag{4}$$

In the equation, Sf stands for the fatigue strength associated with a life N in cycles until failure, and the constants a and b correspond to the intercept and slope of the line when plotted on log–log coordinates. By taking the logarithm of both sides of Equation (4), we can easily find and determine these constants using the following solution process:

$$S_f = b \times logN + Log\ a \tag{5}$$

To derive expressions of the constants a and b, we can substitute the two known points $(10^3, fS_{ut})$ and $(10^6, S_e)$ into Equation (4), which represent the relationship between N (cycles to failure) and S_f (fatigue strength). By solving a and b, the resulting equations can be written as follows:

$$a = \frac{(f \times S_{ut})^2}{S'_e} \tag{6}$$

$$b = -\frac{1}{3} \times log\left(\frac{f \times S_{ut}}{S'_e}\right) \tag{7}$$

By solving Equation (4) for the life in cycles corresponding to a completely reversed stress, the variable S_f can be substituted with σ_{ar}.

$$N = \left(\frac{\sigma_{ar}}{a}\right)^{1/b} \tag{8}$$

The conventional S-N diagram is specifically applicable to scenarios involving completely reversed loading. In the literature, Basquin's equation is often used in the context of load reversals, in which there are two reversals per cycle. The estimation of S-N (stress–life) behaviour for fully reversed loading can be expressed as follows:

$$\sigma_{ar} = \sigma_f' \times (2 \times N_f)^b \tag{9}$$

In the equation, σ_{ar} represents the alternating stress in a completely reversed scenario, N_f represents the number of cycles or fatigue life, b represents the fatigue strength exponent representing the slope of the line, and σ_f' represents the fatigue strength coefficient. When dealing with situations in which the specific parameters are not readily available, the equations serve as useful methods for estimating the high-cycle S-N line [24].

2. Methodology

2.1. Software and Analysis Tools

In this study, a combination of analytical methods and numerical simulations was employed to analyse the behaviours of the components under cyclic loading conditions. The following software and tools were utilised to conduct the analyses and simulations:

SolidWorks Simulation Premium Student Edition 2023: This software package offers a comprehensive suite of simulation capabilities, including finite element analysis (FEA), static stress analysis, and fatigue analysis. The software provides a user-friendly interface that defines geometric models, applies loads and boundary conditions, and obtains stress, strain, and deformation results.

Finite Element Method (FEM): FEM is a numerical technique used to discretise complex structures into smaller elements to enable analysis. It allows the accurate modelling of stress distribution, deformation, and strain within components subjected to various loading scenarios.

ASME Carbon Steel Curves: The ASME Carbon Steel curves were employed to establish fatigue data of the component under investigation. These curves provide a basis for the prediction of the fatigue life of carbon steel structures under cyclic loading conditions.

The utilisation of SolidWorks Simulation Premium Student Edition 2023 enabled the creation of accurate geometric models, definition of loading conditions, and extraction of stress-related information. FEM was employed to simulate the behaviour of the components and obtain stress concentration factors, maximum stress values, and fatigue life predictions.

Transparency regarding the software and tools used is vital to promoting reproducibility and further research in this area. By sharing this information, we aim to facilitate future investigations and promote the advancement of knowledge of structural integrity analysis and design optimisation.

2.2. Experimental Method

In situations in which a stress raiser, such as a notch, groove, hole, or fillet, is present, it is common to refer to any such stress raiser as a notch for brevity. The nominal stress, which is denoted as S, is conventionally defined in these cases as an axial stress, elastic bending stress, elastic torsional stress, or a combination of these stresses. When calculating the area A and the second moment of area I, the cross-section used is the remaining net area after the removal of material to create the notch.

In the context of linear–elastic stress–strain behaviour, the nominal stress S is connected to the actual stress at the notch. This relationship allows us to understand and quantify the stress distribution and behaviour in the vicinity of the stress raiser.

$$\sigma = K_t \times S \tag{10}$$

The elastic stress concentration factor, which is denoted as K_t, is a quantity that is used to align with the chosen definition of the nominal stress S. This factor helps us to account for the amplification of stress levels around a stress raiser, supplying a measure of the degree of stress concentration in the vicinity of the notch. Values of K_t are available from a variety of sources, such as [16].

However, for the unnotched bending case, the linear–elastic material behaviour assumed in obtaining K_t does not apply beyond yielding. The actual stress σ now becomes less than $K_t \times S$.

Therefore, when comparing S-N curves, as depicted in Figure 4, for a notched plate specimen, if the curves are plotted either as S (stress) or $K_t \times S$ (stress concentration factor multiplied by stress) against the number of cycles until failure, they will not align with the curves obtained via simple axial loading.

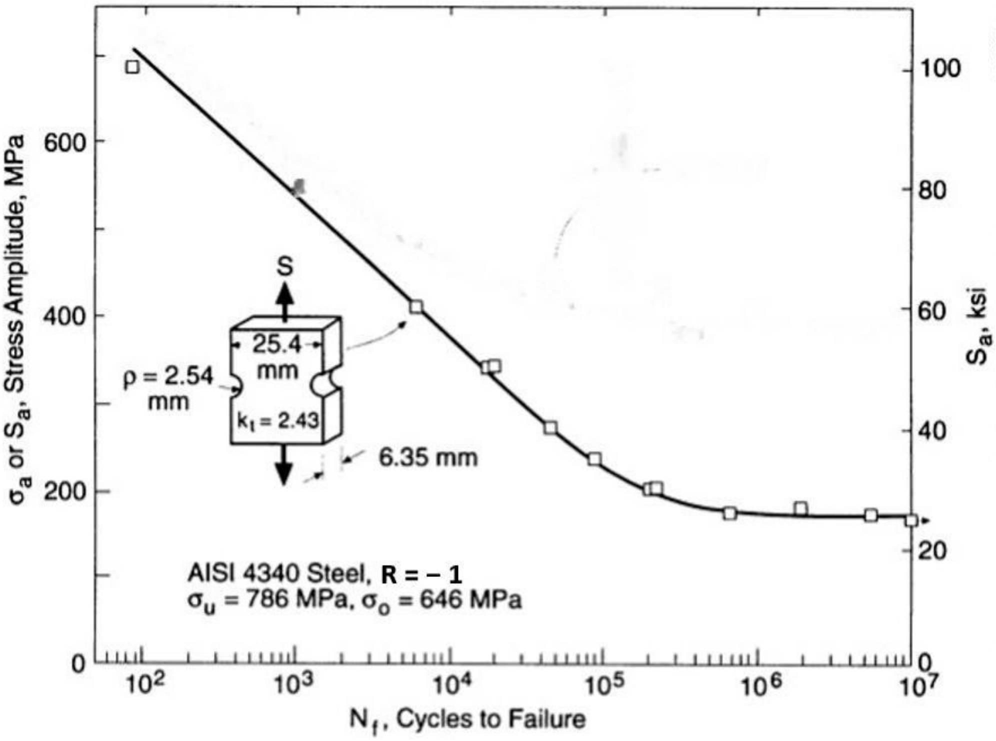

Figure 4. Test data of a ductile metal illustrating variation in the S-N curve's stress amplitude with life [29].

