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Motion Sim and FEA.

ACHA6010 structural design and analysis.

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## Abstract

Chain drive is the most common form of energy transfer in the motorcycle industry (Waghmare and Durgam, 2021). A study of the common chain link, half link and its use in a racing application. The problem for this work being design improvement with already simple geometry. Using a CAD model of both a half link and whole link 5/16 standard steel chain an FEA (finite element analysis) is carried out and validated against real data. This study will test a standard link to determine failure mechanisms which occur. A topology study will determine if weight reduction is achievable. Using acquired data the following questions are addressed. What are the implications of having a half link in the chain? Does it compromise strength? Is a carbon fibre chain achievable? What realistic weight reduction could be implemented?

The coupled Ansys environment is far superior to other FEA engines. Following a validation model it factors in a greater body of detail in the material science sector. Then accounts for the response of the thermal properties of a given study and the impact on the surrounding environment. Rigid dynamic studies account for motion loads and all this is fed into the static structural study for the solver to accurately compile the results.

## Table of Contents

|                               |    |
|-------------------------------|----|
| Abstract .....                | ii |
| 1. Introduction .....         | 1  |
| 2.1 Literature Review .....   | 2  |
| 2.2 Load considerations ..... | 2  |
| 3. Methodology .....          | 4  |
| 3.1 Model .....               | 5  |
| 3.2 Meshing .....             | 5  |
| 3.3 Coupled Model. ....       | 8  |
| 4. Results .....              | 10 |
| 5. Conclusion .....           | 17 |
| 6. Further Work .....         | 18 |
| 7. References .....           | 19 |
| Appendix 1. ....              | 20 |
| Appendix 2. ....              | 22 |
| Appendix 3. ....              | 26 |

## 1. Introduction

Racing motorcycles use a multitude of final drive gear ratios for an optimised track set up. Some reasons for a ratio adjustment are firstly to maximise the motorcycles top speed on the longest straight, but also to ensure that while shifting gears the engine rpm falls back to a point where peak torque or power is produced (Bradley J, 2018). One specific problem associated with ratio adjustments on motorcycles is the available chain or slack in chain adjustment which is limited by the swing arm slot in which the axle locates, this could be a mere  $\pm 30\text{mm}$  (Foale). The wheelbase adjustment on some bikes can affect other geometry such as trail and will also affect the overall stability or turning ability. Hence a wider range of adjustment is desirable. The use of a Half link will enable the chain to be adjusted in length by increments of 16mm where a standard chain link consisting of 3 pins and a set of inner and outer plates measures 38mm. The length of the link to be installed or removed does not correspond to the measurement that the rear axle will move in the dropout. The actual movement by the axle will be less than half of the overall length of the link and is dependent on the final drive sprocket diameters (Cossalter). The chain itself must withstand the output forces produced by the engine and deliver to the back wheel.

## 2.1 Literature Review

A chain transmits power by means of tensile force. A motorcycle chain will catastrophically fail with little or no notice. Some failures are caused by incorrect installation, high levels of wear and excessive force transmitted. It can be said that as chains are used stretching occurs. But not in an elastic sense. The materials wear out causing free play to develop. This is compensated for by moving the rear wheel back to take up slack. If the chain is too loose, then slippage can occur with changes in speed causing the chain to jump. Two negative impacts can occur if the chain is too tight. One being a condition of over tension as the bike slows down causing the rear end to become unweighted. Two being output shaft and bearing damage as an over tensioned chain can physically pull the drive sprocket aggressively as the suspension moves. If a situation occurs where a new chain is placed over old sprockets, higher levels of friction are present thus, the chain can wear out faster (Nikhil S et al, 2016). For the application of racing, it is common to avoid o or x ring type chains. The narrower design of a standard link is more efficient at delivering power. A chain without seals will need more cleaning and lubrication (Bradley J, 2018).

A typical material choice for a chain link is Normalised British Standard EN8, EN9. This is heat treated to 35-40 HRC to achieve a tensile strength of 70 – 80 kg mm<sup>2</sup> (Bhoite et al, 2012).

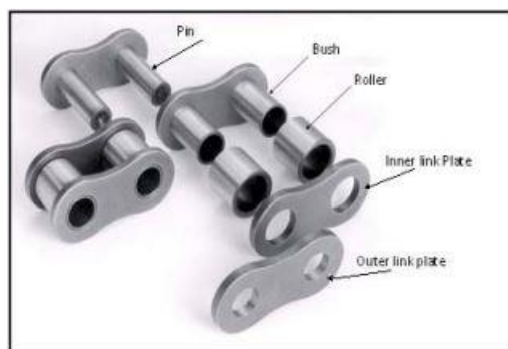


Figure 1: Standard roller chain link. (Bhoite et al, 2012)

Figure 1 shows the configuration for a standard roller chain link consisting of main pin, inner and outer plate, bush and a roller.

## 2.2 Load considerations

Throughout a regular cycle the nominal tensile load fluctuates. This is a main consideration for all types of chain.

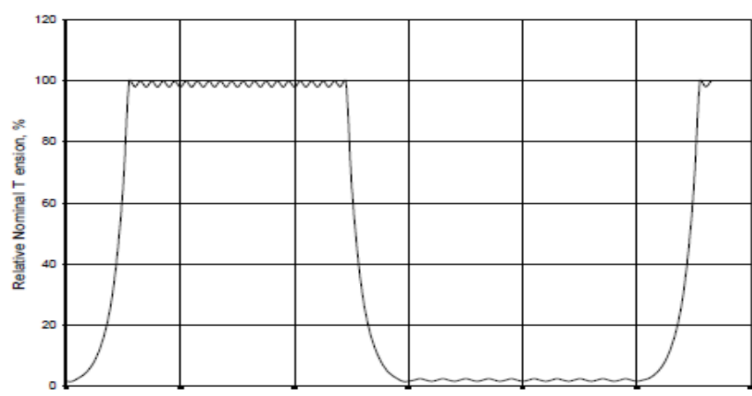


Figure 2: Tension varies in a chain. (Bhoite et al, 2012)

Figure 2 shows roughly the tension variation in a chain of 100 pitches as it runs around 20-tooth sprockets.

Various ways in which a chain experiences loads are outlined below.

A. Shock Load. The Characteristics of the power source cause shock load variations. Occurrence is regular and repeating. Per shaft revolution this can occur more than once.

B. Inertia Load. Inertia loads differ from shock loads, caused by occasional, unexpected, and unusual chain events such as up and down shifting or rear wheel lock ups.

C. Centrifugal Tension. Centrifugal force is generated as the chain travels around the high-speed drives sprockets. Can also occur as the chain travels over a curved path between sprockets.

D. Catenary Tension. Caused by the weight of that portion of the chain that hangs in a catenary generates additional tensile loads in the chain.

E. Chordal Action. As a chain engages the sprocket, it forms a regular polygon. That causes the chain to rise and fall each time a roller engages a sprocket tooth. This is called chordal action. The tension in the chain changes slightly every time the chain speed changes.

F. Chain Vibration. Vibration can cause very large increases in chain tensile loading if the vibration occurs at or near the natural frequency of the chain.

The tension in a chain link increases very rapidly as the link exits the driven sprocket. The increase from loose side to tight side average tension occurs over less than two sprocket teeth. The tension in a chain link decreases very rapidly as the link enters the drive sprocket. The decrease from tight side to average loose side tension occurs over less than two sprocket teeth. Transient spikes are present in the tension data at the point where the link exits the driven sprocket and at the point where the link enters the driven sprocket. Impact force tends to increase as chain tension increases; however, the relationship is not monotonic. Impact force tends to increase as chain speed increases; however, the relationship is not monotonic. For a chain traveling in the horizontal direction, the vertical component of the impact force is much larger than the horizontal component. The magnitude of the horizontal component of the impact force increases more rapidly than the magnitude of the vertical component as the chain speed increases, indicating that the angle of impact (as measured from a vertical line) increases as chain speed increases. as a link moves around the drive, the forces in the link vary.

ANSI number 40 riveted steel roller chain and 40B12 sprockets are common materials.

Data from the tight side of the chain span were separated from the data collected on the loose side of the chain span. Average values for chain side plate force were determined for both the tight and loose spans. as would be expected, the data indicate that the addition of the preload tends to shift the tension in the tight side of the chain by the amount of the preload. The value of the tight side tension was predictably sensitive to the linear chain speed.

Spikes in tensile load correspond to transient forces associated with rapid changes in the link tension. (Taken from Conwell & Johnson, 1995)

### 3. Methodology

Good validation models ensure that software is accurate and delivering reliable results. A comparison can be made between computational methods and software. Depending on conditions, the part can be exposed to a point load, UDL, temperature or pressure. Figure 3 shows the validation model.

To conduct a test the following properties from the example must be imported into Ansys. This example can be found in the Appendix section of this report (Dlubal).

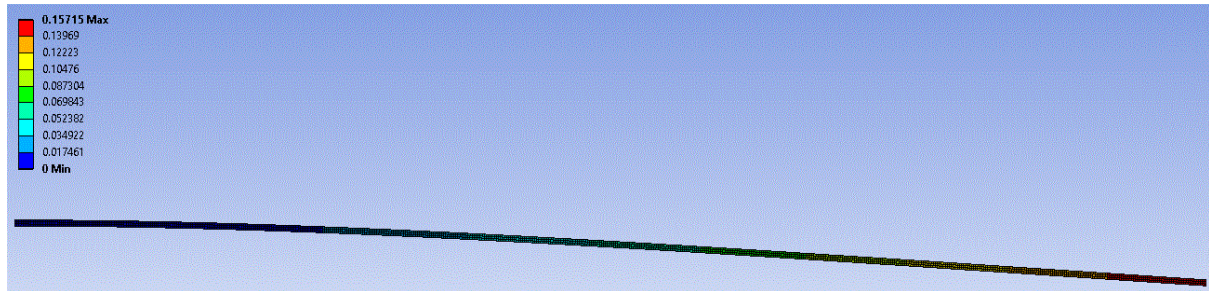


Figure 3: Validation Model, Deformation under UDL (Conway).

Above figure 3 Shows that the software can illustrate the deflection to within 0.02 of 1%.

Now the mathematical analysis against the other material ANSI 1040 is calculated. All of the material properties were imported as an XML type document from the Granta Edupack Software (Granta Edupack Software , 2022).

Ansys Results.

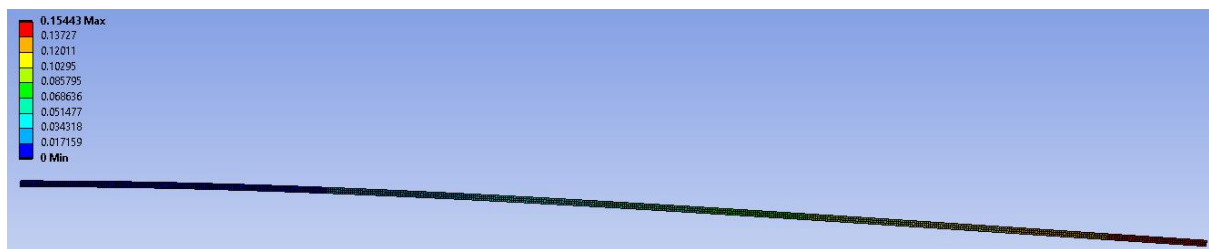


Figure 4: Validation of EN8 equivalent material. ANSI 1040 (Conway).

