Master of Science Thesis

Fillet Weld Fatigue Lifetime
Parametric Finite Element Analysis

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Abstract

The fatigue life time of welded components is the dominant factor at the design of mechanical and automotive structures and components where fatigue failure has a crucial outcome in use of fillet welded structures and it commences mostly from the weld toe and propagate to the parent material or even to the weld root area. Fillet welds are the imperative type of weld used in many industries because of the geometry and fabrication cost of the structure.

The main objective of this research is to increase the fatigue life of welded components using the Effective Notch Stress Method (ENSM). Different radius and angle combinations are used and tested using the Palmgren-Miner’s damage accumulation method and from this testing, life at different combinations can be estimated.

Since this research is based on parametric Finite Element Analysis - FEA, a 2-D finite element model is used to evaluate fillet weld joints fatigue life time. In this model the throat thickness of the fillet weld determines the leg length and its impact on the fatigue life time of the weld. The fatigue life at the weld toe differs from the throat thickness although it is affected from it. The variations made in the weld toe using different radius and angles gives a significant improvement in fatigue life and also increases the strength of the weld root. The Effective Notch Stress Method (ENSM) is used to estimate the fatigue life of the weld structures where the weld toe is easily accessible. This method can also be used to determine the fatigue strength which in turn can be useful in real time applications.

Key words

Fatigue Strength, Fillet weld, Weld toe radius, Effective notch stress method, Parametric Finite Element Analysis - PFEA.
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1 Introduction

Volvo Construction Equipment AB (Volvo CE) in Braås, Sweden is a leading manufacturing company in the world and it produces the Articulated Truck Dumper (ATD) [1] also known as the dump hauler. ATD is a heavy-duty truck used to transport bulk goods such as sand, gravel, stones and rocks etc., over rough terrains. The above mentioned ATD is illustrated in Figure 1.

![Figure 1. Illustration of a Volvo CE Articulated Truck Dumper](image)

Owing to the nature of ATD’s service environment, they are subjected to various types and magnitudes of dynamic load cases. The consequences due to dynamic loads can cause many mechanical failures. The risk of failure (R\text{f}) is the function of the probability (p) and the consequences (c), see equation 1.

\[ R_f = p \cdot c \]  

The ability of a structure or component to maintain its design geometry and dimensions is known as structural integrity [2]. Structural integrity in structures has an insignificant difference between safety and disaster. For lifetime assessment of a structure’s integrity the assurance of human’s health and safety depends on environmental protection, asset’s integrity, commercial availability and laws and regulations [3].

There are several structural failures that can cause a fracture. Some of the most common root causes are improper design and engineering, manufacturing, acceptance criteria, maintenance and excessive loadings [4]. Fatigue failure is estimated to contribute about 80 percent of all mechanical failures in the world [5].
There are two general types of deformation.

I. Elastic Deformation
II. Plastic Deformation

Elastic deformation is a state where the structure could regain its original shape once the applied excessive force is removed [4]. In plastic deformation, the structure cannot regain its original shape once the applied force is removed, see Figure 2.

![Figure 2. Illustration of stress-strain curve.](image)

A typical stress strain diagram for steel is illustrated in the Figure 2. The initial graph is a straight line where the stress is directly proportional to strain. This structural behavior is similar to elastic deformation. Plastic deformation occurs when the excessive load is applied and therefore the graph tends to fall in the region where the increase in strain occurs, this is also known as nonlinear plastic limit.