The discrepancy between the S-N curves arises due to the presence of the stress concentration factor K_t in the notched plate specimen. The stress concentration factor accounts for the elevated stress levels in the vicinity of the notch, resulting in localised stress concentrations. Therefore, the fatigue behaviour of the notched plate differs from that of a part subjected to simple axial loading.

The inclusion of the stress concentration factor alters the stress distribution along the specimen, leading to variations in the number of cycles until failure. This discrepancy highlights the importance of considering the geometric features and stress concentration factors when predicting the fatigue life of components with notches or other stress raisers.

It is crucial that engineers are aware of these differences and take them into account during the design and analysis stages. Special consideration should be given to notch sensitivity and the influence of stress concentrations on fatigue failure. By incorporating proper design modifications, such as filleting, or implementing stress-reducing techniques, the detrimental effects of stress concentrations can be minimised, improving the component's fatigue performance.

The findings emphasize the significance of conducting fatigue studies specific to notched components, considering the unique stress distributions and localised stress concentrations caused by the presence of notches. This tailored approach allows more correct predictions of the component's fatigue life and helps to design robust and durable structures that can effectively withstand cyclic loading conditions.

2.3. Analytical Method

The elastic stress concentration factor, which is denoted as K_t, represents the relationship between the maximum stress observed in a stress raiser and the nominal stress calculated using conventional mechanics-of-materials formulas. Unless otherwise specified in a scenario, the nominal stress is computed based on the dimensions of the net cross-section. To ensure accuracy, the equations have been derived to closely align with the extensive data presented in the referenced literature. These equations demonstrate a strong fit to the data points, which is typically within a margin of error below 5%, across the specified variable ranges [30].

Figure 5 illustrates a rectangular plate specimen measuring 31 mm × 25.4 mm × 6.35 mm, featuring opposing semicircular notches. The purpose of this analysis is to examine the stress distribution in the plate surrounding the notches. The dimensions of the notches are considered while supporting a constant plate width and centre distance between the notches. The plate is subjected to a tensile load to ease stress evaluation.

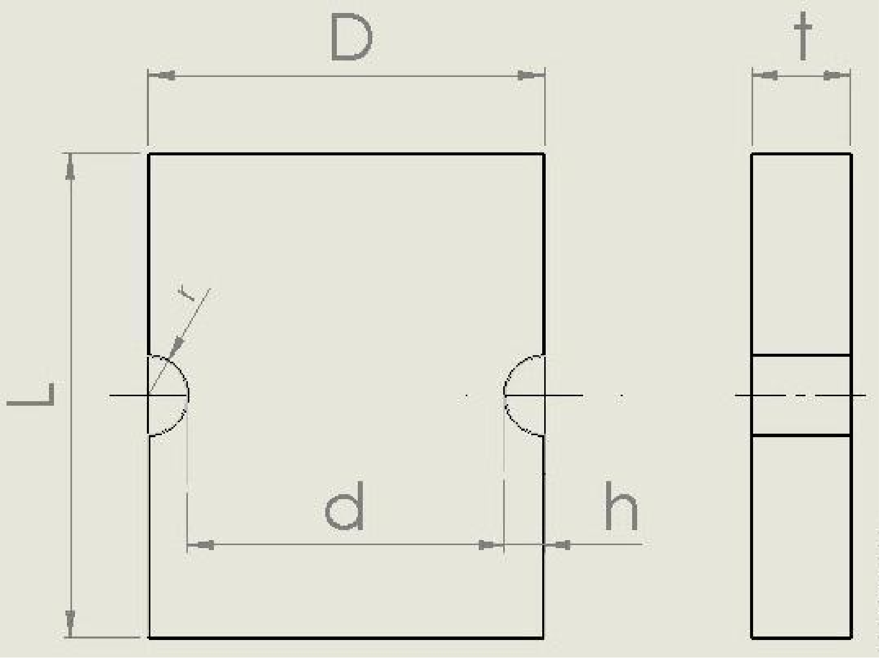

Figure 5. Opposite single semicircular-shaped notches.

Dimensions for the notched plate are depicted in Table 1.

Table 1. Dimensions for the semicircular notched plate.

Dimension	Value	Units
r	2.54	mm
h	2.54	mm
t	6.35	mm
D	25.4	mm
d	20.32	mm
L	31	mm

To incorporate the localised stress elevation caused by a stress raiser, engineers use the stress concentration factor or theoretical stress concentration factor. This factor quantifies the relationship between the calculated peak stress and the nominal stress that would exist in the structure under the assumption of a uniform stress distribution. The mathematical expression for this factor is defined as follows:

$$K_t = \frac{\sigma_{max}}{\sigma_{nom}} \quad (11)$$

The conventional approach used to determine the nominal stress in a notched member involves dividing the axial load by the cross-sectional area measured at the specific notch position [30]. Assuming the axial load = 20,195 N, this relationship can be represented by the following expression:

$$\sigma_{nom} = \frac{Axial\ Load}{Cross\ Sectional\ Area} \quad (12)$$

$$\sigma_{nom} = \frac{F}{A} = \frac{F}{t \times (D - 2 \times h)} = \frac{20,195}{6.35 \times (25.4 - 2 \times 2.54)} = 157\ \text{MPa} \quad (13)$$

In a simple rectangular plate with opposite semicircular-edged single notches, the stress concentration factor K_t for various dimensions can be written as follows:

$$K_t = 3.065 - 3.370 \times \left(\frac{2 \times h}{D}\right) + 0.647 \times \left(\frac{2 \times h}{D}\right)^2 + 0.658 \times \left(\frac{2 \times h}{D}\right)^3 \quad (14)$$

$$\begin{aligned} K_t = 3.065 - 3.370 \times \left(\tfrac{2\times2.54}{25.4}\right) + 0.647 \times \left(\tfrac{2\times2.54}{25.4}\right)^2 \\ +0.658 \times \left(\tfrac{2\times2.54}{25.4}\right)^3 = 2.422 \end{aligned} \quad (15)$$

Therefore, the maximum stress of this rectangular plate can be calculated as follows:

$$\sigma_{max} = K_t \times \sigma_{nom} = 2.422 \times 156.511 = 379\ \text{MPa} \quad (16)$$

The material analysed is an allowed steel with ultimate tensile strength = S_{ut} = 724 MPa. Therefore, for the rotating beam endurance limit at 10^6 cycles, the specimen used in testing can be expressed as follows:

$$S'_e = 0.55 \times S_{ut} = 0.55 \times 724 = 39\ \text{MPa} \quad (17)$$

Fatigue strength fraction f for the value range of 483 < S_{ut} < 1379 (MPa) can be estimated using the following equation:

$$\begin{aligned} f = 1.06 - 2.8 \quad & \times \left(10^{-3}\right) \times S_{ut} + 6.9 \times \left(10^{-6}\right) \times S_{ut}^2 \\ & = 1.06 - 2.8 \times 10^{-3} \times 105.007 + 6.9 \times 10^{-6} \times 105.007^2 \\ & = 0.842 \end{aligned} \quad (18)$$

