

Design of the Denison jig

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'This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has lead to the award of a degree.'

Signed:

Date:

Abstract

Whilst conducting tensile tests on the Hounsfield tensile test machine there were many inconsistencies in the results we were getting, there were suspicions that the collets were failing or not function correctly; this report analyses the Hounsfield jig used to conduct these tensile tests, the reason the Hounsfield tensile test machine was giving us inconsistencies was found and analysed. A new jig was developed to be incorporated on to the Denison Tensile test machine which is more accurate; a new design was developed through the use of a CAD software (Solidworks) and analysed through every stage of design consideration, issues were found along the way of designing the new jig but were addressed and overcome. Using the material properties of the specimen we will be testing, a thorough material selection analysis was developed, all relevant properties and requirements were taken into consideration when choosing a handful of materials that were suitable for our application. Through the use of a program called CES edupack; this allowed us to find materials effectively and reliably. All design consideration was modelled with the use of a Solidworks, each of the designs were subjected to loads which would be apparent in their service life and the results were analysed; we were able to improve upon the design from the information were received. This allowed us to develop a final design which is suitable for use on the Denison machine. A manufacturing process was then chosen with the consideration that this is a product that is tailor made for our needs to use the jig for the Denison machine; the process was then discussed, and pros and cons were weighed up and why it would be applicable for our product.

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Introduction.

This project's final aim is to design a jig which will allow us to run tensile strength tests on the Denison machine using the dumbbell/dog bone specimens that are being used in the Hounsfield machine.

There have been inconsistencies in the results from the Hounsfield machine and has raised concern as to why this is happening. There are two main suspicions; that the collets which hold the specimen during the tensile test are slipping/failing or that the calibration for the Hounsfield machine is incorrect.

This report aims to provide the reader with a general direction when designing a product. This report will cover every stage of the design process; from analysing the Hounsfield and determining the error in which is causing the inconsistencies with the results, to running different designs through a CAD program (setting up our design for the CAD analysis, to the interpretation of the results), all the way through to manufacturing processes which would be used to produce our final product to be used on the Denison machine.

Aims and objectives

The aim of this report is to have given the reader a complete understanding of the steps taken to develop the new Denison jig, and give an insight to what considerations to take when deciding to either improve on a design or develop a new product.

The objectives for this report is to produce an analysis for the Hounsfield jig that will determine the reason of its failure and design up on it to produce a new jig that can be mounted to the Denison and be able to function correctly throughout its service life

Method for designing the Dennison Jig

When redesigning a product there are many stages to go through, this will outline how we will approach redesigning the Hounsfield machine collets to be used on the Denison machine.

Every design method will differ depending on the objectives of the study; if an engineer wanted to design a car it would be completely different to an engineer who wants to design a mobile phone. The main part of a design process is that it follows a systematic approach to the end goals. (Haik, 2014).

The method which will be used is as follows:

- Analysing the Hounsfield collets to determine the issue.
- Developing a jig to work on the Denison machine.
- Choosing a material that will fit the requirements for this application.
- Testing our design through a CAD software.
- Choosing a manufacturing process to produce the new jig.

By analysing the Hounsfield collets first this will give us a better understanding of what to avoid and how the collets have failed already. After this we can start to brainstorm and develop design ideas, we can then add on to these ideas we have developed. Because we were given them material of the specimens we would be testing we could determine a suitable material for the jig. We could then move on to run our designs through a CAD software which would give us a better understanding as to whether the design is feasible and what needs to be improved further; after this is completed we should have our final product and be able to select a suitable processing method for production of the new jig

Analysis of original collets

Upon inspection of the collets for the Hounsfield there are obvious signs of what we thought looks like ware and tare. Upon closer inspection, it is not ware and tare; but that the collets are failing and that this is our cause of the error.

Pin hole.

Upon inspection of the original collets, we can see clear signs that the collets are not acting /performing the way they should. One of the reasons we first assumed that it was the collet was failing is due to the divot in the pin hole of the collet. This is the only securing point for the collets whilst the test is going on, so if this is fail the rest of the jig wouldn't be functional.



Figure 1 one of the two collets which make up the Hounsfield jig. (Better condition)

As we can see in figure(1) the hole for the pin is circular and has minimal ware and tare, this collet has sustained excess ware and tare due to the failing collet. Although the ware isn't apparent on the pin hole, it will be show in the next section. This picture was added to show the difference in ware between both the collets that were failing.



Figure 2 the second collet which makes up the Hounsfield jig. (Worse condition)

As we can see in figure(2) highlighted in the red circle is a divot where the pin has been pressing against only the inner edge of the pin hole. This indicates to us that the collets aren't sitting correctly whilst in use or that they are rotating whilst under load. This fits well with the concerns we have; if the collets aren't sitting correctly then the collets will not be able to hold the specimen securely therefore the tests we conduct are likely to fail or be inaccurate.

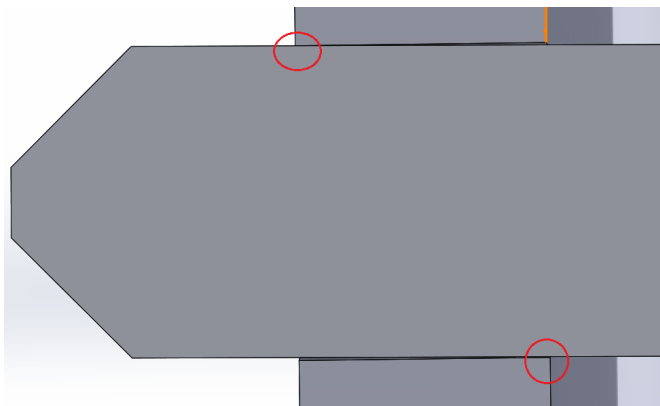


Figure 3 Reason for the divot. (Through CAD)

As the collets come apart, we can see the pin makes contact with the collet at only two points rather than the entire surface which is what we would expect to see. Whilst this is under tension, the force applied will cause the divot to happen and the result is what we see in figure(2).