Above, figure 4 shows ANSI 1040 material being subjected to the same experiment within Ansys. A deformation of 154mm is shown which lines up with the mathematical model.

### 3.1 Model

A standard 5/16 roller chain link is created using Solid works. The measurements used for the whole link were then used to create a half link.

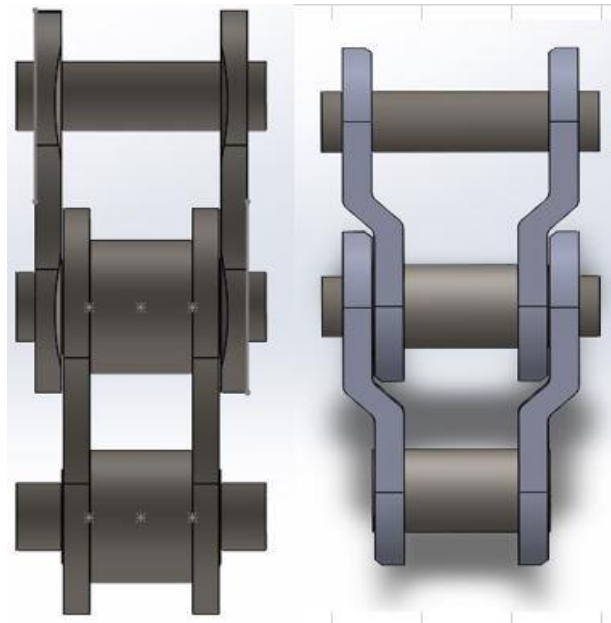


Figure 5: Build and configuration of Both links (Solidworks, 2022)

Above figure 5 shows the top view CAD models of both the whole link (left) and the half link (right) side by side. Both chains are assembled to a length of 3 rivets and then set up so a static simulation can be carried out in Ansys.

### 3.2 Meshing

Discretising a component or “Meshing” is a popular method amongst FEA software where the subject is broken down into small pieces called elements. The size and shape of these elements impacts the results. Too big and finer detail is lost. Too small and computational demands increase (Chen, 2000). Although Images 6 - 9 are captured in the Solidworks environment, the same theories are applicable to Ansys. Figure 10 shows the final ideal mesh of a link in Ansys.

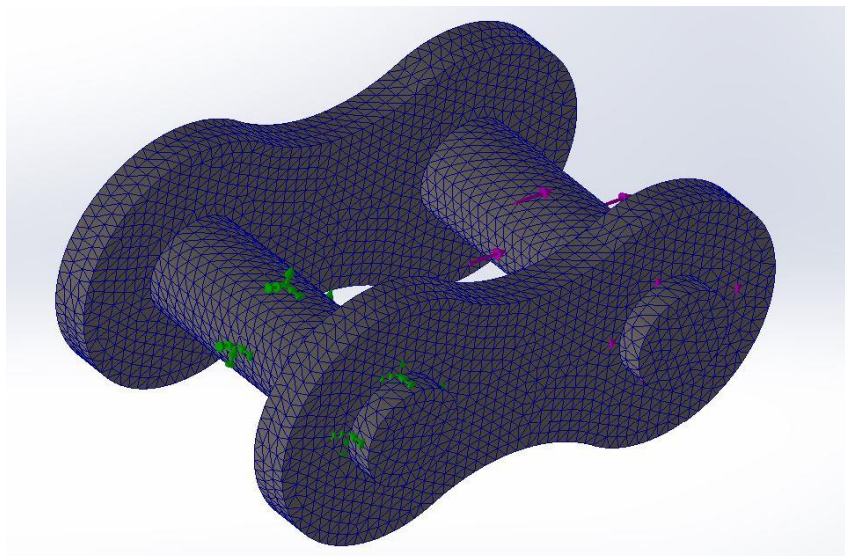


Figure 6: Mash with 3 rows of elements across the width (Conway).

It is advised to have a minimum of 3 elements across a face hence the thickness of the inner and outer plates will need a finer mesh at this stage. One row would solve compression, another to solve extension and a neutral axis through the middle (Harrison). So, to find the ideal size one can simply divide the width of that face by 3 and modify the mesh options. This allows an upper and lower limit for the size of each element as shown in Figure 6.

Running the finest mesh is not usually the best option as this increases the resolve time dramatically. The objective being high accuracy with the fastest resolve times. The mesh in figure 6 can be re generated with the intention of further refinement and trouble shooting.

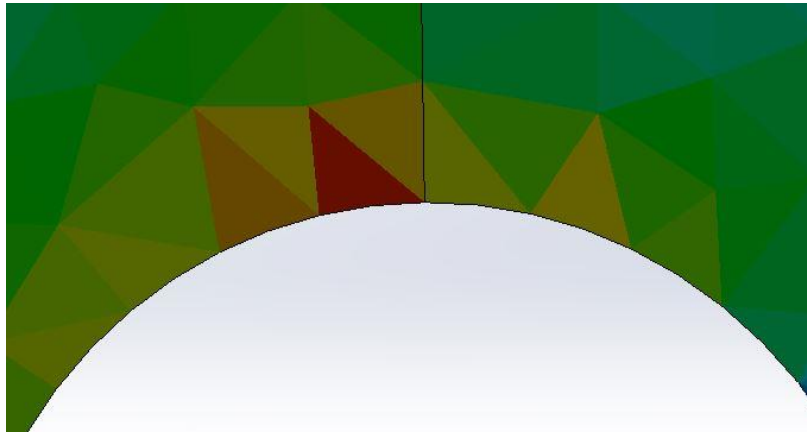


*Figure 7: Identifying areas of low resolution (Conway).*

Figure 7 shows How the element size can create issues in areas of concentrated stress. Accuracy is lost. Therefore, Mesh control can be applied to specific edges to increase accuracy such as in figure 8.

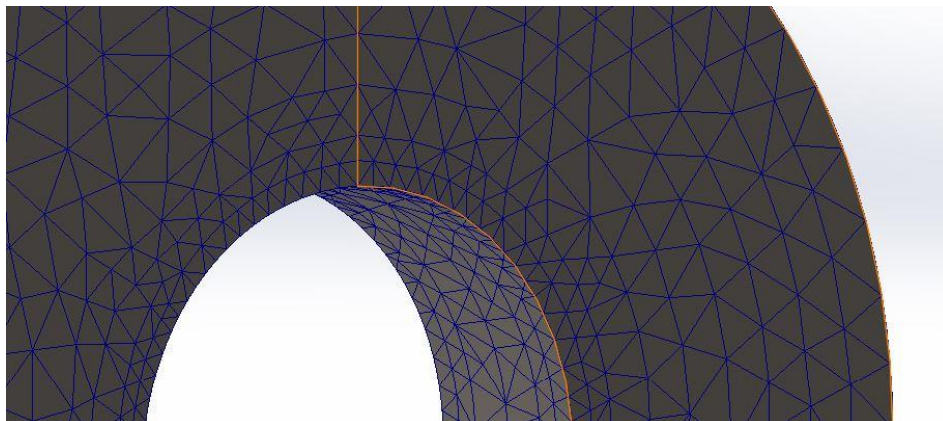


*Figure 8: Redefining edges (Conway).*

Figure 8 shows where a mesh control optimised the elements gradual increase in size stepping from 0.2mm to 0.6mm . The chain rivet acts on this inner edge so a choice was made to not include the outer radius edge of the outer plate to save the computational time.

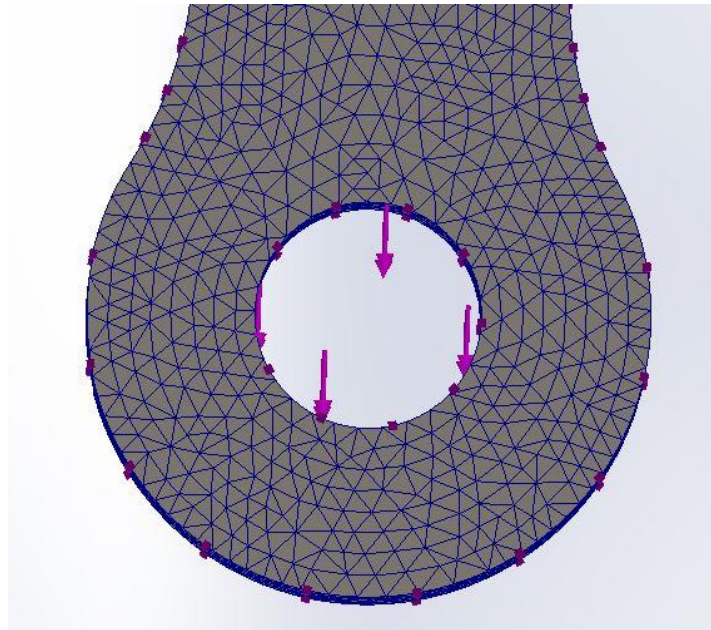


Figure 9 : Other mesh problems to look out for (Conway).

Figure 9 Shows above the hole where a lack of symmetry has occurred in the mesh at the top. To solve this a curvature-based mesh could be applied, a change to hexagonal shape or more refinement in the control settings

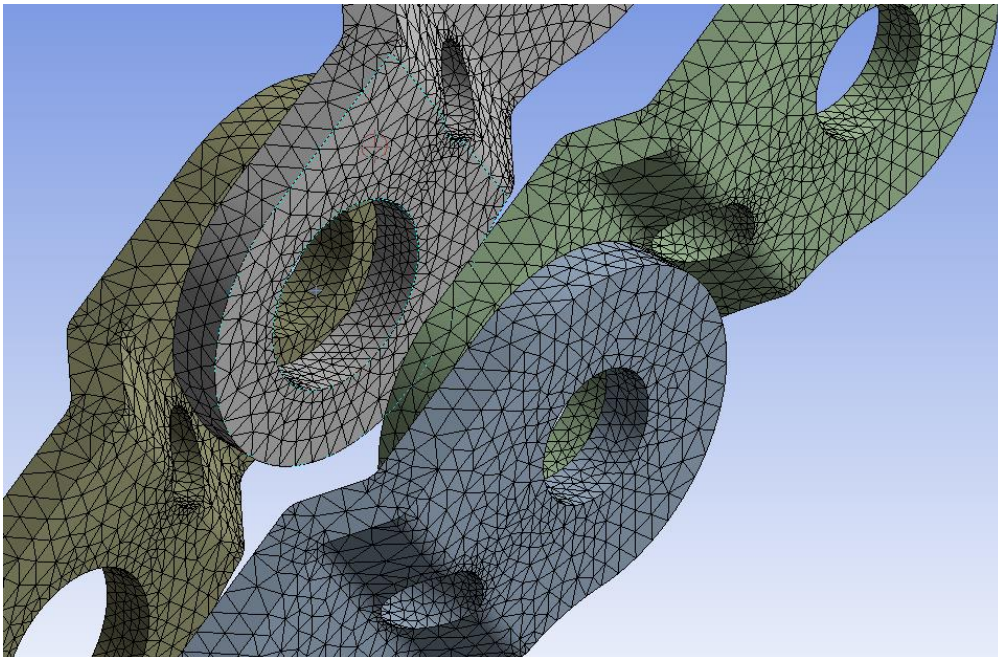


Figure 10: The final mesh quality in Ansys (Conway).