There are two general types of fatigue [6]:

I. Low cycle fatigue
II. High cycle fatigue

Low cycle fatigue is initiated with less number of load cycles thus, a propagation of a crack or failure is faster. Low cycle fatigue is characterized by repeated plastic deformation as it corresponds to stresses above the yield point [7]. Displacement, stress and strain magnitudes are calculated by equations No. 2, 3 and 4 [8].

\[
\sigma = \frac{F}{A} \quad (2)
\]

\[
\delta_i = l_i - l_0 \quad (3)
\]
\[ \varepsilon = \frac{\delta l}{l_0} \] (4)

**Nomenclature of Equations 2 - 4**

- \( A = \) area [m²]
- \( l_1 = \) length at time 1 [m]
- \( F = \) force [N]
- \( l_0 = \) length at time 0 [m]
- \( l = \) length [m]
- \( \delta l = \) length displacement [m]

Figure 3. Represents the Low cycle and High cycle fatigue

High cycle fatigue is initiated with large number of load cycles thus, a propagation of a crack or failure is slower. High cycle fatigue is characterized by repeated elastic deformation as it corresponds to stresses below the yield point [9].

### 1.1 Weld Joints

Weld joints play an important role in the evaluation of the structural integrity of welded components. In the arc welding process, the designer should understand the structural integrity that influences the base material and the manufacturing processes [10].

Steel materials consist of polycrystalline alloys made of iron and carbon. The mechanical and thermal properties of steel depend on the geometry, actual grain size and chemical composition of alloys. The chemical composition of the steel materials can be controlled by the steel making process whereas, the geometry and grain size
is controlled by the forging and rolling process [10]. It is illustrated in Figure 4.

![Diagram showing mechanical properties and variables related to welding](image)

Figure 4. Illustration of welded joint [10], with the author’s permission.

In general, there are two types of weld joints; Butt weld joints and fillet weld joints, see Figure 5.

![Illustration of Butt (left) and Fillet (right) weld joints](image)

Figure 5. Illustration of Butt (left) and Fillet (right) weld joints.

The simplest form of a weld joint consists of a weld metal and two base metals. The mechanical properties are influenced by Weld Residual Stress Affected Zone (WRAZ) and Heat Affected Zone (HAZ) [11]. The weld residual stress and strain (WRS) magnitudes of the WRAZ are approximated by one of Computational Welding Mechanics (CWM), analytical modelling of experimental data acquisitioned by various distortion measurement techniques or Meyer hardness testing [12].

The microstructural properties of the base materials and the HAZ are examined by metallurgical microscopy [13]. HAZ consists of five sub zones: base material, coarse and fine grained zones, heat affected zone and temperature. The sub zones of each individual plate material possess different physical compositions, grain
geometries, grain sizes and microstructures. Furthermore, rarely the two base materials are identical to each other, see Figure 6.

![Figure 6](image.png)

Figure 6. Illustration of the different thermal and mechanical material properties within a single pass weld joint’s cross section area [10], with the author’s permission.

In the past two decades, significant improvements have been made in structural analysis methods [14]. The production of safety, cost-effective means of analysis and inspection are the unique challenges in large engineering structures. Over the last two decades new methodologies and new technologies have been implemented in structural analysis mostly for durability [15]. Structural integrity assessment includes the following:

I. Fatigue assessment
II. Materials and metallurgy
III. Fatigue and creep analysis
IV. Corrosion
V. Weld metallurgy

There are several methods for the fatigue assessment which are used for the welded structures and components. For the time being International Institute of Welding (IIW) [14] recommends four different types of Linear Elastic engineering approaches to be used at fatigue lifetime analysis, they are:

I. Nominal stress
II. Hot spot
III. Effective notch stress
IV. Linear Elastic Fracture Mechanics (LEFM)

The main aim of these methods is to improve the design, fatigue life and optimize of welded structures or components. Assessment and comparison of these methods can be found in [16]. Figure 7 illustrates the work effort required by fatigue analysis of welded joints for several assessments in fatigue life.
The most common cause for the damage in welded structure is fatigue. The following opinions are used to explain the fatigue problems [17].

- Weld Geometry determines the fatigue lifetime.
- The fatigue life is influenced little by material strength of base plate and weld metal.
- Fatigue life is governed by stress range. The later discussion in this study ensures the statement.

The fatigue failure occurs in an area where the stress concentration is at higher magnitude than the average stress in the surrounding area. When the weld material is not properly penetrated in fillet welds, it may initiate cracks at the weld root including weld toe [13]. There are three well known methodologies for calculating fatigue life by using an S-N curve; namely the Nominal stress, hot spot stress and Effective notch stress approach [18].