After solving constants for a and b, the resulting equations can be written as follows;

$$a = \frac{(f \times S_{ut})^2}{S'_e} = \frac{(0.842 \times 724)^2}{398.192} = 1108\ \text{MPa} \quad (19)$$

$$b = -\frac{1}{3} \times log\left(\frac{f \times S_{ut}}{S'_e}\right) = -\frac{1}{3} \times log\left[\frac{0.842 \times 724}{398.192}\right] = -0.061 \quad (20)$$

For a fatigue analysis over 10^4 cycles to failure, the fatigue strength S_f associated with a life N in cycles until failure can be referred to as Basquin's equation and is defined as follows:

$$S_f = a \times N^b = 135.358 \times (10^4)^{-0.061} = 632\ \text{MPa} \quad (21)$$

Stress amplitude is equal to the alternating stress and endurance limit calculated, i.e., S'_e = σa = σar = 0.941 × Sut = 682 MPa. Therefore, the estimation of S-N (stress–life) behaviour for fully reversed loading, life in cycles correlating to a completely reversed stress can be given as follows:

$$N_f = \left(\frac{\sigma_{ar}}{a}\right)^{1/b} = \left(\frac{682}{1108}\right)^{1/-0.061} = (0.615)^{1/-0.061} = 2891 \text{ cycles} \tag{22}$$

The results obtained via this analytical method are summarised in Table 2.

Table 2. Analytical method results.

Property	Value	Units
Nominal stress (σ_{nom})	157	MPa
Maximum stress (σ_{max})	379	MPa
Stress concentration factor (K_t)	2.422	N/A
Ultimate tensile strength (S_{ut})	724	MPa
Endurance limit (S'_e)	398	MPa
Fatigue strength fraction (f)	0.842	N/A
Constant (a)	1108	MPa
Fatigue strength exponent (b)	−0.061	N/A
Fatigue strength (S_f)	632	MPa
Stress amplitude (σ_a)	682	MPa
Fatigue life (N_f)	2891	cycles

2.4. Finite Element Method

The finite element method is a numerical technique widely employed in engineering to approximate solutions to various problems. In the case of structural steel plates, finite element analysis is used to assess stress concentration phenomena.

The choice between a 3D problem and a 2D problem depends on the complexity and accuracy required in the analysis. In this study, a 3D problem was chosen over a 2D problem for several reasons:

Out-of-plane effects: In real-world scenarios, structural components can experience deformations and stress distributions in all three dimensions. Using a 3D analysis, the study aims to capture the full behaviour of the rectangular plate, including out-of-plane effects that could significantly impact stress concentrations at the notches.

Complex geometry: The presence of semi-circular notches and their interaction with the surrounding geometry can lead to complex stress patterns in three dimensions. A 3D analysis provides a more accurate representation of these complex stress distributions.

Realism: While 2D analyses are useful in terms of simplifying geometry and reducing computational complexity, they may overlook certain physical effects that only manifest in 3D simulations. This study's objective is to provide a comprehensive understanding of stress concentration and fatigue life, which justifies the use of a 3D analysis.

In the finite element analysis presented in this paper, the axes of symmetry were indeed utilised to simplify the model and streamline the analysis process. These axes divide the structure into symmetric segments, allowing the analysis of only a fraction of the full geometry while maintaining accuracy in regions in which symmetry conditions hold.

The decision to implement axes of symmetry was informed by the geometry of the rectangular plate specimen and the nature of the loading conditions. The plate's geometry exhibited inherent symmetry due to the presence of opposite semi-circular notches on either side. Furthermore, the loading conditions were designed to maintain symmetry.

The employment of axes of symmetry was a judicious choice that significantly streamlined the analysis process while maintaining accuracy in places where symmetry conditions held. The decision was based on the geometric characteristics and loading conditions of the rectangular plate specimen, and steps were taken to ensure the validity of symmetry assumptions through thorough inspection and verification. This approach allowed efficient analysis of and valuable insights into the stress distribution and fatigue life in the presence of notches.

In this study, careful attention was given to accurately model critical areas, like the notches. Finite element entities were created to match each notch's geometry. The dimensions, shape, and position of the notches were precisely defined. Specific element types suitable for curved geometries were selected to accurately represent the notches.

Mesh refinement was employed to capture stress concentration effects around the notches. The mesh was gradually refined near the notches to ensure smooth transitions between stress values. This refinement involved using smaller elements and more integration points in regions of interest. The approach was validated through convergence testing, confirming that the refined mesh accurately represented stress gradients without significantly altering overall results.

By focusing on accurate modelling of critical areas and mesh refinement, the study effectively captured stress concentration phenomena around the notches, providing valuable insights into the potential failure mechanisms and fatigue life.

In this study, SolidWorks Premium Student Edition 2023 was employed to perform stress analysis on a rectangular plate specimen using single notches found on opposite semicircular edges.

Comparison with other FEM software:

To ensure the reliability and accuracy of the finite element analysis, a comparison between the results obtained via SolidWorks simulation and other widely used FEM software packages, such as ANSYS Static Structure 2019, was conducted. This comparative analysis aimed to validate the findings and assess the consistency of results across different simulation platforms.

Similarities and differences:

The results obtained via SolidWorks simulation were found to have close agreement with the outcomes of the ANSYS Static Structure 2019 simulation, as shown in Figure 6. The stress distribution patterns, deformation behaviour, and critical areas of stress concentration demonstrated remarkable similarity across ANSYS simulations. This consistency in results provided a strong indication of the accuracy and validity of the analysis conducted using SolidWorks.

Minor variations were observed in stress magnitude, which can be attributed to differences in numerical algorithms, element formulations, and convergence criteria employed by each software package. However, these differences were well within acceptable ranges and did not impact the overall trends or conclusions drawn during the study.

Validation of SolidWorks results:

The comparative analysis results summarised in Table 3 served as a valuable validation of the SolidWorks simulation results. The close agreement with established ANSYS software confirmed the robustness of the methodology employed and the accuracy of the model created using SolidWorks.

Table 3. Comparison SolidWorks and ANSYS results.