Collet lip.

After we investigated the pin hole, we then went on to investigate the lip in which the specimen presses against; as the pin hole had a divot so apparent we expected to see the same amount of wear and tear on the lip. We found excess and uneven ware which will be shown in the following figures.

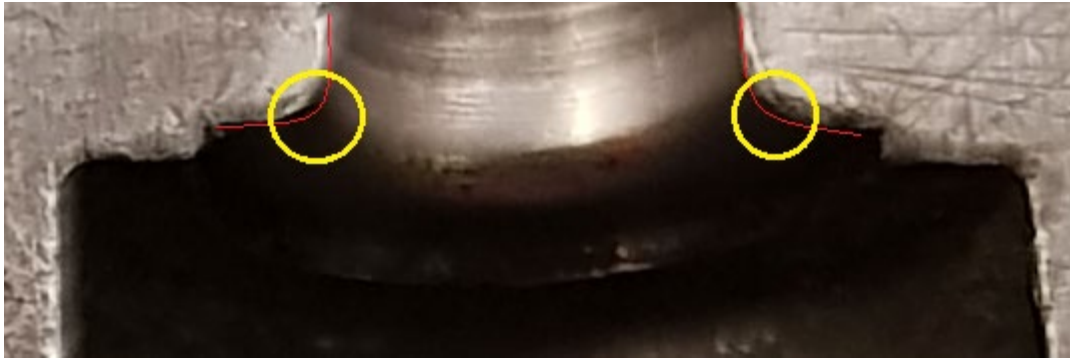


Figure 4 Collet lip where the specimen will press against.

This is the lip of the collet that is failing; we can see from yellow circles, there is more material removed from the lip on the left than there is on the right. This is down to the force no longer being applied evenly. After multiple uses and the specimen being pulled more from one side than the other it is evident that the collets are sustaining more ware and tare and has shortened the life span of the collet.

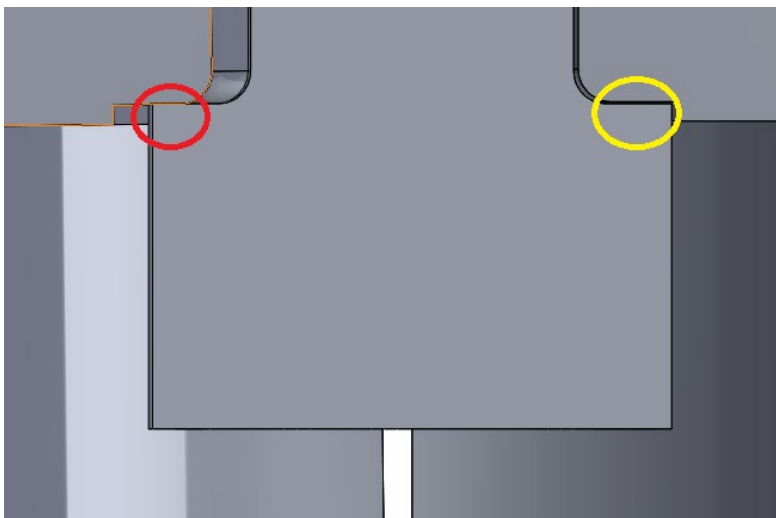


Figure 5 Solid works rendering of the figure above.

From this figure it is easier to notice how the specimen is sitting, this figure shows how the failing collet is working currently; the yellow circle represents the specimen sitting correctly on one side, whilst the red circle shows the specimen sitting incorrectly. This shows how out jig would be used in its current state.

Entire jig assembled.

When we assembled the collets to check for play we noticed an obvious gap at the top and as we checked the lower portion of the assembly there was no gap. The gap was very noticeable whilst it was sat on the table not under tension.

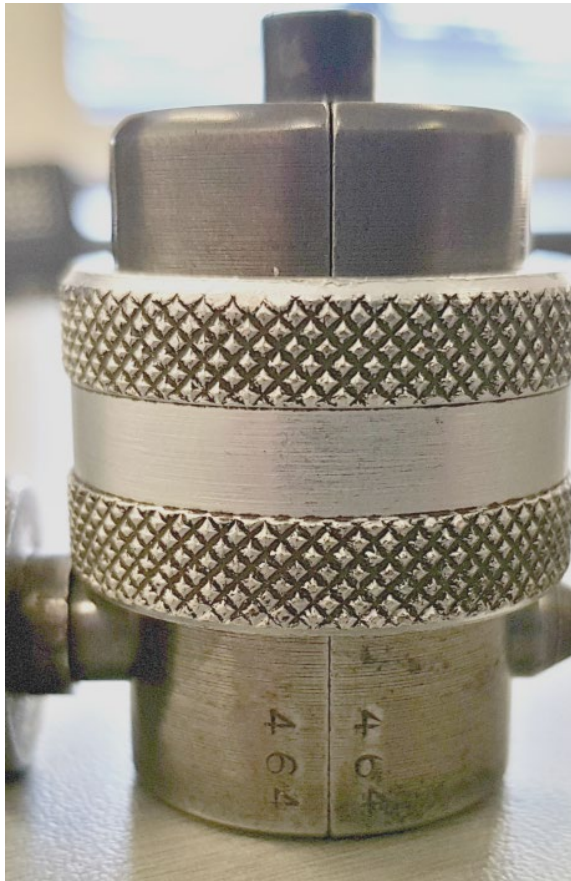


Figure 6 Hounsfield collets assembled.