Above figure 9 shows a high-quality mesh in the Ansys environment. Up to 3 elements across on the width in areas of high interest. Reducing to 2 elements when the geometry is simple or straight. Areas of high concentration of stresses have increased in quantity and reduced in size. Settings used are element order set to “program controlled”. Global element size of 1mm and local selected faces being all of the holes set to .0005mm. Under the “Sizing” tab the Transition set to “slow”.

### 3.3 Coupled Model.

It is beneficial to use rigid dynamic study for the purpose of studying components in motion. The chain link will be tested in a static study for the purpose of reviewing available refinement and failure modes. As such, this study will include a rigid dynamics section, engineering data, steady state thermal and static structural all coupled together so the different results carry forward their relevant information improving accuracy. Engineering Data is where mentioned previously the ANSI 1040 material information is contained which is then coupled to the rigid dynamics study. One can now import the geometry and opening the modelling tab. The use of correct joint types to mimic real life interaction between components.

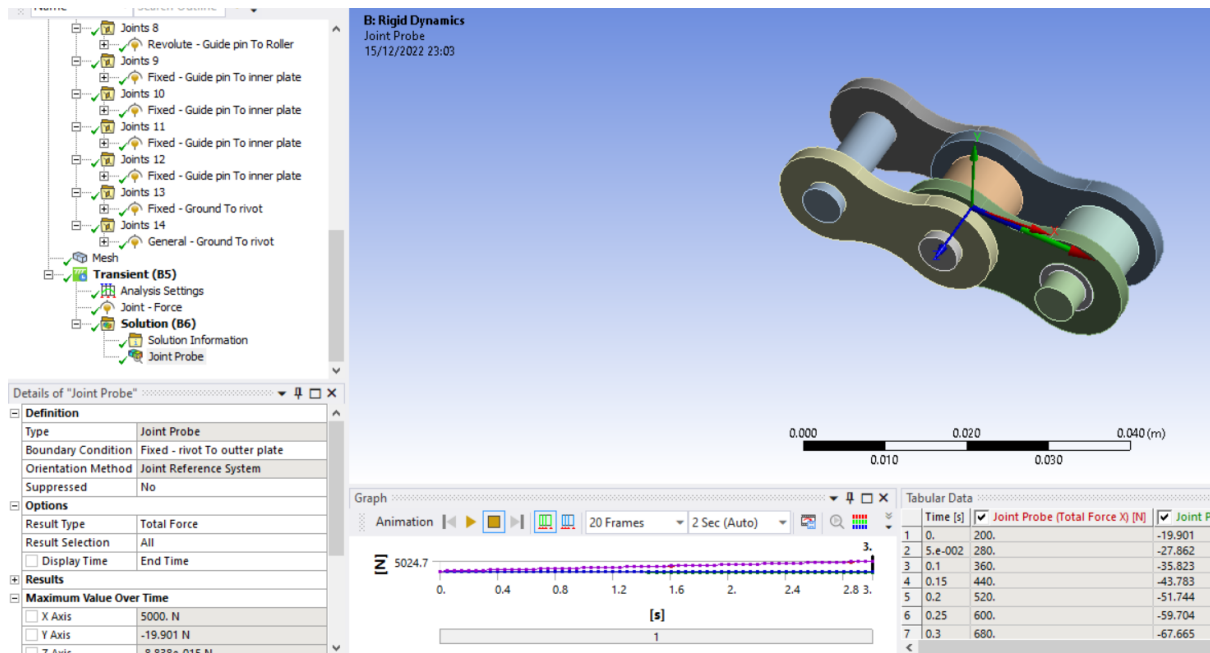


Figure 11: Rigid dynamics, Joint types and joint probe (Conway).

Figure 11 shows the joint interactions within the chain link system. Here, a force is applied pulling the link apart at 5000N. After the transient study has processed the vertical dark blue line can be placed out a point of interest so to extract the required results.

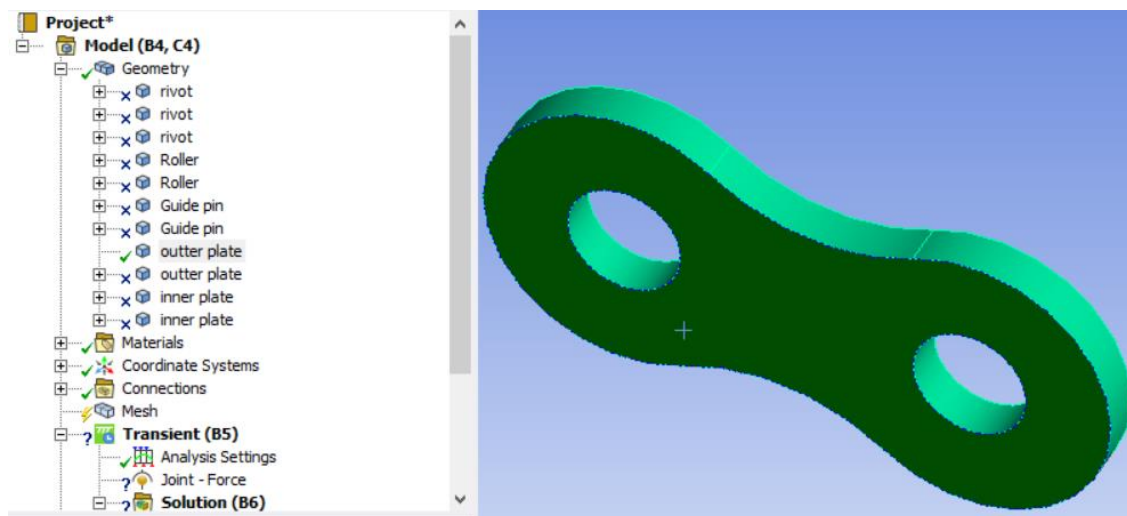


Figure 12: Transient Study, no visible mesh (Conway).

In figure 12 above the result at 3 seconds highlights the biggest magnitude so this is retrieved before pursuing onto the static structural study. The mesh function in a ridged dynamics study is not required to run the study therefore when the user click generate mesh, nothing will appear to happen in the graphics window.

| Graphics Properties                 |                                   |
|-------------------------------------|-----------------------------------|
| Definition                          |                                   |
| <input type="checkbox"/> Suppressed | No                                |
| <b>Stiffness Behavior</b>           | Flexible                          |
| Coordinate System                   | Default Coordinate System         |
| Reference Temperature               | By Environment                    |
| Treatment                           | None                              |
| Material                            |                                   |
| <input type="checkbox"/> Assignment | Carbon steel, AISI 1040, norma... |

Figure 13: Stiffness behaviour (Conway).

The first step of the static structural study is to isolate the main component of interest. The outer plate of the link has been chosen as this is the most common point of failure. All other components have been suppressed at this point. These suppressed components won't be looked at in the equations for the solver output for any further iterations. Importing motion loads is the next step. Then check that the material choice is still current and stiffness behaviour is set to flexible such as in figure 13 because this study will look at deformation.

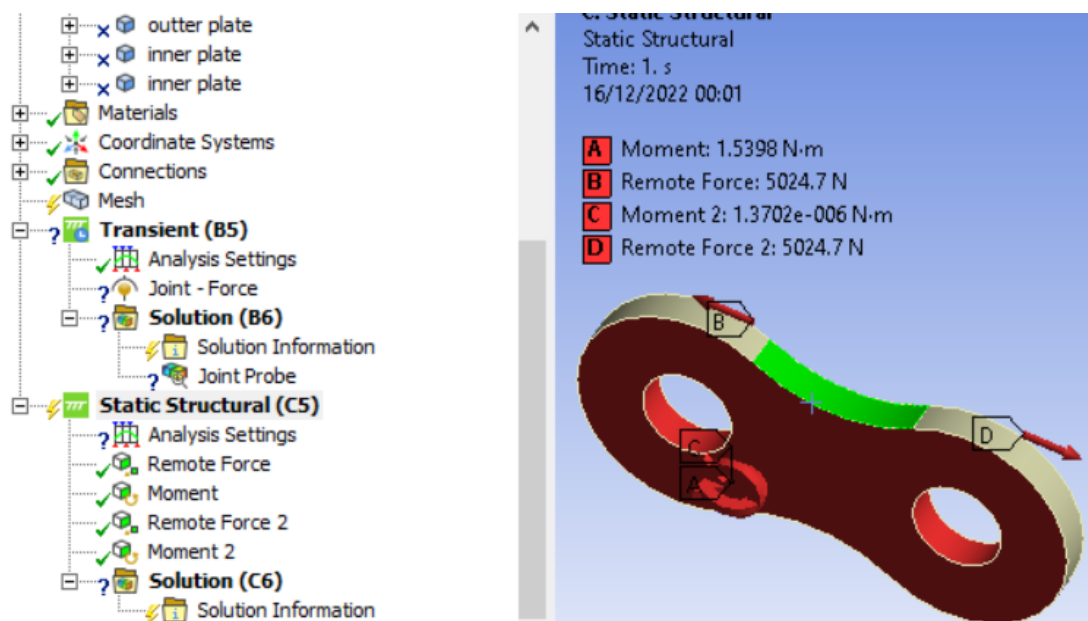


Figure 14: Static study can see the imported data (Conway).

It can be observed in figure 14 that under the static structural tab all of the forces and moments have now been added and are displayed in the graphics area.

## 4. Results

The following set of results stems from FEA studies which follow the Results of Conwell and Johnston which measures 100lbs at 1300 RPM Of the driven sprocket where a strain gauge was mounted to the outer plate of 1 link. This is the equivalent of 444N (units, n.d.).