Property	ANSYS (MPa)	SOLIWORKS (MPa)	Error Percentage (%)
Maximum principal stress	396.13	395.914	0.05

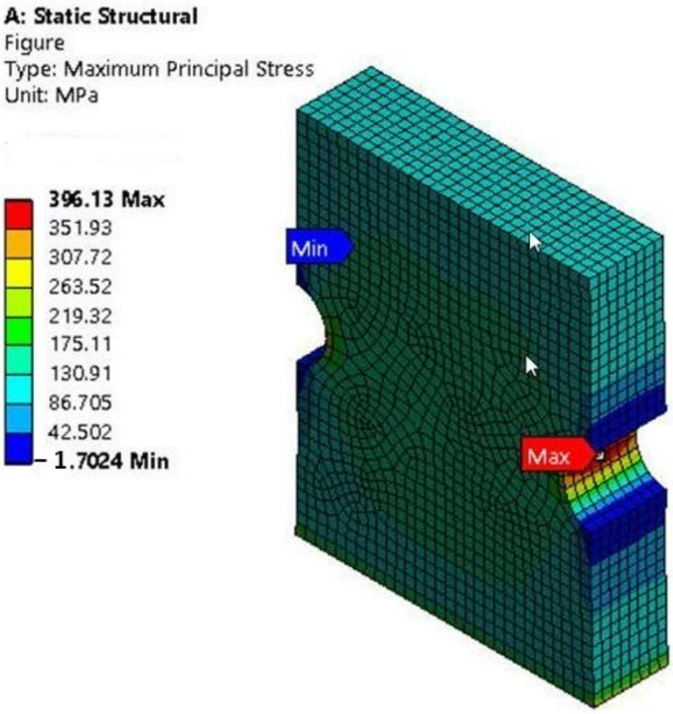

Figure 6. Maximum principal structural (ANSYS).

By performing this cross-platform comparison, any uncertainties about the software-specific biases were effectively mitigated, strengthening the credibility of the results obtained via the SolidWorks simulation. This validation process ensured that the insights gained from this study could be confidently relied upon when making informed design decisions and optimising the structural integrity of similar components in practical applications.

The dimensions of the plate are 25.4 mm in the x-direction, 31 mm in the y-direction, and 6.35 mm in the z-direction, as illustrated in Figure 7.

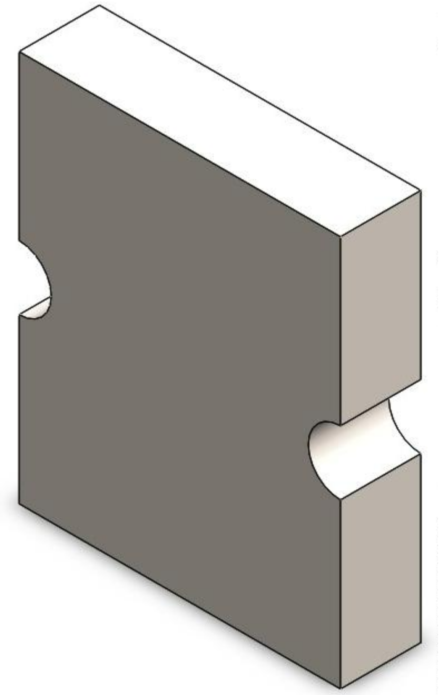

Figure 7. Three-dimensional CAD view modelling for a semicircular notched rectangular plate.

To achieve the desired solution, SolidWorks Simulation Premium Student Edition 2023 was utilised to perform stress analysis and determine the fatigue notch factor of the rectangular plate measuring 31 mm × 25.4 mm × 6.35 mm. Figure 8 presents a 3D model of the rectangular plate featuring the opposing semicircular notches. To conduct a static analysis of the plate, it is essential to apply proper fixtures that restrict out-of-plane rotations and free body motions. In this case, a single fixture was implemented on the lower face of the plate to prevent any motion perpendicular to the plate's plane.

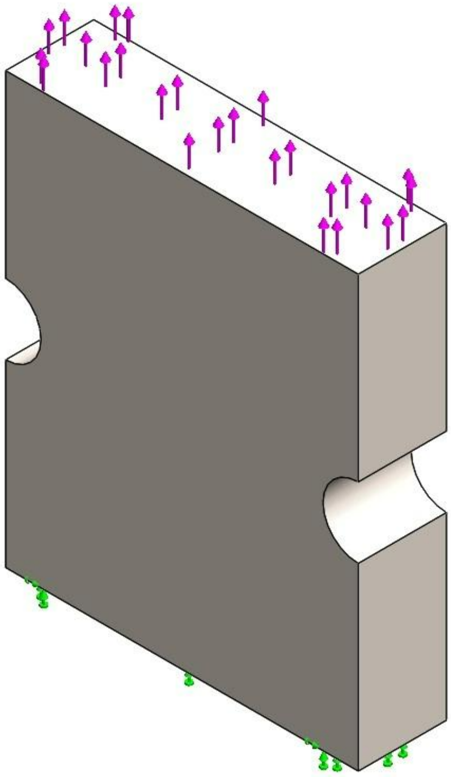

Figure 8. Three-dimensional model of rectangular plate with single opposite semicircular notches under loading and constraints.

The aim of this study was to obtain the solution for the analysed model, supplying insights into the stress distribution and potential areas of stress concentration within the rectangular plate. By subjecting the plate to a uniform tensile load of 20,195 N, engineers could assess the structural response and evaluate the impact of the notches on the plate's mechanical behaviour.

The implementation of fixtures and the application of specific loading conditions were crucial steps in accurately simulating real-world scenarios. By considering these boundary conditions, the static analysis yielded valuable information about the plate's deformation, stress distribution, and potential failure mechanisms.

The findings of this analysis can serve as a foundation for further investigations, such as fatigue studies, to evaluate the long-term performance and durability of the notched plate under cyclic loading conditions. This comprehensive understanding of the plate's behaviour helps us to make informed design decisions, enhancing the structural integrity and optimising the performance of similar components in practical applications.

To find the best mesh size for correct and efficient analysis using SolidWorks Simulation Premium Student Edition 2023, a mesh sensitivity analysis was conducted. This analysis involved creating multiple meshes with different element sizes or refining mesh density levels from coarse to fine and evaluating the resulting stress and deformation distributions. To present the mesh sensitivity results, a table or plot can be included, showing key output quantities, such as von Mises stresses or displacements, which were obtained for different mesh densities. These results were compared to find out if further mesh refinement significantly affects the outcomes. It is important to note any convergence trends observed and explain why a particular mesh density was chosen for this analysis. By comparing the results obtained using different mesh densities, we could assess the convergence behaviour and find the proper mesh size. A mesh sensitivity study investigation was completed to confirm that the stress did not depend on the mesh element number.

Through careful analysis and comparison of mesh size with equivalent stresses, it was seen that the von Mises stress difference values decreased from a coarse to a fine mesh density until reaching an element size of 0.847 mm. However, after further decreasing the element size, as shown in Table 4, it was found that the equivalent stress did not change, or the change was negligible. This result confirms that the equivalent stress did not change value under an element size of 0.847 mm. The 3D model of the rectangular plate was discretised into a mesh using an element size of 0.847 mm.

Table 4. Comparison between mesh element number and equivalent stress (mesh study).