1.2 Background and Problem description

Articulated Truck Dumper (ATD) structures are manufactured using various arc welding processes, the approximations of fatigue life cycle of welded joints are of paramount interest to Volvo CE at their structural integrity optimization work. There are many industrial standards and institutes like IIW and DNV GL [16] for assessments of fatigue life in welded joints. Arc Welding is a manufacturing method used to join the two metallic materials by melting. The most common weld joints are used in the industry is butt and fillet weld joints.

Dump Haulers are subjected to tough loading conditions [19]. In order to increase the performance of the machines, its components and systems must be durable and cost optimized. The durability requirements must be fulfilled. Welds are an important part of the load carrying structure. Hence, weld geometry and its variation must be considered when predicting the fatigue life. Volvo CE has experienced and
identified that fillet weld’s root and toe are the most critical areas in the weld joints [19]. At those points it’s hard to calculate using the Nominal and Hotspot stress method. In order to identify the stress magnitudes at those points, effective notch stress method is used to calculate the stress at weld root and weld toe [14]. There is a need for benchmarking fatigue life approximations towards experimental data. Therefore, Volvo CE intends to perform several investigations to identify where the current theory (Fatigue calculation knowledge) is standing in relation to the empery (true measured data) [19].

1.3 Aim and Objectives

The main aim of this study is to increase the understanding of how radius and angles cross section of fillet weld geometries affects the fatigue lifetime of welded steel structure.

Where the objectives of the study are:

I. To generate a numerical two-dimensional (2D) model of a double-sided fillet weld joint’s cross section, for the sake of linear elastic Finite Element Analysis (FEA) of mechanical load cases of interest to Volvo CE.

II. To evaluate the 2D FEA results with analytical formulas found in literature.

III. To conduct a parametric study of different weld geometries using 2D FEA for various weld cross section geometries i.e. lengths and notch radius.

IV. To develop a measuring gauge in order to physically calculate the weld life and compare it with the existing method used in Volvo CE Braås.

1.4 Hypothesis

A fillet weld joint’s fatigue lifetime can be approximated by using different sets of radius and angle combinations in the effective notch stress method.

1.5 Research - Questions

The research questions are:

1) Can the different set of radius and angle combinations using effective notch stress method govern the stresses and result in higher fatigue life than existing method used in Volvo CE at fillet weld joint?

2) Can change in leg length parameter provide better fatigue life than fixed vertical leg length weld geometries?

3) One can use simplified measurement tool to define the weld Class in Production?

1.6 Limitations

This study only focuses on the use of the effective notch method by the use of 2D FEA analyzing high cycle fatigue phenomena using the commercial Finite Element software ANSYS APDL.
1.7 Reliability, Validity and Objectivity Research Methods

The Reliability, Validity and Objectivity of this parametric Finite Element Analyses is obtained by the following precautions

1) In this study, experiment and numerical investigation have been used during the process. During the process of experiment, a number of specimens of the same material were used and each specimen was tested several times, which guaranteed the reliability of the result.
2) The fillet weld radius used was based on the Volvo Weld Standard. All specimens used in this experiment regime were of the same material and of the same size, to reduce variation in experimental results.
3) The leg length of the fillet weld is also an important variable in test on fatigue life and Volvo weld standard used. Thus, all specimens were tested with the exact same leg lengths and different loading conditions to make the result objectively.

1.8 Research Methods

The research method of this study is Parametric Finite Element Analyses and the use of the engineering approach Effective Notch Stress Method. Parametric studies are the variance of parameters in a finite element analysis. The purpose of parametric studies is to evaluate the responsiveness of the analysis to different parameters [20].

The Finite Element Analysis (FEA) is the simulation of any given physical phenomenon using the numerical technique called Finite Element Method (FEM). Usually it is used to reduce the number of physical prototypes and experiments and optimize components in their design phase to develop better products [21].