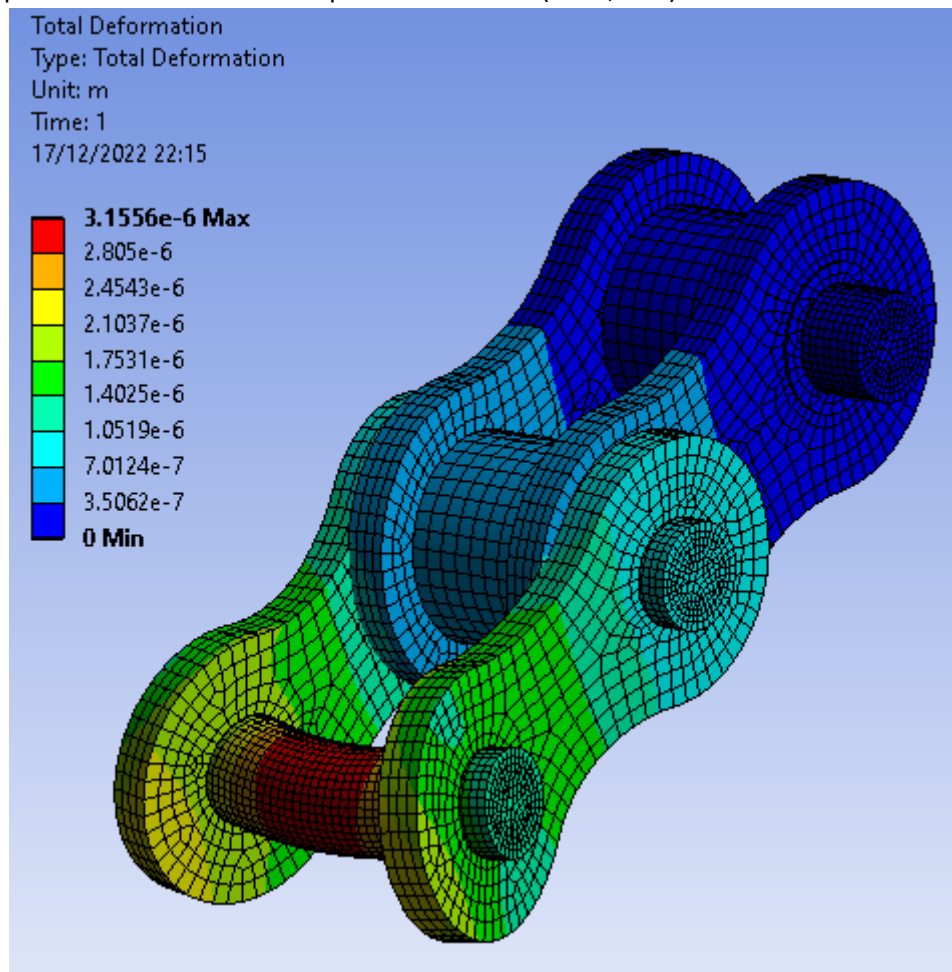


Figure 15: Standard link total deformation (Conway).

Above figure 15 is an isometric view of the standard link showing that for an input force of 444N a deformation of  $2.8 \times 10^{-6}$  m occurs.

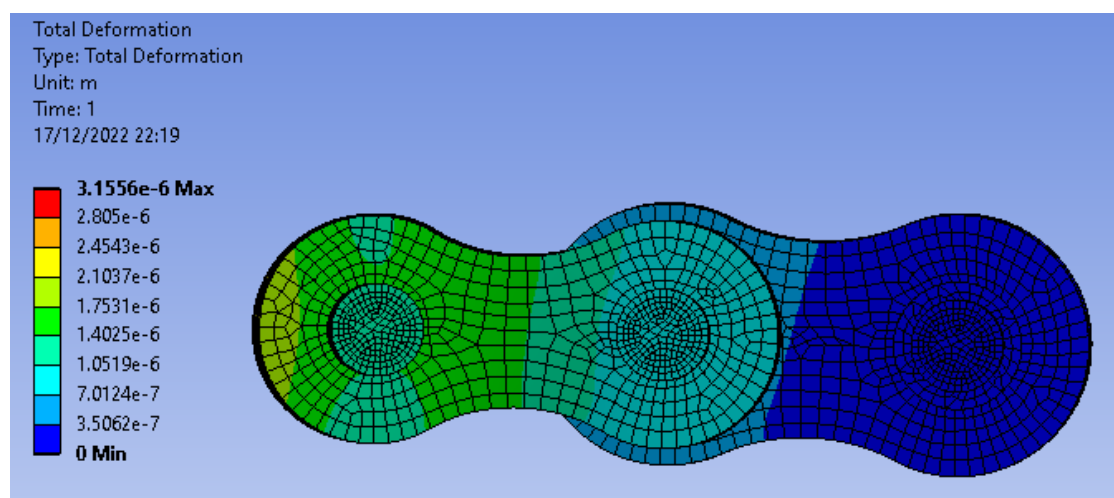


Figure 16: Side view of total deformation in the standard link (Conway).

Above figure 16 shows the side view of the same deformation as it develops across the link.

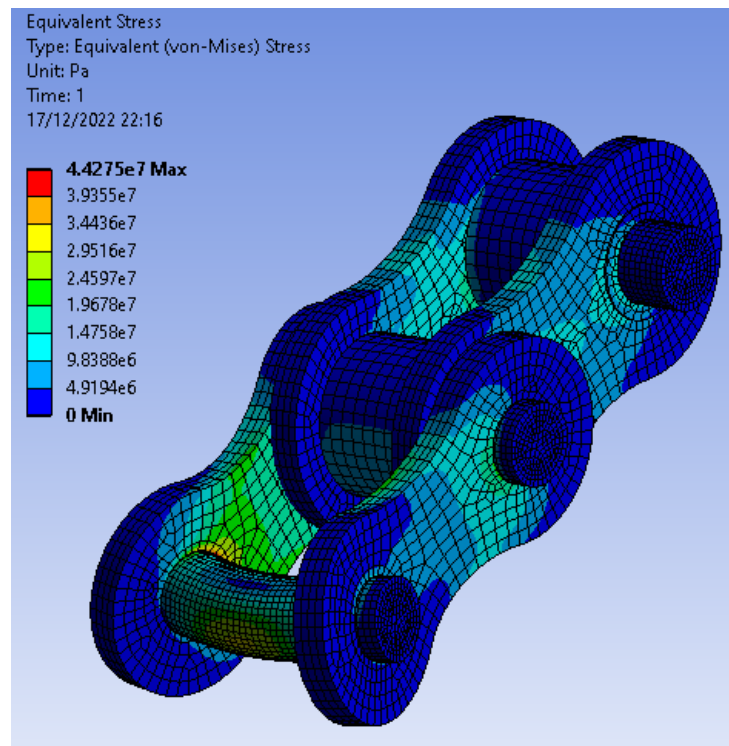


Figure 17: Equivalent Stress (Pa) Isometric view, Standard link (Conway).

Above figure 17 shows the stress in the standard link at a Max value of  $4.4 \times 10^7$  Pa with the same input force. The highest region of concentration being the leading rivet interaction at the outer plate.

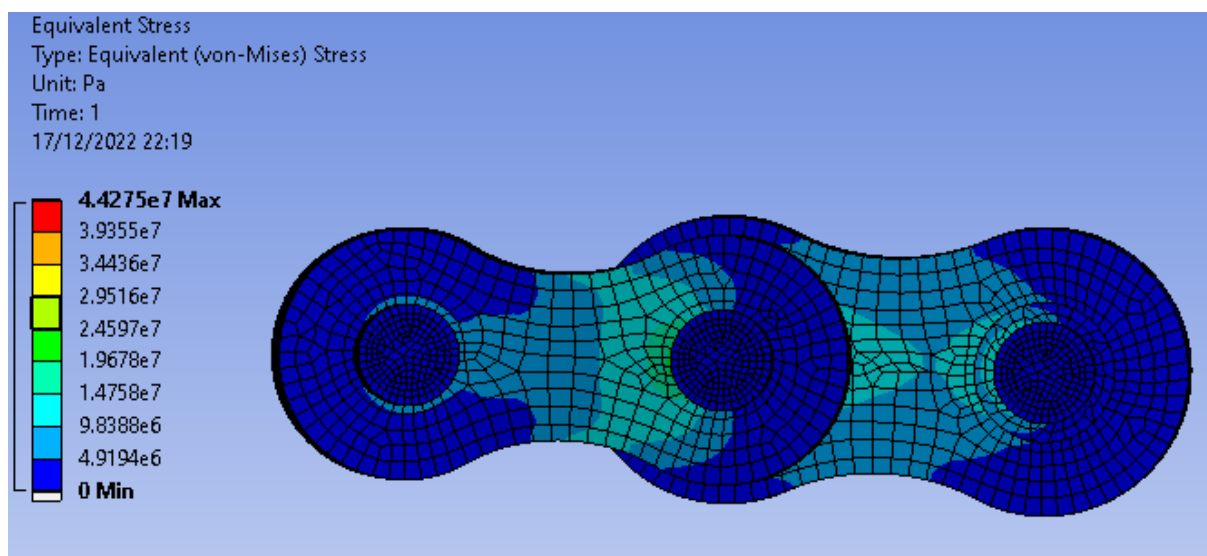


Figure 18: Side view of equivalent stress in the standard link (Conway).

Above figure 18 shows the same stress from the side view.

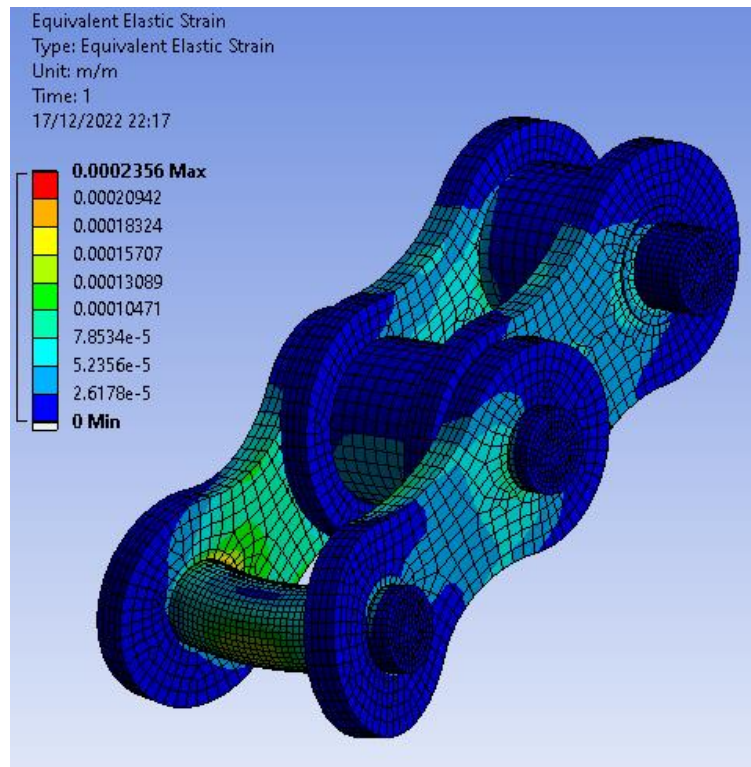


Figure 19: Equivalent Elastic Strain, Standard link (Conway).

Above figure 19 shows the Elastic strain within the system at 444N input force. Again, highest concentration being around the interaction between the outer plate and the rivet.