For us to understand why this is so important to notice is because if the jig isn't holding the specimen correctly, the force won't be applied directly straight, we will see the specimen's breaking or deforming in an unusual way or in a way it wasn't designed to break. That is why it is so important to ensure that the collets are functioning correctly, this will be investigated further into the report.

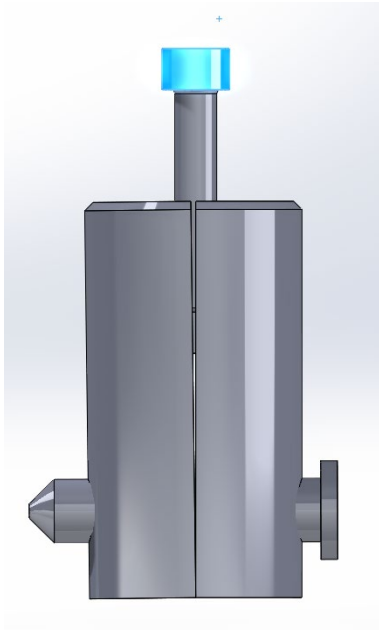


Figure 7 CAD rendering of Hounsfield collets assembled.

This is the CAD model we have used in all the above CAD renderings. Although the gap is exaggerated, this is just a rendering for the reader to gain a better understanding of what is happening within the collet that we cannot see.

Simulation constants.

Materials

Before we begin conducting our tests, we need to input the materials which we are using.

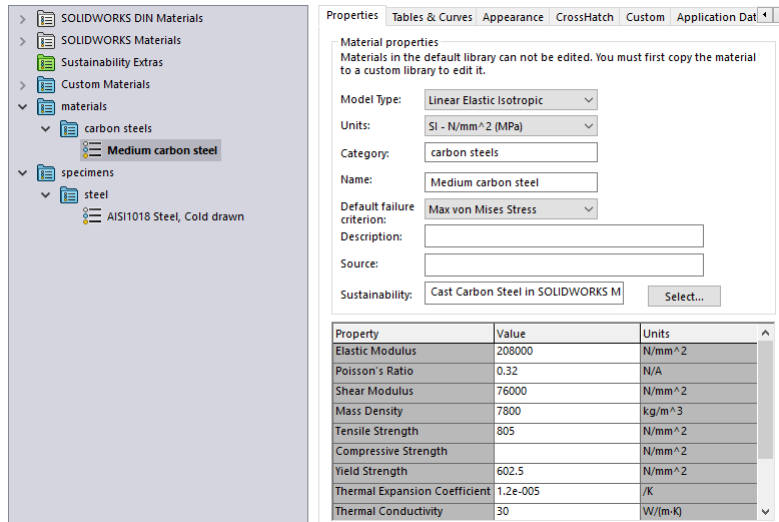


Figure 8 Medium carbon steel added to SW library

For the accuracy of our studies Medium carbon steel was added to the Solidworks library of materials, all values added were averages as discussed in table 2 of the material selection section.

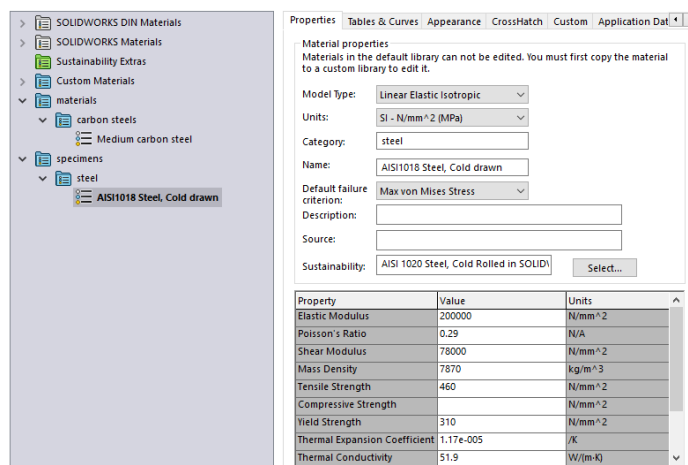


Figure 9 Plain carbon steel added to Solidworks library.

For the accuracy of out studies, plain carbon steel was added to the Solidworks material library using the values discussed in the material requirements section of the report.

Simulation constants

As a basic simulation for the Hounsfield jig, we added all the parts together into a single part file to run a simulated tensile test.

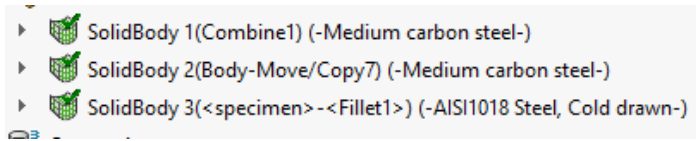


Figure 10 Solid bodies for simulation.

Combined the main body and the collets together; this assumes perfect function of the entire jig, that there is no movement in the bodies and they all remain where/how they are supposed to be located. Both jigs were applied the medium carbons steel material whilst the specimen was applied the cold drawn steel material.

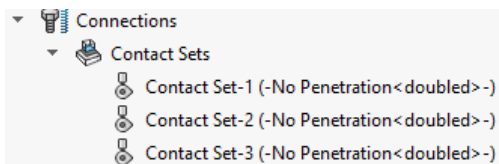


Figure 11 Contact sets for simulations

There were 3 contacts set to refrain the specimen from penetrating through the two jigs; two lips of the specimen were set to not penetrate through the lips in the collets, whilst the length of the specimen was set so it was correctly restrained.