The key benefit of parametric features is that they let users see the effects of design changes quickly. With adequate planning, users can define an FE (Finite Element) model entirely in terms of variables or parameters with Mesh Characteristics, Loads characteristics and even boundary conditions. Model dimensions and mesh density can be changed with equal ease [20].

2 Methods

2.1 Weld class

The weld class discussed in this chapter is the engineering approach of the parametric finite element analysis. The denotations of the radius range parameter is as stated in the Volvo Weld class. A set of radii can be defined in each weld class range and the evaluation can be related to the fatigue life. In Volvo CE the weld class relates with both radius range and lifetime.
The Volvo CE Weld Standards are divided into five weld classes.

I. VS
II. VE
III. VD
IV. VC
V. VB

Generally, the weld class depends on geometry of FE model and weld joint type. The VB class has the most stringent requirements due to its greater constant life compared to other standards.

According to Volvo CE, the fillet welds are done with different radius for achieving greater constant life, see Table 1. The different types of fillet weld joints are modelled, analyzed and evaluated to classify them according to the Volvo CE weld classes. They are influenced primarily by the radius (r) and secondarily by lifetime range. In Volvo CE, the life of weld of each weld class is double its previous class [19], see Table 2.

<table>
<thead>
<tr>
<th>Weld class</th>
<th>VE</th>
<th>VD</th>
<th>VC</th>
<th>VB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2. Constant life of weld standards, [19] with Volvo CE’s permission.

2.2 Effective Notch Stress Method
The Effective Notch Stress Method (ENSM) is a fatigue assessment method, which has been of significance importance in the industrial applications and has been involved in several fatigue design recommendations such as International Institute of Welding (IIW) and DNV GL. The engineering approach involves using an independent of the notch root loading, depending on the material fictitious radius and neglecting the residual stress in a material. This method was proposed by Miki [15]. The main aim of this method is to calculate weld toe and weld root with a reference radius. As shown in figure, the reference radius is applied to the weld toe.
The reference radius values range from 0.3 mm to 4 mm.

Figure 8. Effective notch stress method

A radius of 1 mm has proven to be consistent in most cases [14]. Notch radius of 1 mm is added without leading with the sharp edges is because sharp edge provides high stress, see Figure 8.

The main purpose of including the radius at the notch is to see the parameters action on fatigue life and the most dominant parametric factor for fatigue stress is notch, which is the prime to evaluate the strength close to the reality. The limitation of this method is the computational timing, measuring and calculating. It requires more time when compared to other two methods [22].

The effective notch method suits for the butt welds when the flank angle is 30 degrees and 45 degrees is suited for fillet welds. The fatigue strength of the weld is related to S-N curve which incorporates the stress and number of cyclic loadings in their respective coordinates. The radius of 1 mm as notch radius is suitable for steel plates thicker than 5 mm and radius of 0.05 mm is for the plates thinner than 5 mm [18].

2.3 Palmgren-Miner’s Damage Accumulation

According to the Palmgren-Miner’s rule, when the damage is equal to 1 then the failure occurs and the various failures may lead to cracks initiation on the surface of material. Applying constant amplitude, cyclic stresses occur on material which causes the failure after some specific number of cycles [18].

Palmgren-Miner’s rule is the simplest model of cumulative damage. It is represented below, see equation 5.

\[
\sum_{i=1}^{k} \frac{n_i}{N_i} = D
\]

The equation 5 can be carried off as assessing the life of each stress level and adding the all values together. For quantifying the damage, the product of stress and number of cycles through each stress, one using equation 6.
\[ D = N \cdot \sigma^k \]  \hspace{1cm} (6)

**Nomenclature equation 5 - 6**

- \( n_i \) = number of cycles accumulated at stress
- \( D \) = Damage fraction
- \( k \) = Stress factor in weld material
- \( N_i \) = Average number of cycles to failure

![Figure 9. Illustration of damage quantification.](image)