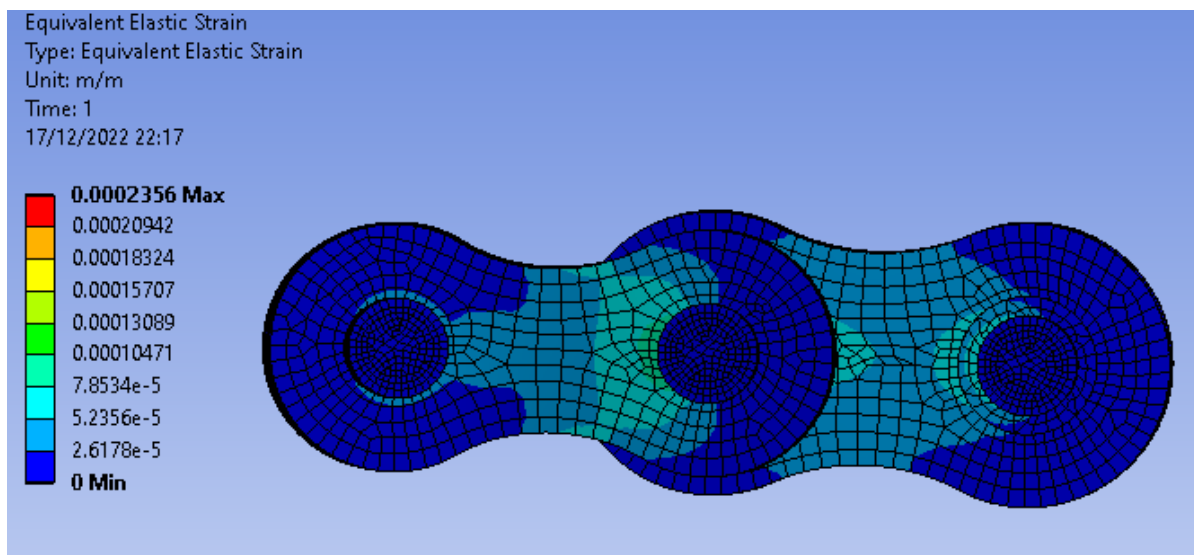


Figure 20: Equivalent elastic strain, side view. standard link (Conway).

Above figure 20 shows the same Strain from the side view.

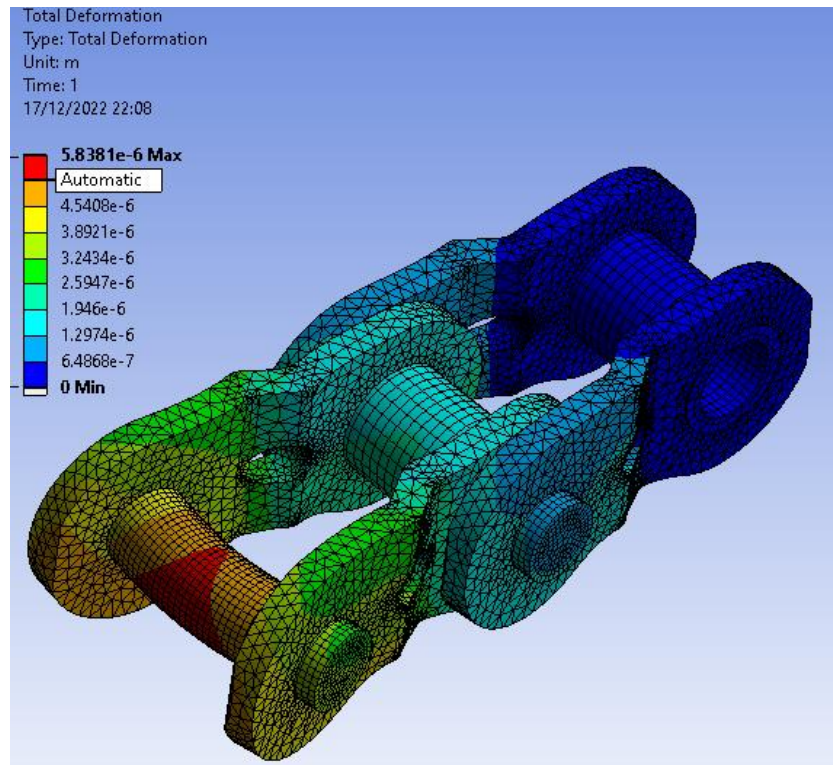


Figure 21: Half link, isometric, total deformation (Conway).

Above figure 21 shows the deformation in the half link to be a Maximum of 5.8e-6m after an input force of 444N. This chain has a hole in place following the topology study in Solidworks. This design has marginal increase in deformation compared with the standard link.

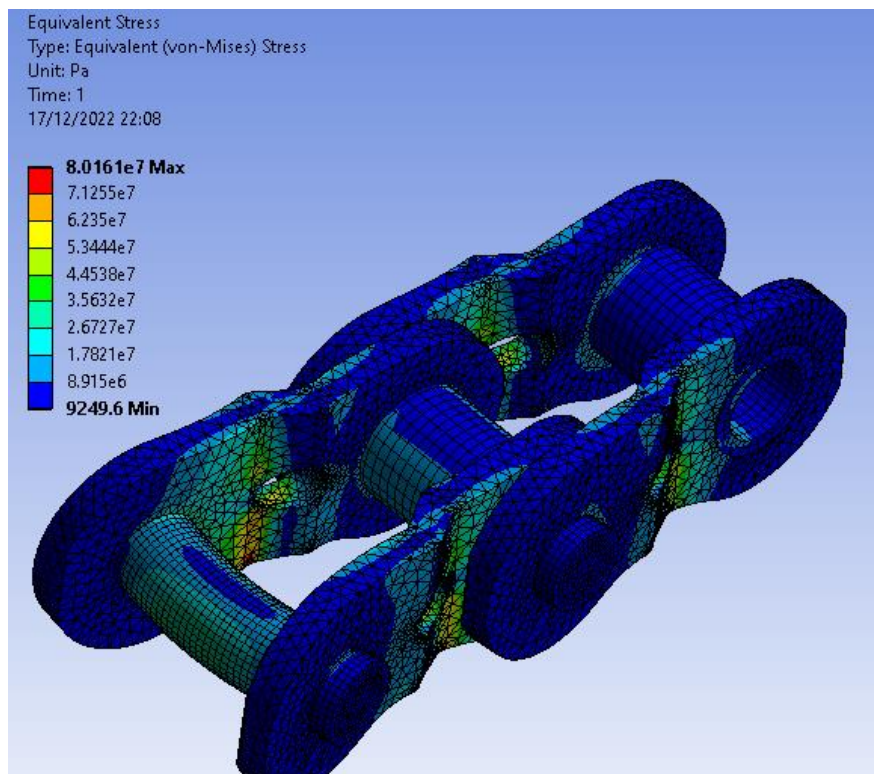


Figure 22: Equivalent Stress (Pa), Half link, Isometric (Conway).

Above figure 22 shows the half link to have stress of  $8\text{e}+07\text{Pa}$  with the same input force of 444N. Most concentration appears to be in the Mid region around the angle feature and the weight reduction hole.

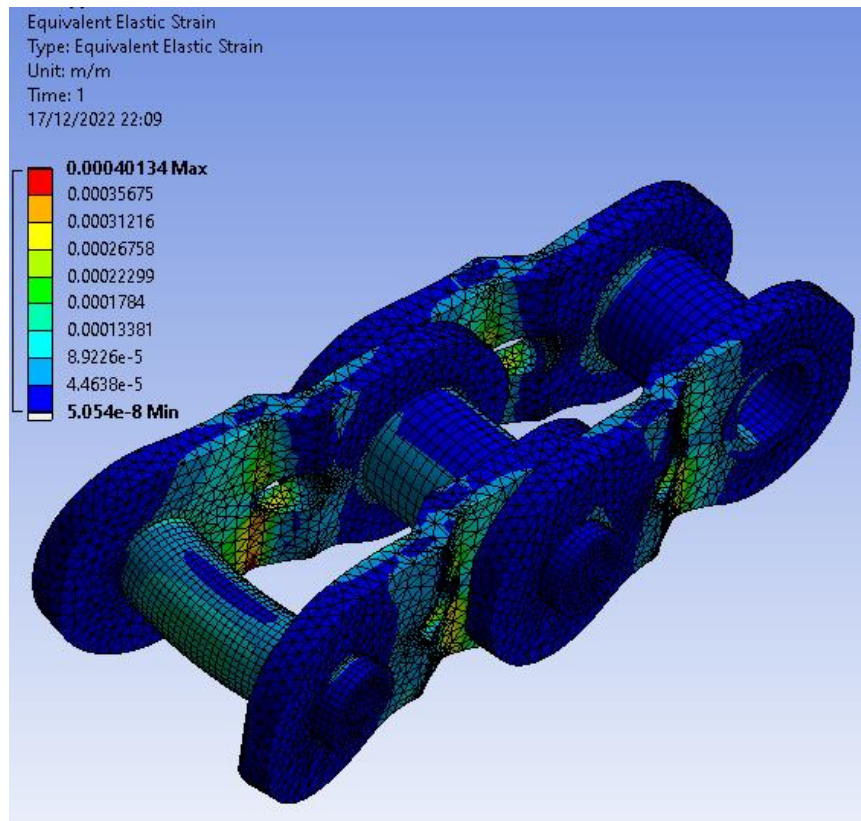


Figure 23: Elastic strain, Isometric (Conway).

Above figure 23 shows the elastic strain in the half link at  $4.0\text{e}-04$  for the same input force of 444N. Once again concentrated around the middle of the plate feature.

The two links were then tested at 5000N. the following images are the Isometric View of the deformation, stress and strain.

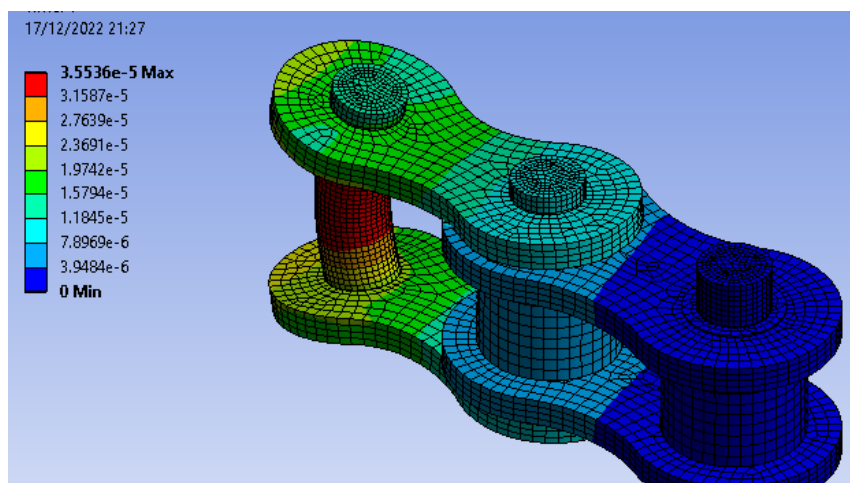


Figure 24: 5000N, Standard link, Deformation (Conway).

Above figure 24 shows the deformation of the standard link resulting from the input force of 5000N.  $3.55\text{e-}5\text{ m}$  is larger than the 444N test but in the grand scheme of things still quite small.