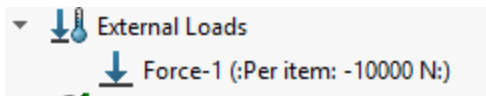


Figure 12 The force used in the Hounsfield simulation.

This is the force that will used over all the simulations that are not with in an assembly.

All stress plots will have the tensile strength as the maximum stress, this is just so we know if the part is failing under the load we have applied.

Result setup

For the results we will be concentrating on will be the stress plot and strain plot; these are the two most important plots for our study, this will give us an approximate as to what level or stresses and deformation we are seeing.

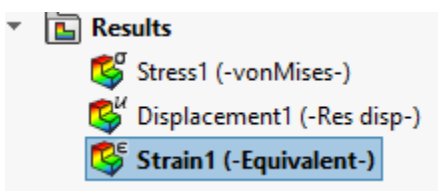


Figure 13 Results tab in Solidworks simulation.

We will not be analysing the displacement plot as it won't give us any reliable information; the way the study has been setup allows one jig to move under force, so the displacement table is flagging the movement as a displacement and this is not what we want to see. This is not an issue to us, we are only running base line tests for all the design considerations and when we are satisfied with the final design we will put it into an assembly and run a full analysis to be able to accurately simulate it in a more realistic way.

The stress plot allows us to see the maximum stresses in our study, it will usually be displayed in red; as default Solidworks will show us out maximum stress in the colour red, this can be problematic as some may think that the stresses highlighted in red are reaching tensile or yield strength. This gives us an understanding as to where the part/component would be at its weakest or most likely to fail.

The strain plot shows the pressure a component is seeing in response to a load; the load will spread itself through the part based on the stiffness of the material. Usually we will see the load being distribute in a way that allows the load to be evenly distributed.

Hounsfield FEA simulation.

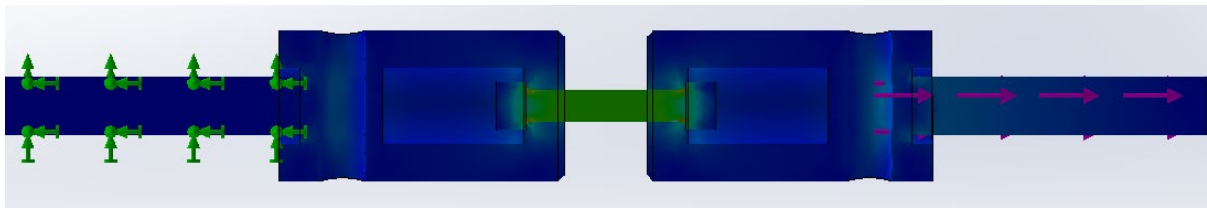


Figure 14 Hounsfield jig simulation.

This is an overview of the setup of the Hounsfield tensile test, the Green arrow on the left side of the jig is where we set our fixture, which restrains it from moving during simulation. On the right side of the set up the purple arrows are the force we applied, we applied the force in the opposite direction to the second jig.

Results

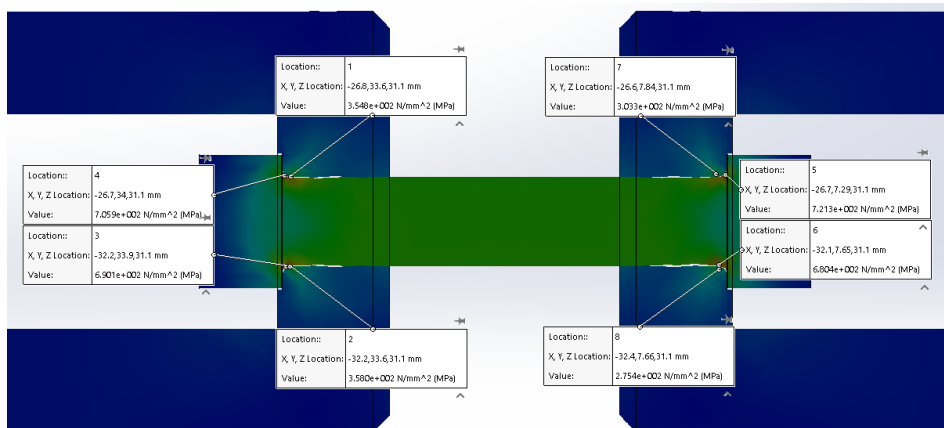


Figure 15 Stress probes for the Hounsfield

These boxes we see are called probes, this allows us to see the forces acting upon a specific point of choice; this grants us an option to be able to see what is happening within our model at different points or selected points.

locations 1, 2, 7 and 8 represent the forces acting up on the lips of the collets; the highest stress we see acting on the collet is in location 2;

The force seen in location 2 is given to us as $3.580 \times 10^2 \text{ N/mm}^2$, the $\times 10^2$ seen in this number symbolises $\times 10^2$ so in this case $\times 10^2$ means $\times 10^2$.

These results tell us that there are no excess forces seen on the collet, the red sections seen on the specimen corners symbolises the highest stresses seen in this specific study; this doesn't necessarily mean that the material has reached yield or tensile strength. The highest stress points on the collet do not exceed the yield stress not the tensile strength.