The constant amplitude stress \( \Delta \sigma_i \) with the repeated \( n_i \) is the sum of total fatigue damage collected by each individual loading. The fatigue life damage is calculated through each stress [19], see equation 7.

\[ L = \frac{C}{D} \]  \hspace{1cm} (7)

The Normalized life is calculated according to the minimum stress value obtained on initial radius taken. The minimum stress at 0.3mm radius is normalized to the value of 1 [19], see equation 8.

\[ \text{Normalized life } = \frac{1}{n_{eq} \cdot \sigma_{eq}(r, v)^k / L} \]  \hspace{1cm} (8)

**Nomenclature equation 7 - 8**

- **Capacity** = 1
- **D** = Duty
- \( n_{eq}, \sigma_{eq} \) = Minimum stress of \( r \) and \( v \) at initial radius
3 FE Modelling

3.1 Finite Element Model
The specimen is a T type fillet weld joint as shown in the figure. It is modelled in ANSYS Mechanical APDL where the finite element analysis is carried out. While modelling, the height of weld (Vertical Leg Length) is fixed equal to length of throat thickness and horizontal leg length of weld is changed according to the respective angle used. Depending on the method used for analysis, different modelling parameters have to be set. The modelling as shown in the Figure 10 corresponds to the size of mesh. The element type used for analysis is element 183 [18], which improves the surface stress formulation. Due to linear analysis, the current LS solver was used as a solver option with steady-state setting. The convergence criteria to determine the number of elements required in a model to ensures that the results of the analysis are not affected by changing the size of the mesh. The stresses are calculated at the surface of the fillet radius by extracting the node points.

The general dimensions of the T type fillet joint assumed for a base material is length 200mm and thickness of 12mm. The current improvement is to combine the different angles $\theta$ and radius $r$.

![Figure 10. Illustration of Double-Sided Fillet Weld Model.](image)

3.2 Meshing area
The finite element 2-dimensional model was modelled using 8 nodes type all over the material. The mesh difference was given to find the maximum stress concentration at the weld toe and with the rest of the material. The prime factor is to make a well oriented passage from weld toe radius area to rest area of the model. The weld toe radius area was dead set on 0.25 times of the radius used at the weld toe by the recommendation of effective notch stress method, see Figure 11. This fine meshed area is to encounter the maximum stress at the toe. The rest areas are covered with the mesh size of respective radius used for the fillet weld.
However, the mesh size is maintained in simple geometry and with parametric changes with respect to penetration. The required mesh size is taken from FEM simulation under certain loading conditions. The maximum range of elements used is 40,000.

3.3 Material Properties
The material is assumed to be linear elastic with a young’s modulus, $E = 210\text{Mpa}$ and poisson’s ratio $\nu = 0.3$. Boundary conditions for this model are fixed at one end of the model.

3.4 Loading Conditions
All parameters including the boundary conditions are implemented for all types of radius and angle combinations. The major factor is that boundary conditions are applied on certain coordinates in the model. The tension, symmetry tension and bending are exerted in the model to find the stress at different boundaries.
The displacement at the right end is fixed for all types of boundary conditions. Figure 12 shows the model with tension of 100MPa at Y axis. The same conditions were followed just by adding up with symmetry condition for the two-fillet model, see Figure 13.
The bending moment is applied at the left end of the structure and the displacement is fixed at the right end like other boundary conditions, see Figure 14.

Figure 14. Illustration of the Fillet weld joint’s bending moment.

4 Finite Element (FE) results

4.1 Effective Notch Comparison using Max stress and Normalized life

The Permutation and combination of different weld angles and weld radius values are presented using influence of modified Effective notch stress method. The plots clearly state the stress values at the respective angle and radius.

4.1.1 Maximum Stress Vs Weld Angle

This Section shows the Max stress value at notch radius area against Weld angle, see Figure 15. When evaluating stress for the double-sided fillet weld model the Effective notch radius and weld angle play a vital role in contributing to stress values.
Figure 15. Illustration of max stress obtained for different weld angle

The plotting indicates that the stress values apparently increase as the weld angle of the fillet weld increases. The Area is more likely to be with sharp edges if the angle of the fillet weld gets increased. The total area covered between the root and the weld toe radius will decrease as the weld angle increases. So, the stress at the Notch radius starts to climb sequentially for higher weld angles.