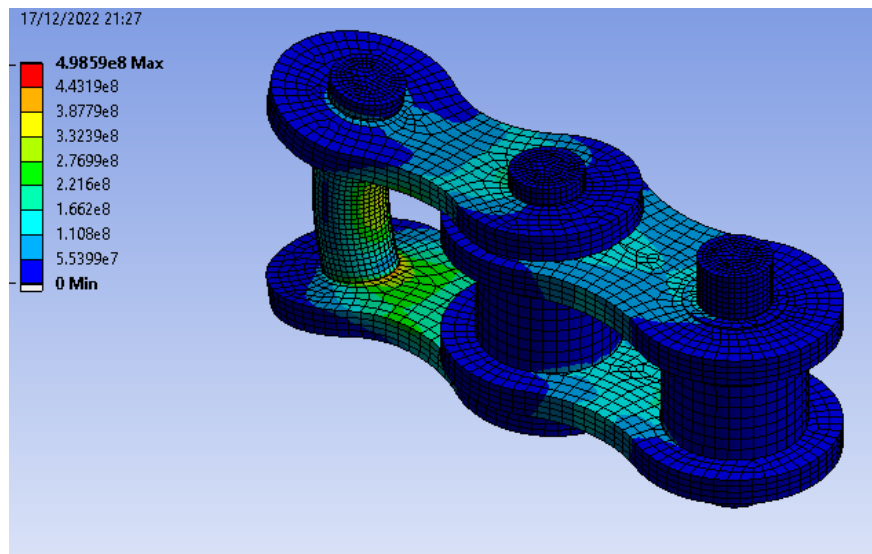


Figure 25: 5000N, Stress, standard link (Conway).

Above figure 25 shows the stress at  $5\text{e+}8\text{Pa}$  after the input force of 5000N.

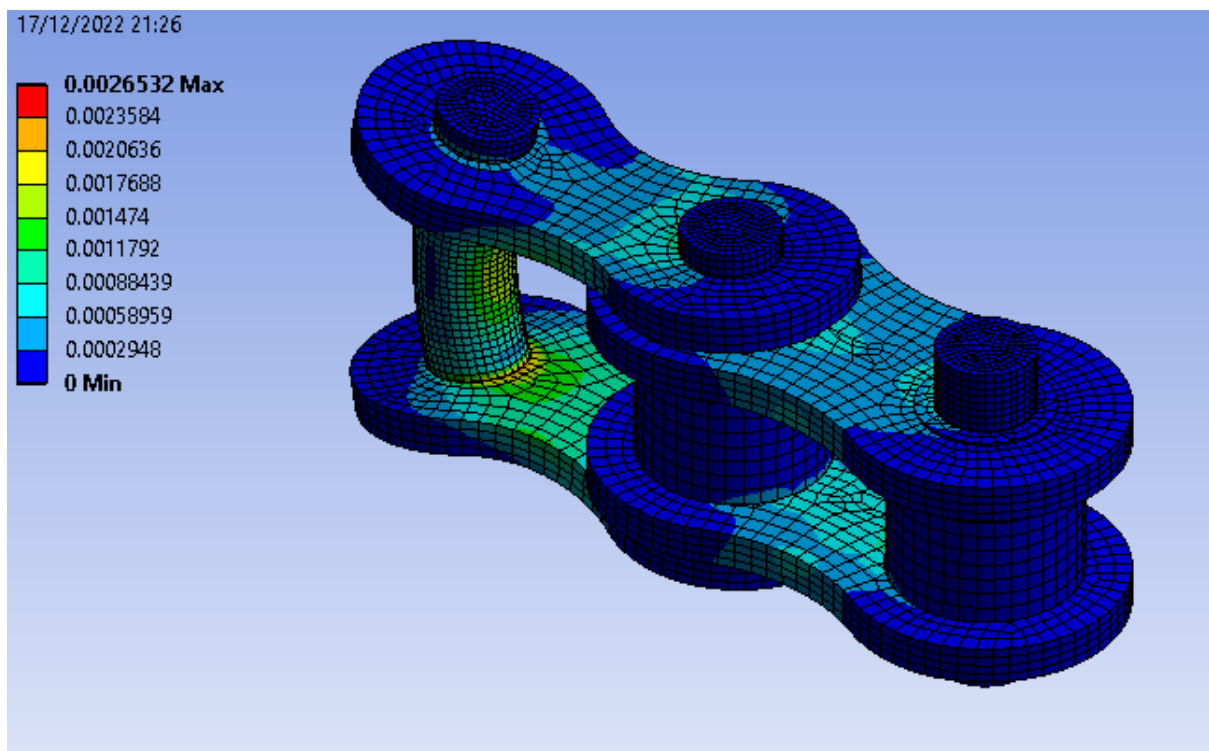


Figure 26: Standard link, strain, 5000N (Conway).

Above figure 26 shows the strain to be  $2.7 \times 10^{-3}$  with the 5000N input force.

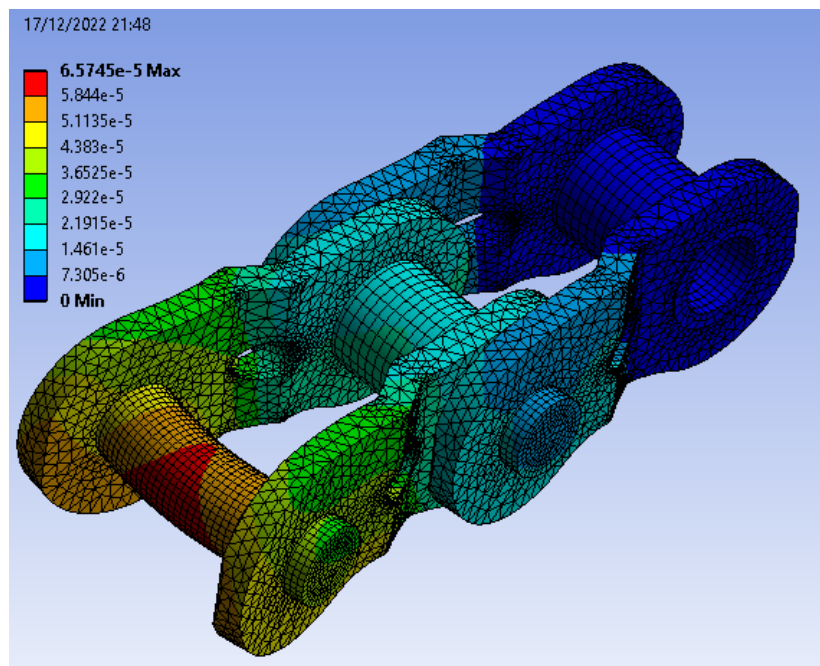


Figure 27: Half link deformation, 5000N (Conway).

Above figure 27 shows a deformation of  $6.6 \times 10^{-5}$  m with the input force of 5000N for the half link.

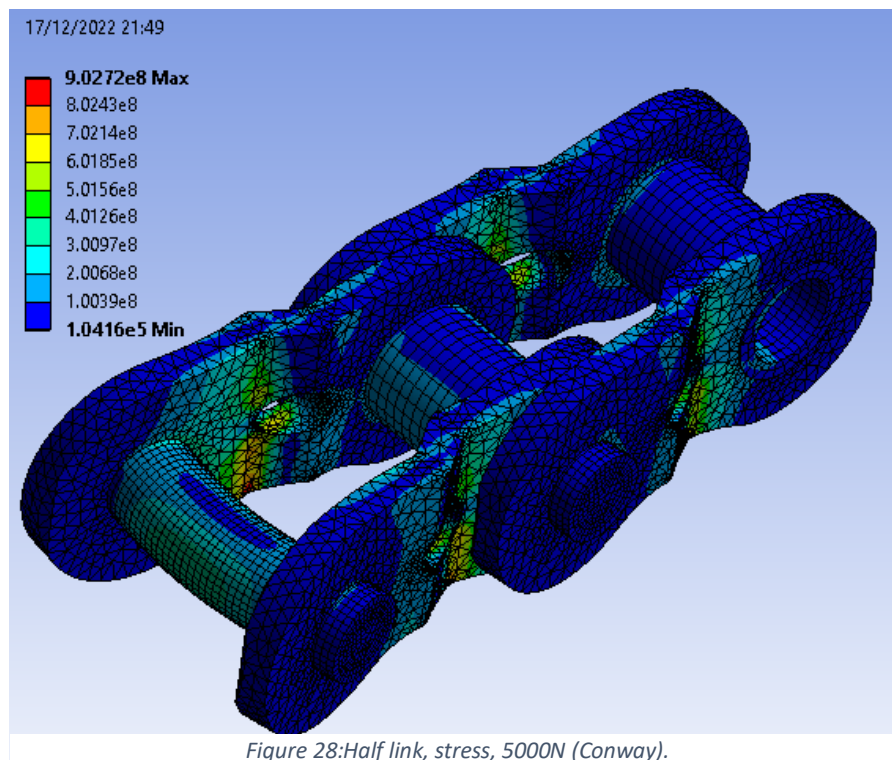


Figure 28: Half link, stress, 5000N (Conway).

Above figure 28 shows the stress in the plate at  $9 \times 10^8$  Pa with an input force of 5000N.

Subsequent images related to these results are seen in appendix 3.

## 5. Conclusion

For this standard experiment both types of link were examined under the same test conditions. The following points become apparent after the study.

From the Results.

1. The standard link distributes the stress and strain across the whole plate which results in lower stress values.
2. The half link has a geometry which directs a higher portion of the stress to the rivet Interface.
3. The half link needs serious weight reduction to be as light as the regular link with chamfers.
4. The weight difference between both links is insignificant at just 4.4 grams.
5. The bending moment follows real world failure models.

From a racing application perspective.

1. An entire chain made of half links would not be worth the expense time and effort.
2. A half link doesn't carry the stress as well as a regular link.
3. A single half link could be useful to achieve specific wheelbase.
4. This study does not test against racing forces.

## 6. Further Work

Careful consideration must be used to analyse the results. Further work should be done to simulate the full chain wrapping sprockets which will eliminate the fixed method examined here. This should also try to replicate some of the shock loadings discussed in the literature review.

The material choice is limiting in the sense that good use of material science can allow for better characteristics for the given application such as effects of heat treatment and other processes. The experiments can be carried endless times trying different materials and heat treatment applications to optimise the design.

Finally real-life testing should be conducted to confirm any computational results where possible. Given the size of a chain link it would be easily achieved to test single links of different materials and properties.

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## Appendix 1.

# Verification Example

Program: RFEM 5

Category: Geometrically Linear Analysis, Isotropic Linear Elasticity, Plate

Verification Example: 0016 – Elastic Bending - Continuous Load

### 0016 – Elastic Bending - Continuous Load

#### Description

A thin plate is fully fixed on the left end ( $x = 0$ ) and is subjected to a uniform pressure  $p$  according to the Figure 1. The problem is described by the following set of parameters.

|          |                 |                       |       |            |     |
|----------|-----------------|-----------------------|-------|------------|-----|
| Material | Elastic-Plastic | Modulus of Elasticity | $E$   | 210000.000 | MPa |
|          |                 | Poisson's Ratio       | $\nu$ | 0.000      |     |
|          |                 | Shear Modulus         | $G$   | 105000.000 | MPa |
| Geometry | Plate           | Length                | $L$   | 1.000      | m   |
|          |                 | Width                 | $w$   | 0.050      | m   |
|          |                 | Thickness             | $t$   | 0.005      | m   |
| Load     | Plate           | Pressure              | $p$   | 2750.000   | Pa  |

Small deformations are considered and the self-weight is neglected in this example. Determine the maximum deflection  $w_{z,max}$ . The aim of this example is to show that a surface of the surface stiffness type *Without Tension* behaves linearly under bending.