Element Size (mm)	Total Element	Von Mises Stress (MPa)
3.391	1039	317
2.967	1609	338
2.077	3470	367
1.505	9259	370
1.165	19,735	373
0.847	49,254	375

The meshing process involves dividing the 3D model into discrete elements to approximate the plate's geometry. In this case, an element size of 0.847 mm was chosen to strike a balance between accuracy and computational efficiency. The resulting mesh, consisting of 49,254 elements, supplied a sufficient level of detail to capture the plate's complex geometry and accurately represent stress distribution. This meshing approach resulted in a total of 49,254 elements, as shown in Figure 9.

Choosing a proper model type and meshing strategy is crucial to obtaining correct and reliable results via finite element analysis. The linear–elastic isotropic model assumes that the material behaviour follows Hooke's law and shows isotropic properties, meaning that its mechanical response is independent of the direction. This model choice allows a simplified representation of the material's behaviour while still capturing the essential characteristics required to perform the analysis. During the analysis, a linear–elastic isotropic model type was selected, employing alloy steel and the mechanical properties specified in Table 5.

Table 5. Mechanical properties of alloy steel.

Property	Value	Units
Elastic modulus	210,000	N/mm^2
Poisson's ratio	0.28	N/A
Shear modulus	79,000	N/mm^2
Density	7700	kg/m^3
Tensile strength	724	N/mm^2
Yield strength	620	N/mm^2

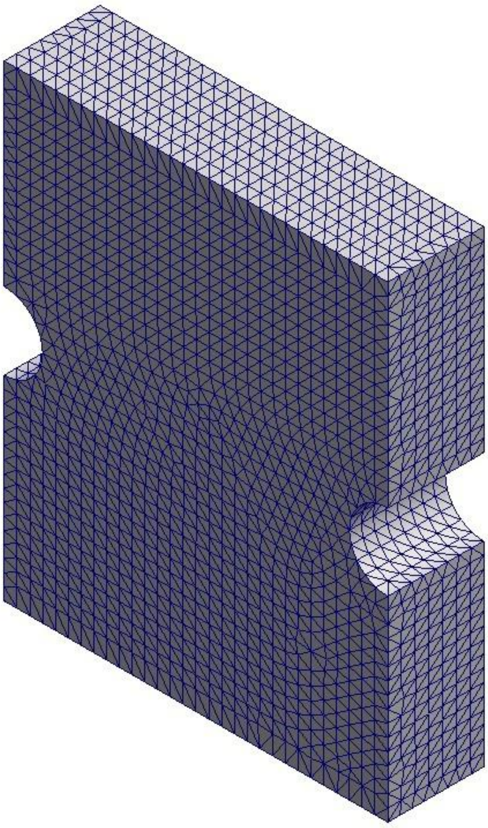

Figure 9. Meshed body of rectangular plate with single opposite semicircular notches.

The alloy steel material properties outlined in Table 5 play a significant role in finding the plate's response under loading. These properties, including Young's modulus, Poisson's ratio, and yield strength, define the material's stiffness, ability to deform under stress, and overall strength.

The mesh settings specified in Table 6 summarise important considerations during the meshing process, such as element type, element formulation, and convergence criteria. These settings ensure the mesh's quality and optimise the analysis to identify correct and reliable results.

Table 6. Solid mesh setting.

Jacobian Points	Element Size	Tolerance	Mesh Quality	Total Nodes	Total Elements	Maximum Aspect Ratio	Percentage of Elements/ Aspect Ratio
16	0.847 (mm)	0.042 (mm)	High	71,995	49,254	3.2525	>3:100

By employing proper model types, material properties, and meshing strategies, engineers can effectively simulate the behaviour of the notched plate and obtain valuable insights into its structural response. These insights enable the identification of potential stress concentrations, areas of high deformation, and critical regions prone to failure, guiding design improvements and enhancing the overall performance and reliability of the part.

3. Results and Discussion

The finite element method (FEM) proves to be a valuable tool for analysing the behaviour of components and assemblies under various loads. By utilising SolidWorks Simulation Premium Student Edition 2023, the maximum normal stress and stress concentration factor have been found. This analysis involved considering a rectangular plate with opposing single semicircular notches, where the ratio of the notch height to the radius is 1. The findings of the static study supply valuable information in the form of stress, deformation, or strain.

To enhance the understanding of the part's response, it is crucial to prove a link between the static study and the later fatigue study. This connection allows a comprehensive investigation of the component's behaviour under cyclic loading conditions. Using the results obtained via the static analysis, engineers can better predict the part's performance and durability, considering the potential initiation and propagation of fatigue cracks.

Furthermore, the evaluation of the stress concentration factor and maximum normal stress helps us to find critical regions within the part. These regions experience higher stress levels, making them susceptible to fatigue failure. By pinpointing such areas, design modifications or structural enhancements can be implemented to mitigate the risk of fatigue-induced failures.

The integration of SolidWorks Simulation Premium Student Edition 2023, along with the ability to link static and fatigue studies, provides engineers with a powerful platform to simulate and analyse the behaviour of components subjected to complex loading scenarios. This approach enables informed design decisions and helps to optimise the structural integrity and reliability of parts and assemblies.

Figure 7 depicts the evaluation of the maximum stress experienced by a rectangular plate with opposing single semicircular notches, with a notch ratio of h/r = 1, under an axial tensile load. The results obtained via the static analysis show that, as predicted, the maximum normal stress (or first principal stress) occurs at the centre of the semicircular notched section. Specifically, the maximum stress recorded is 396 MPa, as illustrated in Figure 10. Additionally, the analysis yields a stress concentration factor value of 2.422.

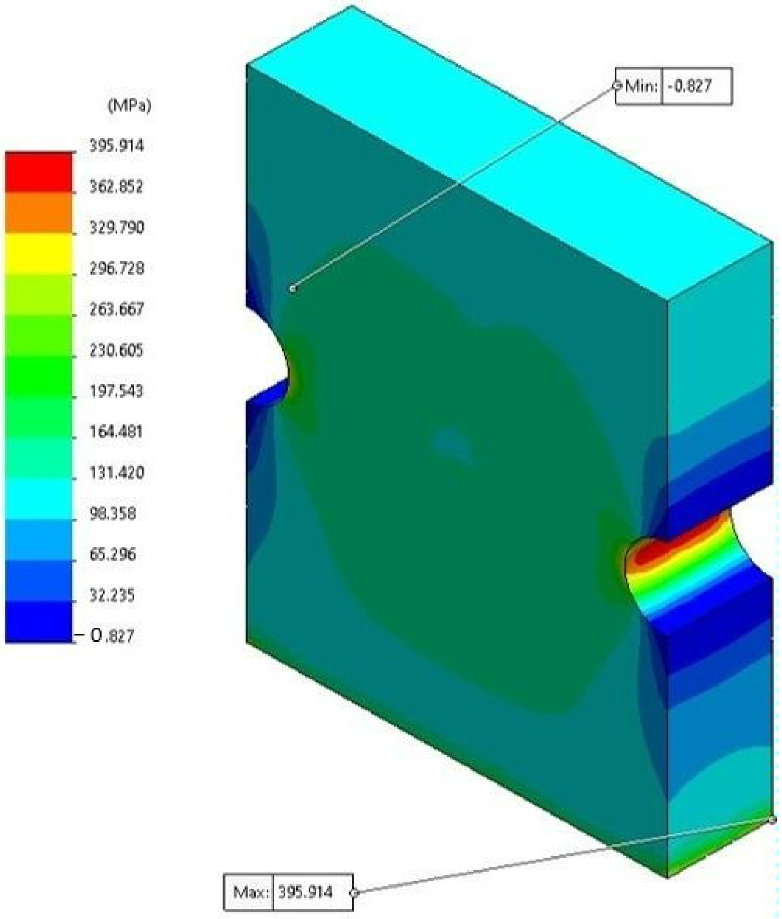

Figure 10. Static stress analysis and P1 first principal stress.