4.1.2 Maximum Stress Vs Weld Radius

The Stress Values are calculated for all combinations of Weld angle and weld radius. Weld radius accommodates the critical area in the welded component and hence the radius influences the area and stress concentration by the effect of notch.

Figure 16. Illustration of max stress obtained for different radii.
The Stress curves of weld toe radius are opposite to that of angle curve because at higher radius large area is occupied and without any mesh of small areas. The sharper area and closed sections would give way to higher stress range. Figure 16 indicates that higher radius subjected to lower stress values and vice versa.

4.1.3 Normalized Life of Weld angle and Weld toe Radius
Normalized life is the capacity obtained from each combination of equivalent stress values taken from the Weld toe radius and Weld angle. It behaves the same as the stress curves as the same values are used to calculate the capacity of each weld combination.

![Figure 17. Illustration of Normalized life obtained for different weld angles](image)

The max stress values are imperative for the normalized factor obtained at the initial radius. The curves plotted are exact opposite of the max stress curves due to the implementation of normalized life factor and due to the discretization of elements the curves at bigger radius is not smooth as the ones to the left. The normalized life is taken at min stress value of 0.3mm radius (initial radius value) as common input value for all the loading conditions.
Figure 18. Illustration of Normalized Life obtained for different radii

4.2 Assessment of Weld Class

A measuring gauge helps to physically predict the weld class which gives similar life. The life of each weld class is twice from their previous weld class. VD gives twice the life when compared to VE, whereas VC gives twice the lifetime of VD. So, it is easy to predict the life of weld using the measuring gauge.

The different weld qualities can be measured manually using a simplified gauge, see Figure 19. The gauge is incorporated with d and h values which are used at the weld toe radius point to check whether the gauge hits the fillet weld material or not. The weld class can be accepted when there is a gap between weld material and gauge. If it is touching it is not considered in that appropriate weld class.

Figure 19. Calculation of lifetime using measurement tool (d and h values).

Where,

\[ d = \text{Weld Distance from the weld toe radius.} \]

\[ h = \text{Height of the gauge} \]

The d and h values are fixed after all possible permutations and combinations. The appropriate d and h value should satisfy all the radius and angle combinations respective to its weld class and gives the closest distance to the FEA contour curves.
Figure 20. Constant life prediction with respect to weld angle

The optimum d and h values are incorporated with all the loading condition contours and the gap between their normalized lifeline and actual constant lifeline is minimized by using such d and h. The VE, VD and VC weld classes are the interpolation of actual life from the estimated life measured using the gauges. The constant life of each weld class (d and h) is plotted near the normalized value to get the closest relation to predict similar life manually.

Figure 21. Constant life prediction after normalization
5 Discussion

5.1 Method
The major limitation of this model is that it requires complex and detailed modelling. The modelling can be time consuming while doing the calculations due to the complex approach of finite element model.

Fatigue life assessment method was performed using influence of effective notch stress method. The assessment includes different combinations of weld toe radius and weld angle under different loading conditions including a 50% of combined value of tension and bending. Effective notch stress method fetches different results for different loading conditions. The fillet weld is modelled according to certain combinations of angle and radius to attain greater constant life and the constant life is achieved by using higher radius at the weld toe. The high stress values accommodated by the weld radius and angle give shorter life to the weld. Based on the analysis, the increase in weld size indicates the higher fatigue life at the weld toe. The simulation of real time conditions would be different from real time testing. Real time testing can be done using fatigue test as it has higher number of load test which result in better assessment. The major aim of this study is to approximate fatigue lifetime using FEM. So, it was performed by ANSYS APDL software found to be challenging to master.