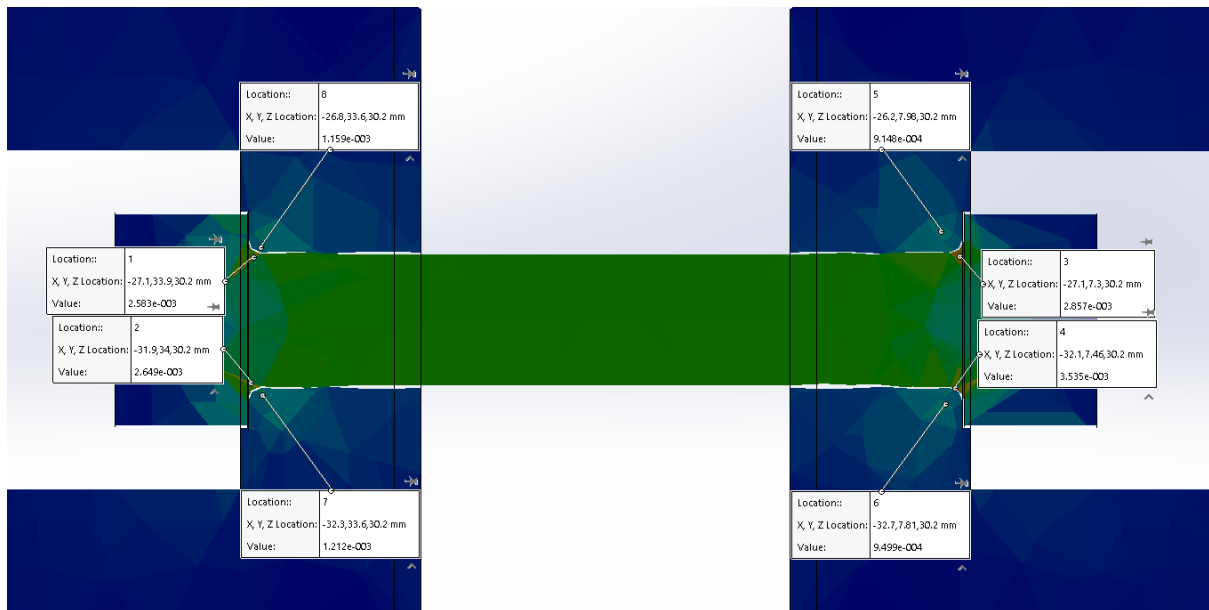


Figure 16 Strain plot for the Hounsfield.

This is the strain plot for the Hounsfield; we have used the probe tool again to be able to read the strain at the most apparent sections in the model. The highest strain points show that the maximum strain is on the specimen and not on the collets, the strain on the collet is minimal and not of concern. There are red/brown sections on the corner of the specimens which is where the specimen would meet the collet, this make sense because the specimen would be trying to deform but would not be able to and it is holding the specimen in the collets.

Interpretation

The Hounsfield jig works and can handle the stresses present in our simulation, this shows that the jig shouldn't have failed the way it did in our analysis of the Hounsfield collets; that means it must have been down to the collets, it could have been a faulty set of collets or it could be down to user error. None the less, this confirms the suspicions we had and also confirms our analysis.

New collets for the Hounsfield.

My colleague Ismail Fadul purchased a new set of collets to run the tests; after running the tests, all inconsistencies in the results had disappeared, this is a confirmation of our suspicions that it was the collets at fault.

New set of collets.



Figure 17 new set of collets for the Hounsfield. (Fadul, 2018)

These are the new set of collets that were purchased by my colleague, as we can see there is no sign of wear and tear. These collets should allow us to run tensile tests, without error or inconsistencies.

Pin hole.

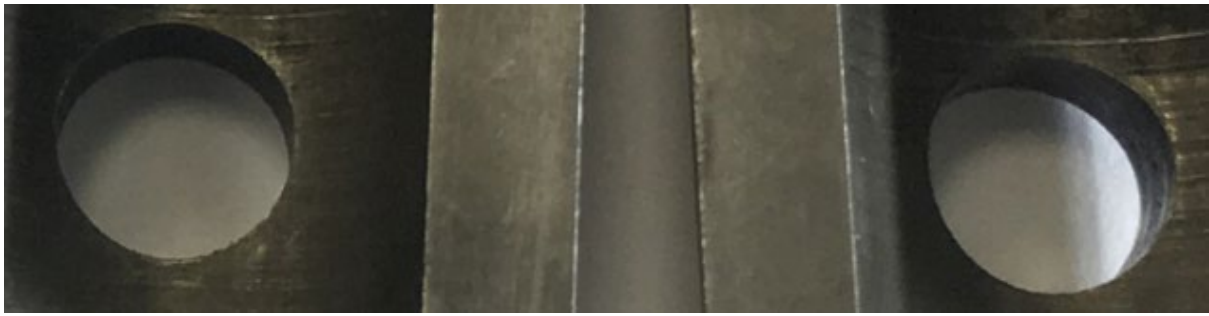


Figure 18 Pin holes on the new set of collets. (Fadul, 2018)

We can see from the figure above, there is no divots in or around the holes for the securing pin. This confirms what was mentioned earlier in the report about the divot in the hole.

Collet lips.



Figure 19 lip where the specimen contacts the collet. (Fadul, 2018)

We can see in the figure above, the edges of the lip where contact between the collet and specimen is made; there is no uneven ware and the lips/edges are uniform across both collets.

Analysis of specimens

Specimens.

The correct way in which a specimen is meant to brake in the tensile strength machine is from the middle as the force should be applied evenly over both platforms.