The observed concentration of stress at the centre of the semicircular notch signifies a region of heightened vulnerability within the part. This concentration of stress can potentially lead to localised failure or the initiation of cracks, especially under repetitive or cyclic loading conditions. Consequently, it is crucial to assess the impact of this stress concentration on the part's overall performance and durability.

By finding the maximum stress and stress concentration factor, engineers can gain valuable insights into the critical areas of the part that are more prone to fatigue and failure. Using this information, proper design modifications, such as introducing fillets, altering material properties, or adjusting the component's geometry, can be implemented to alleviate stress concentration and enhance the part's resistance to fatigue.

Moreover, linking the static analysis results to the later fatigue study allows a comprehensive understanding of the part's behaviour under cyclic loading. This integrated approach enables engineers to predict the component's fatigue life, assess the potential initiation and propagation of cracks, and make informed decisions on its design and performance optimisation.

The findings obtained via the analysis of the rectangular plate with single opposite semicircular notches supply valuable information to engineers, enabling them to enhance the structural integrity and reliability of components and assemblies subjected to axial tensile loads. The combination of correct stress evaluation and the ability to investigate stress concentration factors eases the development of robust and fatigue-resistant designs, leading to improved product performance and longevity.

The percentage of error between the analytical and finite element method used to determine the maximum stresses experienced by rectangular plate with single opposite semicircular notches is presented in Table 7.

Table 7. Error percentage of σ_{max}.

Type of Stress Raiser	σ_{max}, Analytical Method (MPa)	σ_{max}, Finite Element Method (MPa)	Error Percentage (%)
Opposite single semicircular notch	379	396	4.27
Fatigue life (N_f)	2891	2882	0.31

The acceptable value of the error percentage between the analytical method and the finite element method (FEM) can vary depending on several factors, including the specific problem being studied, the complexity of the geometry, the loading conditions, and the accuracy requirements of the research or engineering application. However, in general, a common guideline for acceptable error percentages between analytical and numerical methods is often around 5 to 10%.

In engineering research, an error percentage of up to 5% is often considered to be acceptable, although the precise acceptable range may vary depending on the specific application and the available validation data. The result of 4.27% error obtained in this study via both analytical and finite element methods has such good agreement that the variation between two methods is within the acceptable limits.

The fatigue study aims to analyse the progressive structural damage that occurs in a part when it is subjected to alternating loading conditions. Fatigue refers to the phenomenon of failure of a part occurring after enough cycles under these conditions.

Table 8 supplies a summary of the fatigue data, which is based on ASME Carbon Steel curves, for the part under investigation. The results, as shown in Figure 11, show that the specimen would experience failure after approximately 2882 cycles. Furthermore, the maximum stress (P1 stress) recorded is 396 MPa. Additionally, Figure 12 presents a graphical representation of these data.

Table 8. Fatigue data based on ASME carbon steel curves.

Points	N	S (MPa)
1	10	3259
2	20	2419
3	50	1699
4	100	1284
5	200	985
6	500	710
7	1000	556
8	2000	437
9	5000	341
10	10,000	295
11	20,000	242

Understanding the fatigue behaviour of the part is crucial to assessing its long-term durability and reliability. By examining the fatigue data, engineers can find the number of cycles the part can sustain before failure, which is essential to estimating its operational lifespan. The obtained maximum stress value supplies insights into the critical stress levels experienced by the part during cyclic loading, helping us to find potential fatigue failure locations.

Based on the analysis, the component's design needs to consider the identified failure point at approximately 2882 cycles. Design modifications, such as reducing stress concentrations or altering material properties, can be implemented to improve the component's fatigue resistance and extend its service life.

Furthermore, the comparison between the maximum stress value (396 MPa) and the fatigue data offers a valuable perspective regarding the component's safety margin. It enables engineers to assess the reliability of the design and make informed decisions on the need to introduce further design optimisations or potential operational limitations to ensure the component's longevity.

By conducting a comprehensive fatigue study, engineers can gain crucial insights into the structural behaviour of components subjected to cyclic loading conditions. This knowledge empowers them to develop designs that are robust, durable, and capable of withstanding the predicted operational demands.

One of the primary outcomes of the study is the determination of the maximum normal stress and stress concentration factor through static analysis. These results provide critical information regarding stress distribution and concentration in the vicinity of the notched region. The identification of stress concentration zones is of paramount importance, as these areas are prone to fatigue-induced failures. The data acquired from this analysis contribute to an enhanced understanding of stress patterns in carbon steel structures, specifically when exposed to cyclic loading conditions.

Linking the static study to subsequent fatigue analysis establishes a holistic perspective on the component's performance over its operational lifespan. This integration allows engineers to predict the initiation and progression of fatigue cracks, which is crucial to assessing long-term durability. By establishing a connection between static stress distribution and fatigue life prediction, the study bridges the gap between instantaneous stress states and cumulative damage accumulation.

The observed stress concentration at the centre of the semicircular notch further underscores the need to perform a thorough fatigue study. This concentration of stress acts as a potential catalyst for local failure or crack initiation, particularly under cyclic loading scenarios. The accurate determination of stress concentration factors helps us to pinpoint areas susceptible to fatigue failure, thus guiding design modifications to enhance fatigue resistance.

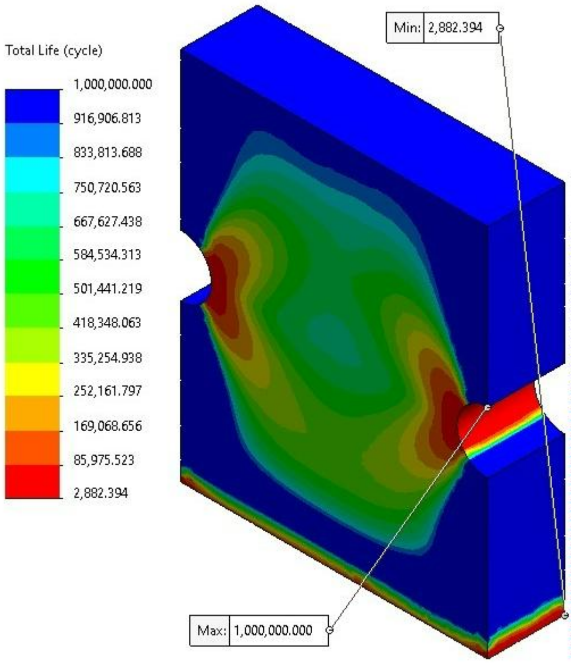

Figure 11. Fatigue notch factor total life.