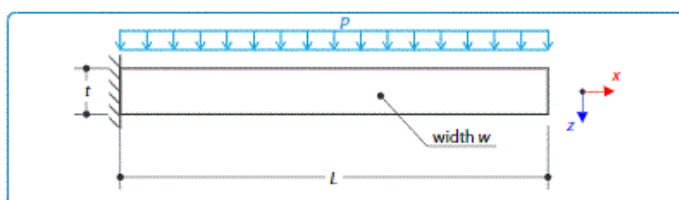


Figure 1: Problem sketch

#### Analytical Solution

The bending moment  $M$  for the plate under continuous loading  $q = pw$  is defined by

$$M = -\frac{q(L-x)^2}{2} \quad (16-1)$$

### Verification Example: 0016 – Elastic Bending - Continuous Load

Recalling the elementary equation for the beam deflection using the Euler-Bernoulli theory

$$EI_y \frac{d^2 u_z}{dx^2} = M \quad (16-2)$$

where  $I_y$  is the quadratic moment of a cross-section with respect to the y-axis and it is given by

$$I_y = \frac{wt^3}{12} \quad (16-3)$$

We integrate the equation (16-2) from 0 to  $L$  twice. Upon applying the boundary conditions for cantilever beam  $u_z(0) = u_z'(0) = 0$ , the solution takes the following form

$$u_z(x) = \frac{qx^2(6L^2 - 4Lx + x^2)}{24EI_y} \quad (16-4)$$

The maximum displacement occurs at the point  $x = L$ :

$$u_{z,max} = \frac{qL^4}{8EI_y} = \frac{3pL^4}{2Ew^2t} = 157.143 \text{ mm} \quad (16-5)$$

### RFEM 5 Settings

- Modeled in RFEM 5.04.0024
- The element size is  $l_{FE} = 0.020 \text{ m}$
- Geometrically linear analysis is considered
- The Mindlin plate theory is used
- Isotropic linear elastic material model is used

### Results

| Structure File | Surface Stiffness Type |  |  |
|----------------|------------------------|--|--|
| 0016.01        | Standard               |  |  |
| 0016.02        | Without Tension        |  |  |

| Surface Stiffness Type | Analytical Solution | RFEM 5              |              |
|------------------------|---------------------|---------------------|--------------|
|                        | $u_{z,max}$<br>[mm] | $u_{z,max}$<br>[mm] | Ratio<br>[–] |
| Standard               | 157.143             | 157.130             | 1.000        |
| Without Tension        |                     | 157.150             | 1.000        |

Figure 1-2: Maths to solve example (Dlubal).

## Appendix 2.

Appendix 2 shows some results from a solidworks study with a topology which led to the weight reduction seen in the halflink.

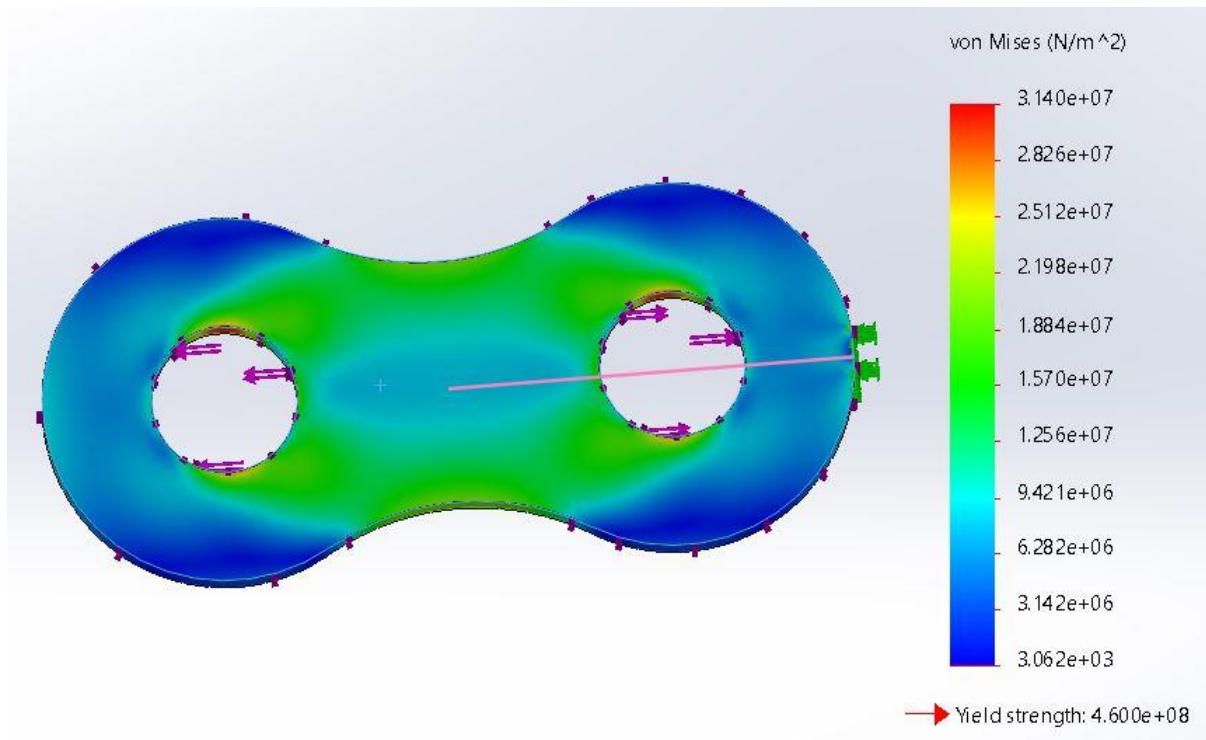


Figure 2-1: 222N force acting in opposite directions (Solidworks, 2022).

Figure 2-1 Shows the stress created by the Pin acting in opposite directions which is averaged at  $1.57 \times 10^7$  N/m<sup>2</sup>. The peak stresses in this case highlighted in red are under the yield strength of the material.

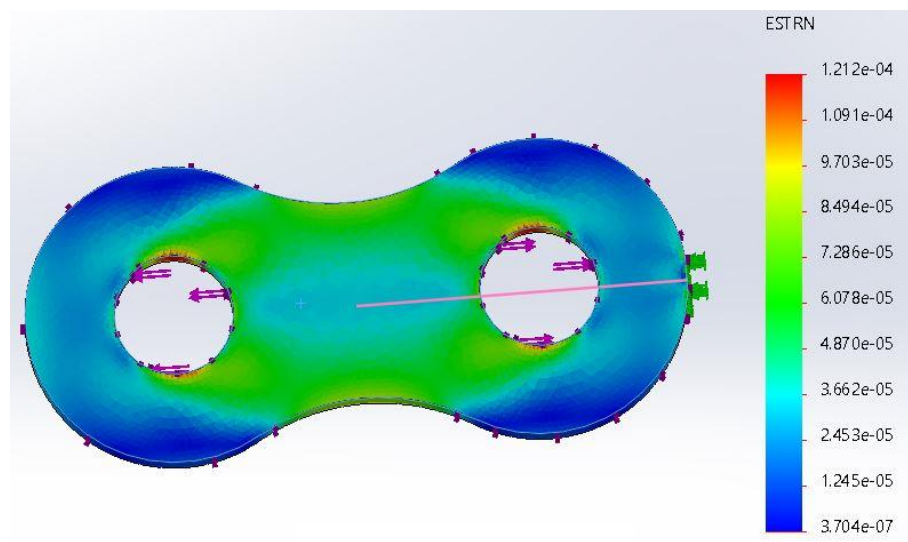


Figure 2-2 Resulting strain (Solidworks, 2022).

Figure 2-2 shows The Strain that develops in the link with a peak of  $1.2 \times 10^{-4}$ .

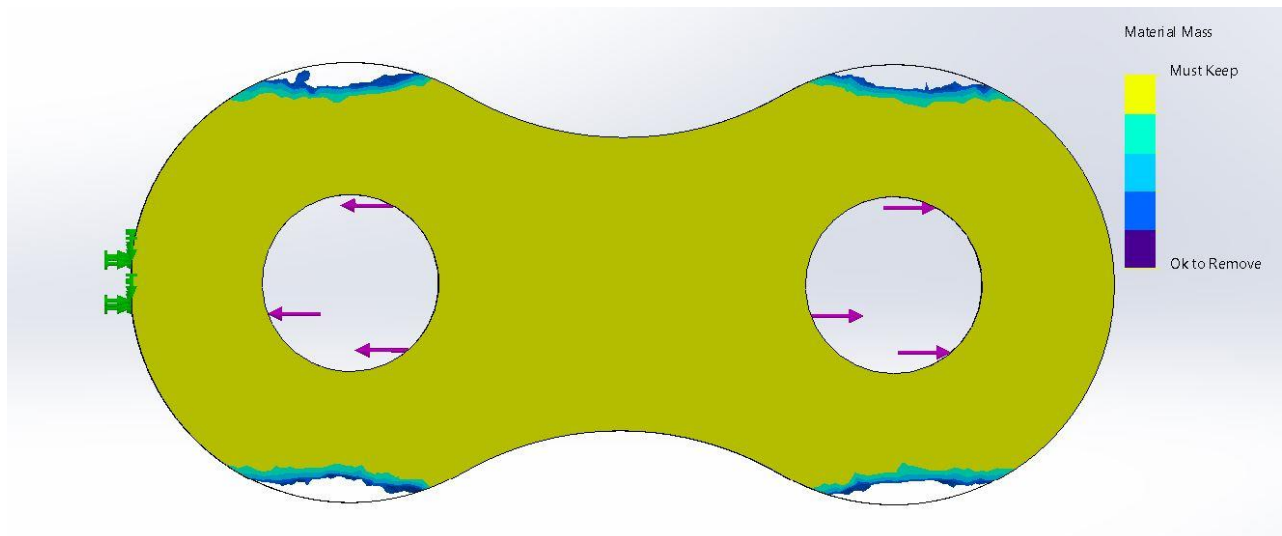


Figure 2-3: Topology 1.

Figure 2-3 shows the results of a topology study revealing that some weight reduction is possible in the blue = clear areas which leads to a new static study after the modifications seen in figure 14.