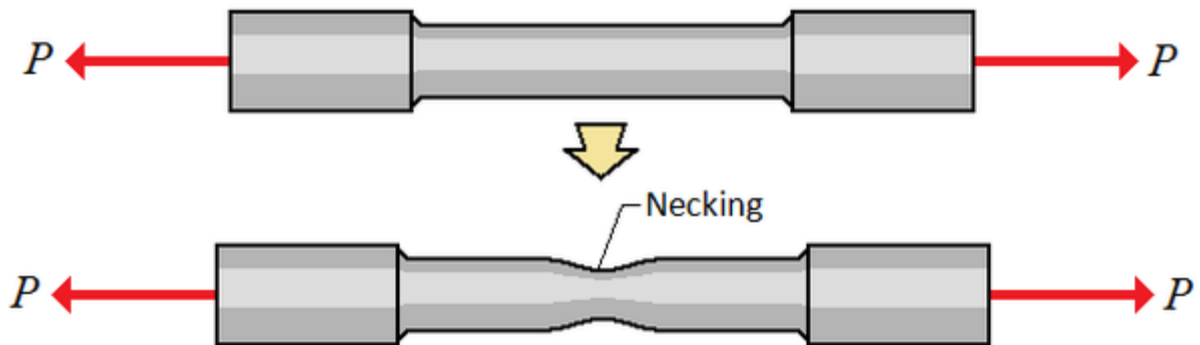


Figure 20 the correct way in which the specimens are meant to brake in the tensile test. (Fais, 2016)

From figure (20) we can see that if both forces applied either side are equal and in exact opposite directions, we will see the specimen brake from the middle (necking). From the tests that have been conducted with the current collets, we can see that is not the case.

Current collets.

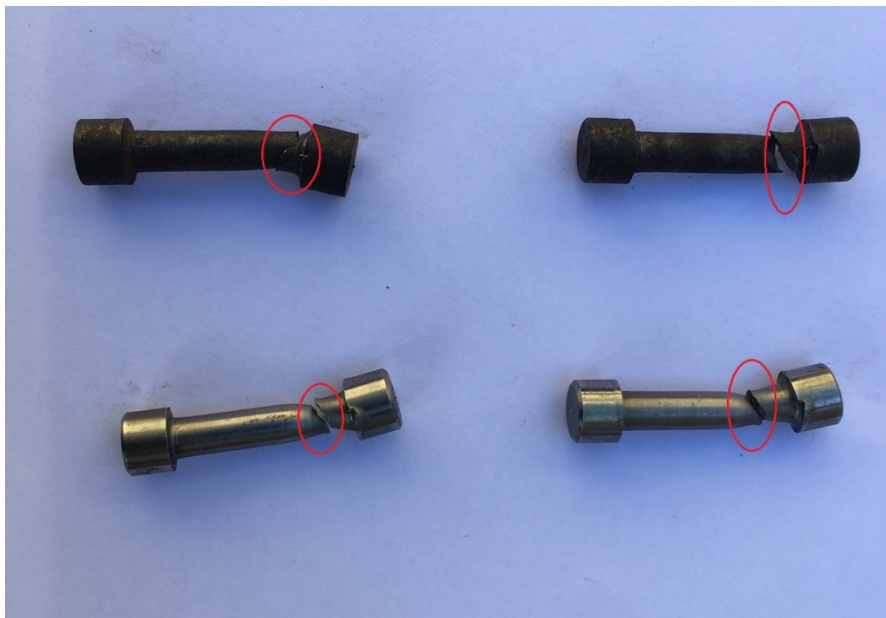


Figure 21 these are specimens that were tested with the faulty collets (Fadul, 2018)

From the figure above, we can see that the necking was not happening from the middle of the specimens; they were happening from the side with the faulty collets. It didn't appear on the side where the other set of collets were set.

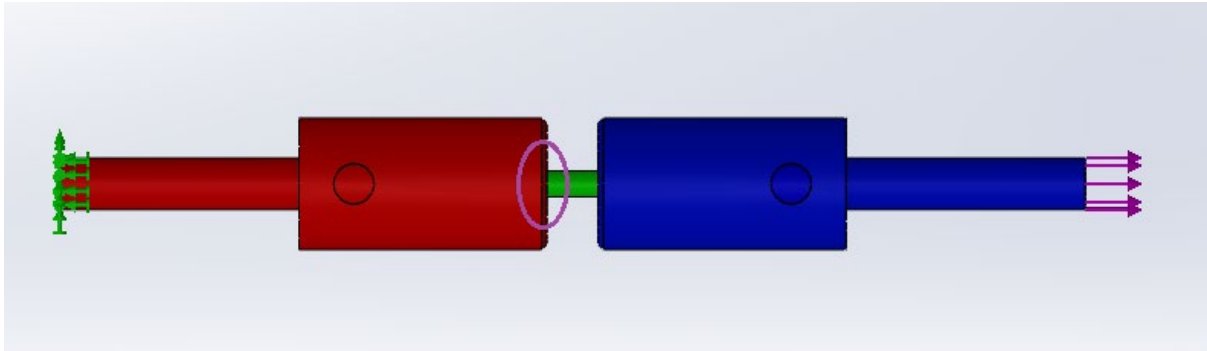


Figure 22 basic diagram to show how the Hounsfield machine would be set up.

This is a basic diagram made to represent of where the specimens were failing originally;

The red section represents the side that used the bad set of collets, the blue section represents the side that used the good collets. The specimen is highlighted in green in the middle of the red and blue section.

The purple circle is where we want to focus; this is the side where the failure occurred in figure(23).