5.2 Parametric study by change in leg length
Apart from the fixed vertical leg length weld type, the change in both horizontal and vertical leg length are examined at the same boundary conditions. The leg length of both horizontal and vertical leg length will change according to the angle used for the fillet welded structure, see Figure 22 and Figure 23.

Figure 22. Illustration of fixed vertical leg length (Constant radius and angle)
5.3 Results

The purpose of using measuring gauge is to predict the similar constant life of FEA contours by accessing the life range of fillet weld. The constant life of weld measured using the gauge should be within the range of respective weld class. So, the similar weld life can be predicted using the measuring gauge manually but even the optimum d and h combination is not able to make a proper reach in phase range as it reaches the previous or next life range, see Figure 21. This study concludes that accuracy is obtained by using correct evaluation method and correct geometry with suitable parameters, thereby providing higher fatigue life to weld toe.

Given below are the answers for the research questions in sequential order

The influence of effective notch stress method can be figured out through the results (see Figure 15 and Figure 16). Different set of radii are involved at the weld toe is the prime factor in this research. Usually effective notch stress method involves a notch radius of 1mm (2.2chapter 2.2) and the fatigue approach of lifetime can be calculated with respect to it. This study deals with a different radius and angle combinations, so the modified set of radii is used in the FE model. The primary part of this study deals with the different sets of radius and angle combinations. The fatigue lifetime of different permutation gives better fatigue results when compared to general effective notch stress method. The fatigue lifetime of radius 1mm is lesser than the fatigue lifetime of radius greater than 1mm, see Figure 17. The different phase range of life concludes that the different sets of radius and angle combinations provide constant fatigue life.
The parametric effect of change in leg lengths gives almost equal stress values as fixed vertical leg length type. The change in leg length causes the change in geometry where the size of the fillet weld gets increased with respect to the angle used, see Figure 22 and Figure 23. So, performing through fixed vertical leg length parameter is feasible and easily accessible to calculate the fatigue life of fillet weld under cross section of different radius and different angle.

The aim of measuring gauge is to incorporate the similar fatigue life of each respective weld class. The thought process was to create a gauge which can give similar fatigue lifetime by reaching all its possible radius and angle combination in respective weld class. But the range of life values started to collide with either previous or next weld class life range, see Figure 20 and Figure 21. Even though the optimum \(d\) and \(h\) values are used the life approximation of fatigue life is not accurate.

6 Conclusion

Based on the results and discussions presented in this document, the present authors have concluded that:

1) Using different radius and angle combinations in effective notch stress method governs the stress range and thus results in higher fatigue life than existing methods used in Volvo CE.

2) Change in vertical and horizontal leg lengths is not feasible as the size of the fillet weld geometry increases with respective to higher angles.

3) The physical prediction of similar fatigue life using a measurement gauge is not possible as the best \(d\) and \(h\) combination reaches the previous or next life range. So, an approximation of lifetime using a measurement gauge is not recommended.

7 Reference


Appendix

This appendix presents the collected data discussed in Chapter 4 together with the obtained weld classes prediction from the experimental data collected.

A1 Max stress Vs Weld Angle

Illustration of max stress obtained for different weld angle at tension loading.

Illustration of max stress obtained for different weld angle at 50% tension and bending loading.
Illustration of max stress obtained for different weld angle at bending moment.

A2 Max stress Vs Weld radius

Illustration of max stress obtained for different radii at symmetric tension loading.
Illustration of max stress obtained for different radii at 50% tension and bending loading.

Illustration of max stress obtained for different radii at bending moment.
A3 Normalized Life of Weld angle and Weld toe Radius

Illustration of Normalized life obtained for different weld angles at symmetric tension.

Illustration of Normalized life obtained for different weld angles at 50% of tension and bending.
Illustration of Normalized life obtained for different weld angles at bending moment.

Illustration of Normalized Life obtained for different radii at symmetric tension.
Illustration of Normalized Life obtained for different radii at 50% of tension and bending.

Illustration of Normalized Life obtained for different radii at bending moment.