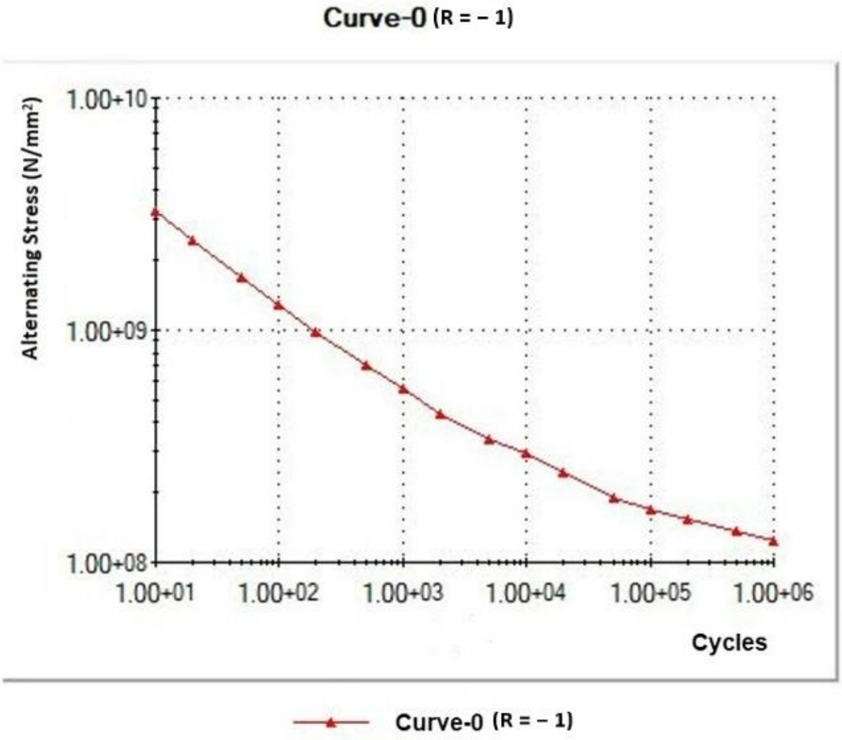

Figure 12. Fatigue S-N carbon steel curves.

The comparison between the analytical method and finite element method (FEM) results demonstrates a close agreement, with an error percentage of 4.27%. This validation enhances the reliability of the study's conclusions and supports the use of FEM to perform practical engineering analyses of similar carbon steel structures.

The subsequent fatigue study based on ASME carbon steel curves provides crucial data on the expected fatigue life of the notched plates. This information is instrumental to the estimation of the operational longevity of components under cyclic loading. Furthermore, the correlation between the maximum stress values and the fatigue data highlights potential failure locations and offers insights into the component's safety margin. This knowledge helps engineers to make informed decisions regarding design optimisations to extend the part's service life.

The quantification of stress concentration factors (SCFs) through our analytical and numerical investigations has yielded valuable insights into the fatigue life of the rectangular plates featuring opposite semicircular edge single notches. While our research primarily focused on the characterisation of SCFs, a deeper exploration of the implications of these findings reveals their significant influence on the overall performance, durability, and design considerations of carbon steel structures.

Impact on performance and durability:

The stress concentration factors play a pivotal role in determining the regions within the component that are most susceptible to fatigue-induced failures. These areas, which are characterised by elevated stress levels, are prone to crack initiation and propagation, especially under cyclic loading conditions. The identification of stress concentration zones provides engineers with a critical understanding of potential failure locations within the structure.

The observed stress concentration at the centre of the semicircular notch underscores the need to perform a comprehensive fatigue study. This concentration of stress acts as a potential catalyst for local failure or crack initiation, particularly under cyclic loading scenarios. Consequently, the accurate determination of stress concentration factors helps us to pinpoint areas that require special attention during the design phase.

Design modifications for enhanced performance:

The insights gained from our investigation offer a valuable basis for appropriate design modifications devised to mitigate the detrimental effects of stress concentration factors. By addressing stress concentration zones, engineers can implement structural enhancements to redistribute stress more evenly throughout the component, thereby reducing the likelihood of fatigue-related failures.

One effective design modification involves introducing fillets or radius transitions at locations of high stress concentration. By gradually redistributing stress, these fillets can minimise the sharp transitions that often lead to stress concentration. Additionally, altering material properties or adjusting the component's geometry can be considered to improve stress distribution and decrease the severity of stress concentrations.

Optimisation of fatigue resistance:

The knowledge of stress concentration factors also informs the optimisation of the component's fatigue resistance. By strategically implementing design modifications based on the insights gained through our study, engineers can extend the fatigue life of the component. This translates into increased operational longevity, reduced maintenance requirements, and enhanced reliability in real-world applications.

Future directions:

While this study has provided valuable insights into the implications of stress concentration factors, there are avenues for further research. Exploring the direct relationship between stress concentration factors and fatigue crack initiation and propagation rates would offer a more comprehensive understanding of the underlying mechanisms. Additionally, investigating the effectiveness of various design modifications and their impacts on fatigue resistance could provide practical guidelines for engineers working in diverse engineering contexts.

This investigation goes beyond the mere quantification of stress concentration factors. It underscores the vital role that these factors play in shaping the performance, durability, and design considerations of carbon steel structures. By leveraging this understanding, engineers can make informed decisions, implement appropriate design modifications, and optimise the fatigue resistance of components, ultimately contributing to safer and more reliable engineering solutions.

In summary, the study's detailed exploration of analytical and numerical investigations of fatigue life in rectangular plates with opposite semicircular edge single notches significantly contributes to the understanding of fatigue behaviour in carbon steel structures. The integration of static and fatigue analyses, the identification of stress concentration zones, and the validation of results collectively empower engineers to design resilient and enduring components, thereby enhancing the overall reliability and performance of carbon steel structures subjected to cyclic loading conditions.

4. Limitations and Potential Sources of Error

Addressing the limitations of a research study is an important aspect of ensuring the credibility and transparency of its findings. This approach will enhance our understanding of potential sources of error and assumptions made during the investigations.

While the study provides valuable insights into fatigue life in rectangular plates with opposite semicircular edge single notches, several limitations should be considered when interpreting the results.

Material properties variability: The paper should discuss the potential impact of material variability on the fatigue life predictions. Material properties, such as Young's modulus, yield strength, and fatigue properties, can vary due to manufacturing processes, heat treatments, and other factors. The study might have assumed constant material properties, which may not accurately represent real-world scenarios.