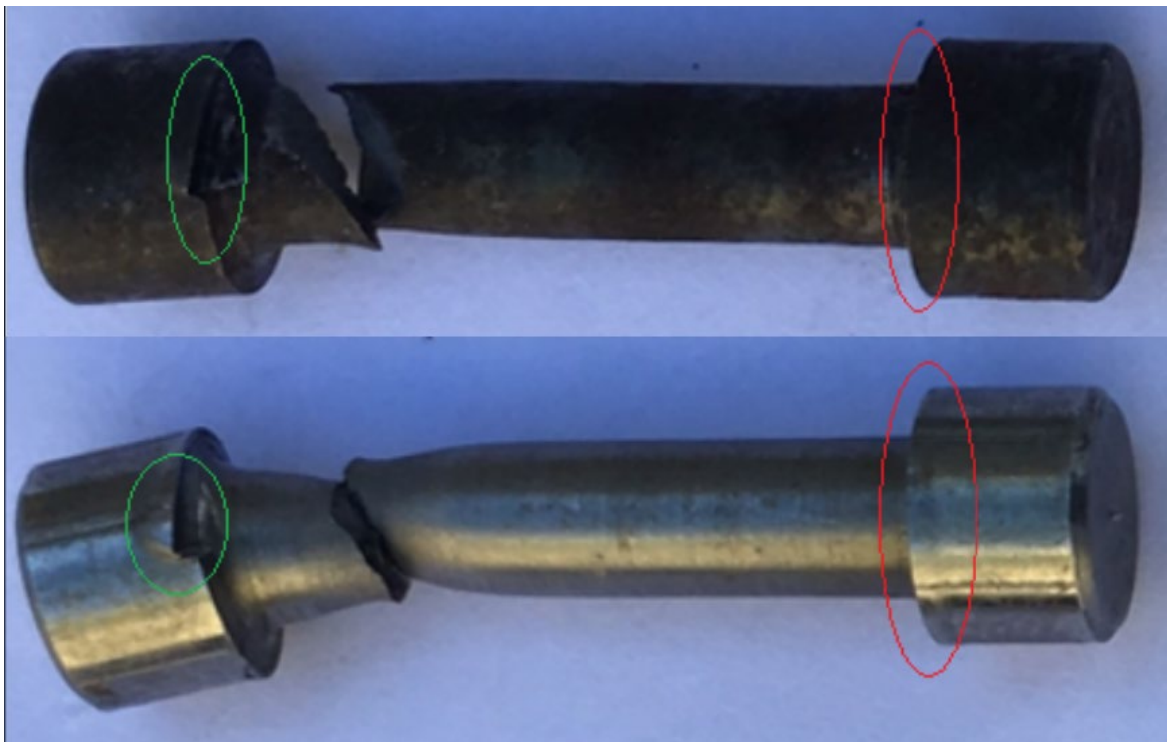


Figure 23 marks from the collets not performing correctly. (Fadul, 2018)

This is one specimen from the same tensile strength but when we compare the red circles to the green circle, we can see a clear different; the red circles show us how the specimens

New collets.



Figure 24 specimens after changing the collets. (Fadul, 2018)

In the figure above, we can see the specimens are breaking in the pattern or in the way that we want; this proves to us that the collets are now sitting flush, and we are no longer having the issue we had with the previous set of collets.

Interpretation.

After analysing the Hounsfield collets, we have determined that the collets were at fault; with this knowledge we can now take this forward into the design considerations. This will help us determine what is required for the new jig for the Denison machine. All the design considerations will be further discussed later into this report.

We are unsure as to why the collets failed with the Hounsfield machine, it could be down to; user error (testing a material these collets are not suitable for), storing the collets incorrectly which could have caused a weakness within the collets, if it is purely down to a design flaw, if it was down to purely wear and tear, or if it was this specific set of collets.

This gives us an insight as to what we need to focus on and take precautions against happening again, with this information we can “over engineering” them and help us set limits as to what materials can and cannot be used with our new set of collets as this is integral to the new jig for the Denison.

Design considerations for collets

Our final goal is to have a working jig where we can test the specimens from the Hounsfield machine on the Denison machine; This process will be carried out with the use of an AutoCAD application; all stages will be fully analysed and justified in their contribution to our end goal.

The Hounsfield machine has two different collets;

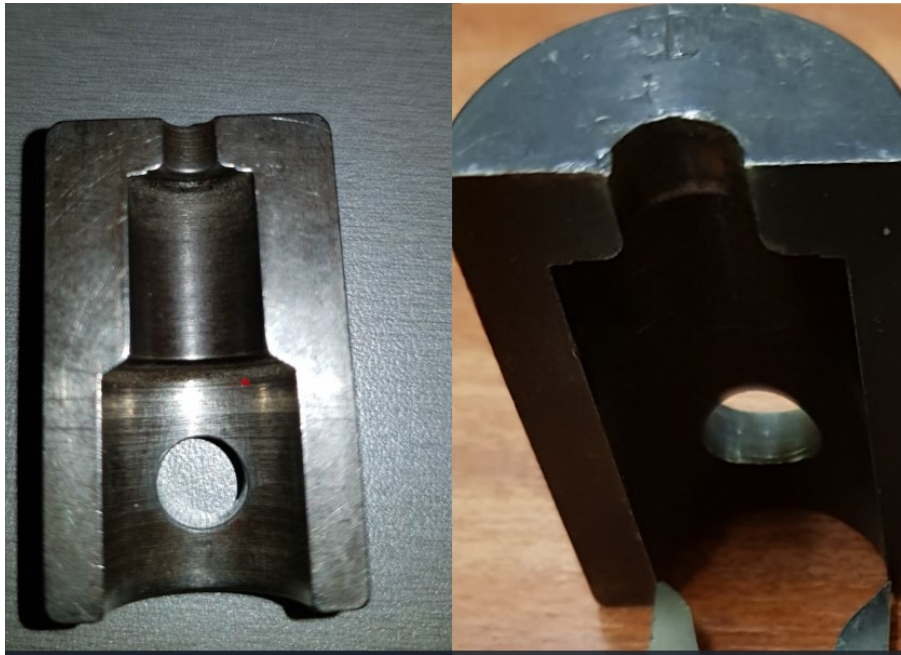


Figure 25 The two different collets for the Hounsfield machine.