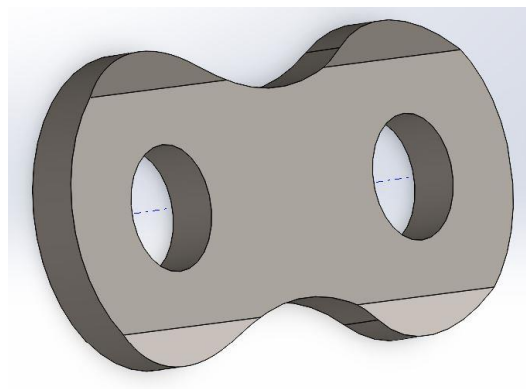


Figure 2-4: Weight reduction as a result of topology 1.  
(Solidworks, 2022)

Following the topology report figure 2-4 shows four chamfers were added to the model. Then the following results emerged from the static study .

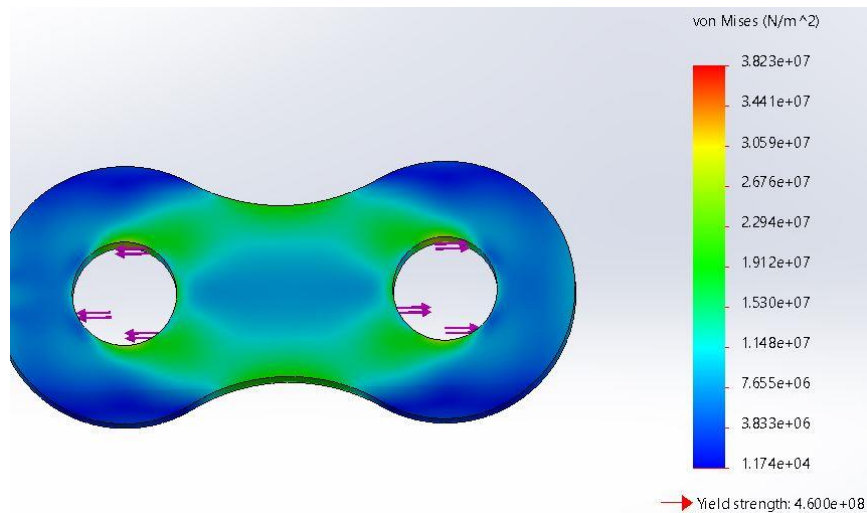


Figure 2-5: Stress after Chamfer (Solidworks, 2022).

Figure 2-5 shows that for the mass reduction the stress increases marginally but the structural integrity of the component is not compromised.

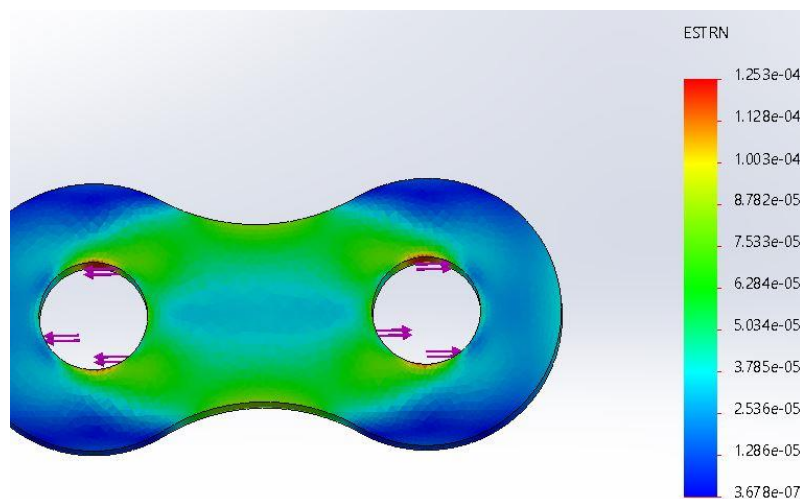


Figure 2-6: Chamfered link strain (Solidworks, 2022).

Figure 2-6 shows a minor increase in the strain. A difference of just 0.04.

The software revealed that two rivets and two outer plates have a mass of 14.41g. When the chamfers are added the mass reduces to 14.29g, a difference of 0.12g. If that weight saving is multiplied across 120 links for example there would be a saving of 14.4g total. The total weight of 120 Outer plates with rivets is 1714.8g

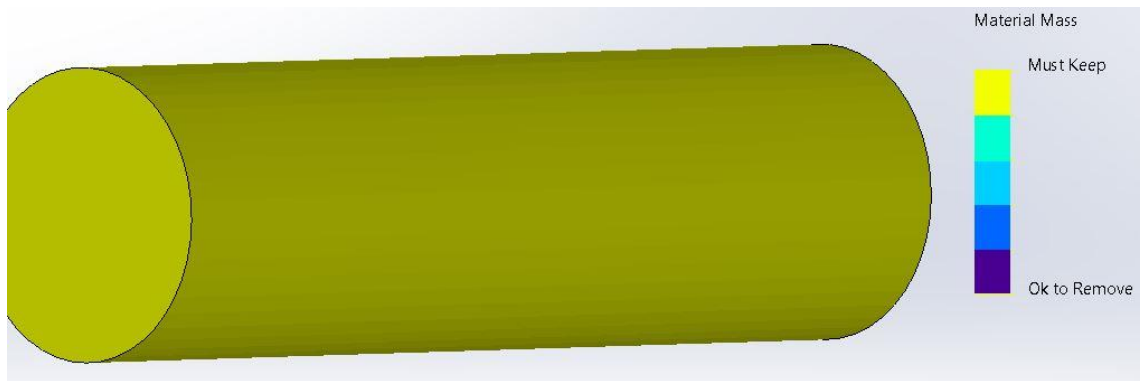


Figure 2-7: Topology on pin (Solidworks, 2022).

A quick investigation was made to see if any weight reduction could be achieved with the rivet. The following topology study was done with a region of preservation being the outer diameter with the hope of a hollow pin being possible. However, this was not the case.

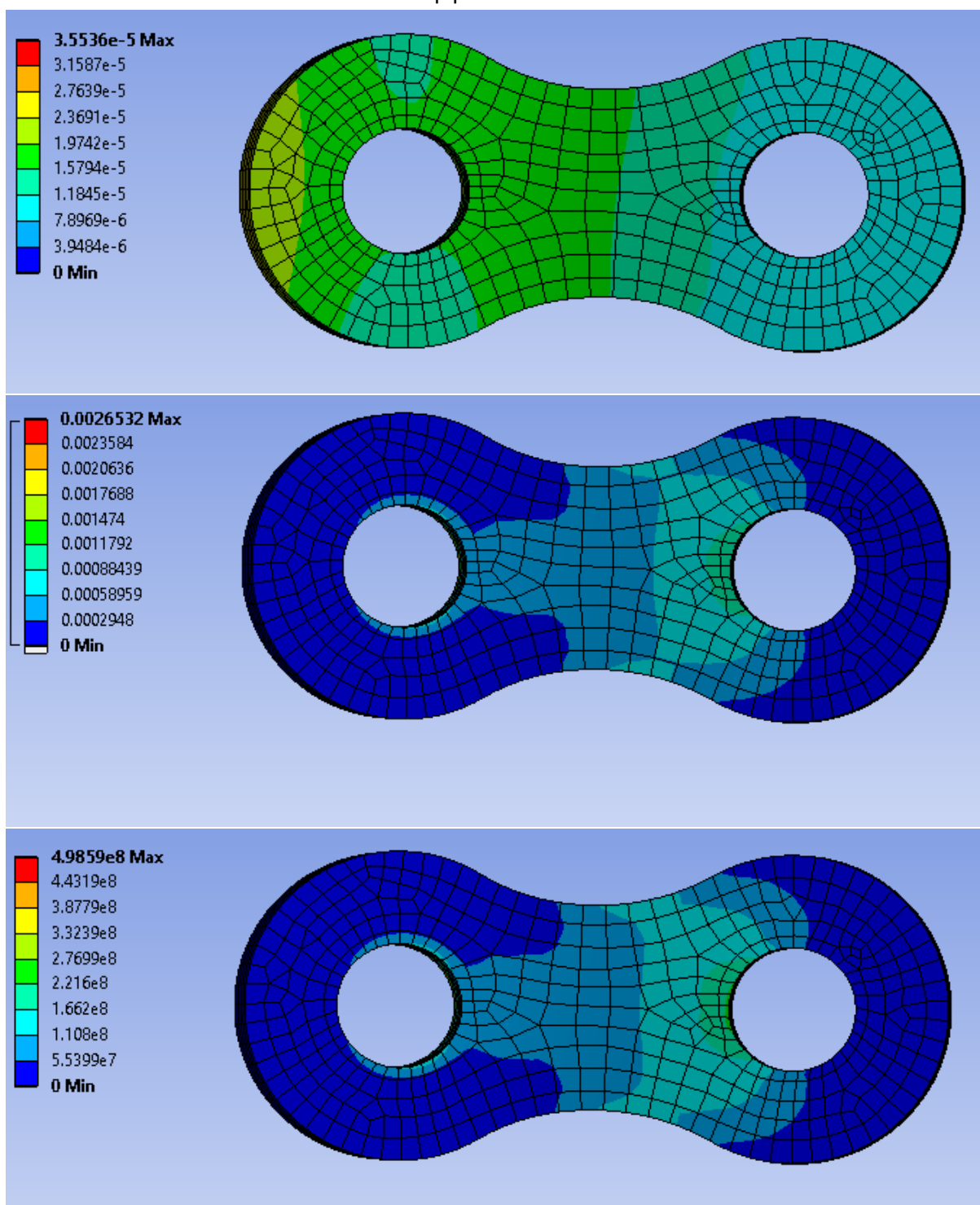
Figure 2-7 shows that a hollow pin is not possible for this material choice.

To progress this study the half link has gone through the same simulations.

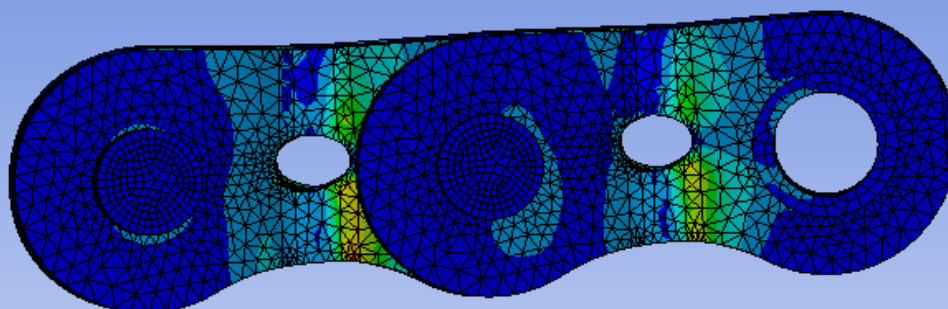
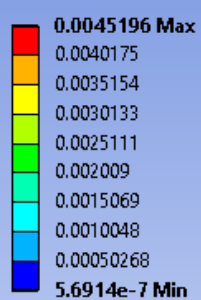
The Mass of two standard rivets and two Half link plates is 14.6g. After the weight reduction this value changes to 14.32g. 120 links adds up to 1718.4g.

The rivet displaces .0018mm on the standard link and as much as 0.05mm on the half link.

## Appendix 3.



17/12/2022 21:47



17/12/2022 21:46