Boundary conditions: Assumptions about boundary conditions could affect the accuracy of numerical simulations. Discussing the choice of boundary conditions, such as fixed or constrained edges, as well as how these choices might influence the results, would provide a clearer picture of the study's limitations.

Geometric simplifications: Addressing the level of geometric simplification employed in the study is crucial. The decision to model semicircular notches as idealised shapes might introduce discrepancies compared to actual physical characteristics. Discussing the potential effects of these simplifications on the findings is important.

Fatigue loading: The loading conditions used in the study should be examined. If the loading spectrum employed is not representative of real-world applications, it could impact the fatigue life predictions. Discussing any assumptions made regarding loading, including load amplitude, frequency, and stress ratios, would help readers to understand potential limitations.

Surface finish and notch root radius: The influence of surface finish and the radius of the notch root on fatigue life should be addressed. Real-world components often exhibit surface imperfections and varying notch root radii. Failing to account for these factors in this study could affect the accuracy of fatigue life predictions.

Experimental variability: If experimental tests were conducted, discussing potential sources of variability and error in the experimental setup, including uncertainties in measurements and testing conditions, are important to understanding the reliability of the results.

Statistical significance: If applicable, discussing the statistical significance of the results would provide insights into the reliability of the conclusions drawn from the study.

Moreover, the study's assumptions are recognised. The assumption of linear–elastic material behaviour, along with the exclusion of plastic deformation effects, may not comprehensively capture material behaviour under specific loading conditions. Furthermore, the authors acknowledge that the sole focus on semicircular edge single notches may restrict the generalisability of the findings to other geometries.

In summary, by openly acknowledging these potential sources of error and assumptions, this paper aims to provide readers with a clearer understanding of the contextual boundaries within which the conclusions should be interpreted. As a trajectory for future work, efforts will be directed towards the mitigation of these limitations and an extension of the analysis' scope to enhance the study's robustness and broader applicability.

By incorporating these points into the limitations section, the research paper will provide a more transparent assessment of this study's scope and potential sources of error, thus enhancing the overall credibility and applicability of its findings.

5. Conclusions

A comprehensive analysis was conducted to examine the behaviour of components under cyclic loading conditions. By employing the finite element method (FEM) and SolidWorks Simulation Premium Student Edition 2023, the maximum normal stress and stress concentration factor were found for a rectangular plate with opposing single semicircular notches.

The research findings supplied valuable insights into the stress distribution, deformation, and strain within the part. Establishing a connection between the static study and the later fatigue study proved to be crucial in terms of understanding the part's response under cyclic loading. Using the results of the static analysis, engineers were able to predict the component's performance and durability, considering the initiation and propagation of fatigue cracks.

The evaluation of stress concentration factor and maximum normal stress played a significant role in finding critical regions within the part that are prone to fatigue failure. By pinpointing these areas, engineers can implement design modifications or structural enhancements to mitigate the risk of fatigue-induced failures.

The integration of SolidWorks Simulation Premium Student Edition 2023, along with the ability to link static and fatigue studies, offered a powerful platform for the simulation and analysis of the behaviour of components subjected to complex loading scenarios. This approach enabled informed design decisions and the optimisation of the component's structural integrity and reliability.

The static stress analysis revealed that the maximum stress occurred at the centre of the semicircular notched section, highlighting a region of heightened vulnerability within the part. The stress concentration factor value showed the size of stress concentration in this region, which could potentially lead to localised failure or crack initiation, especially under cyclic loading conditions.

The comparison between the analytical method and the finite element method (FEM) proved good agreement, with an error percentage of 4.27%. This level of accuracy falls within acceptable limits, enhancing our confidence in the simulation results.

The later fatigue study aimed to analyse the progressive structural damage that occurs in the part when subjected to alternating loading conditions. The fatigue data, which were based on ASME carbon steel curves, offered insights into the component's fatigue life. The analysis revealed that the specimen would experience failure after approximately 2882 cycles, with a maximum stress of 396 MPa.

Understanding the fatigue behaviour of the part is crucial to assessing its long-term durability and reliability. The fatigue data allowed engineers to estimate the component's operational lifespan and find potential failure points. By implementing design modifications to reduce stress concentrations or alter material properties, the component's fatigue resistance and service life can be improved.

Furthermore, comparing the maximum stress value to the fatigue data provided valuable information about the component's safety margin. This assessment enabled engineers to evaluate the reliability of the design and make informed decisions on further design optimisations or operational limitations to ensure the component's longevity.

Conducting a comprehensive fatigue study empowers engineers to gain crucial insights into the structural behaviour of components subjected to cyclic loading conditions. This knowledge enables the development of robust designs capable of withstanding the predicted operational demands and improves the overall durability and reliability of the components.

The investigation into the influence of semicircle size on fatigue life in rectangular plates featuring opposite semicircular edge single notches has yielded insightful results that contribute to a deeper understanding of structural behaviour. The subsequent analysis highlights the implications of varying semicircle sizes on stress distribution, stress concentration, crack initiation, and crack propagation within the notched plates.

With increasing semicircle size, distinct patterns of stress concentration emerge, particularly at the notch root. The stress distribution along both the notch edges and plate surfaces undergo noticeable shifts, revealing a reduction in stress concentration as semicircle dimensions increase, suggesting a potential threshold effect.

The impact of semicircle size extends to crack initiation tendencies, with larger semicircles prompting changes in the locations at which cracks are likely to initiate. Furthermore, the study of crack propagation paths and rates unveils intricate relationships with semicircle size, potentially resulting in altered crack growth patterns.

Crucially, fatigue life predictions for plates with varying semicircle sizes offer valuable insights into the correlation between semicircle dimensions and structural longevity. These predictions serve as a practical guide for engineering design, offering considerations for the optimisation of stress distribution and enhancement of fatigue life.

The study's implications transcend immediate design concerns, encompassing broader insights into fatigue behaviour in notched structures. A comparison with existing models emphasizes the distinctive impact of the semicircle size on fatigue life, particularly within the context of opposite semicircular edge single notches.

In conclusion, the research underscores the pivotal role played by semicircle size in shaping fatigue life in rectangular plates with opposite semicircular edge single notches. The findings provide a foundation for informed decision-making in engineering design and contribute to advancing knowledge in the realm of structural integrity and optimisation.

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Nomenclature

Symbol	Description
$\mathbf{a}$	Constant
$\mathbf{b}$	Fatigue strength exponent
$\mathbf{f}$	Fatigue strength fraction
$\mathbf{K_t}$	Stress concentration factor
$\mathbf{N}$	Number of Stress
$\mathbf{N_f}$	Cycles to failure/fatigue life
$\mathbf{S_f}$	Fatigue strength
$\mathbf{S_{ut}}$	Tensile strength
S'_e	Endurance limit
$\sigma_{\mathbf{a}}$	Stress amplitude
$\sigma_{\mathbf{ar}}$	Alternating stress
$\sigma_{\mathbf{max}}$	Maximum stress
$\sigma_{\mathbf{nom}}$	Nominal stress

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