The collet on the left is the same type of collet that we previously analysed, and the collet on the right is from a different set of collets; these collets are from the same machine and mount in the exact same way.

We chose to improve on the design of the collet on right, as we saw it as a better candidate for improvement; it offered us a better platform to improve up on, and all design considerations will be discussed and justified later in the report.

All design considerations will be mocked up and ran through a SolidWorks simulation to test the design for any issues or any further improvements which could be made. All relevant results will be presented and interpreted to ensure we are making the correct decision in the next step.

Design considerations for main body

Although we will not be redesigning the collets which we originally analysed, we can still address the issues and points of failure we found; we chose to go with the second set of collets as it better accommodated the design improvements we would like to incorporate into our designs which would help us avoid or lower the chance of the points of failure reoccurring.

After investigating the Denison machine mounting points, we started to develop a main body for the new design;

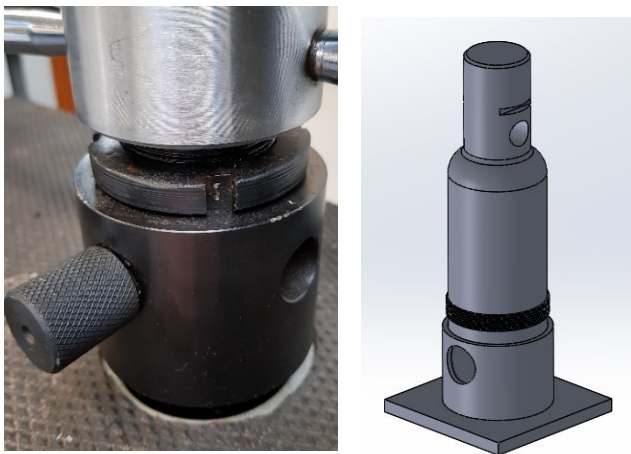


Figure 26 Mounting points on Denison machine (original-new).



Figure 27 mounting points on the Denison Jig (original-new).

From figures (26,27) we can see that the main body is designed to be similar to the original jig mounting points; the reason we wanted to keep it the same as the original is because it is already very effective and also with this decision, there would be no additional work needed to be done to the mounting point on the Denison machine. Therefore, it would allow the Denison machine to remain interchangeable without having to disassemble the mounting point and re-adjust it only for the new jig.

Design consideration 1

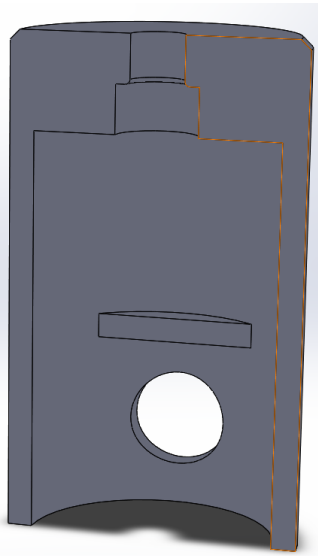


Figure 28 new collet first design

When designing the collets for the new jig the first issue we wanted to address was the rotational force and motion that caused the divot in the pin hole of the original collets we assessed. So, to counteract this motion; we added a notch to the inner face which would wedge into a notch in the main body of the jig, the contact between the notch on the inner face of the collet and the main body would counteract any rotational force caused by possible slippage of the specimen whilst under stresses. We also made the lips which meet the specimen deeper to ensure a snug fit and reduce movement whilst conducting the tensile test.

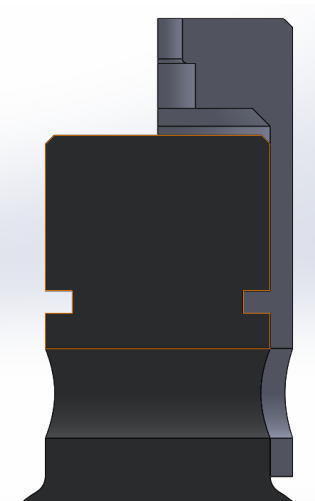


Figure 29 New collet sitting into the new main body (from a later design, only for demonstration).

In figure (29) we can see how the collet would line up with the main body of the jig; with a set tolerance of $\pm 0.02\text{mm}$ it would limit the travel and movement of the collet significantly.

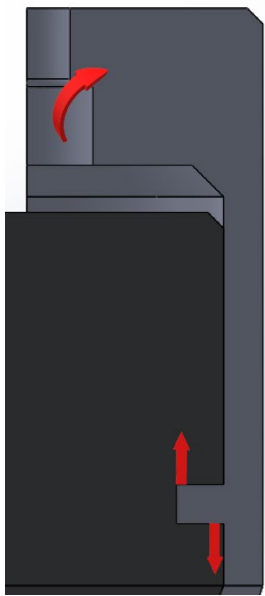


Figure 30 visual representation of how the 'notch' works (from a later design, only for demonstration).

From the red curved arrow at the top of the collet we can see the force being applied is at an angle; this is causing the collet to shift slightly. From the two arrows around the notch, we can see where the notch would be contacting the main body of the jig, and this should limit the movement significantly.

Design consideration 1 FEA

This is the first design considered, we added the notch and changed the depth of the lips. We will subject this jig to the same forces seen in the Hounsfield and have the exact simulation.

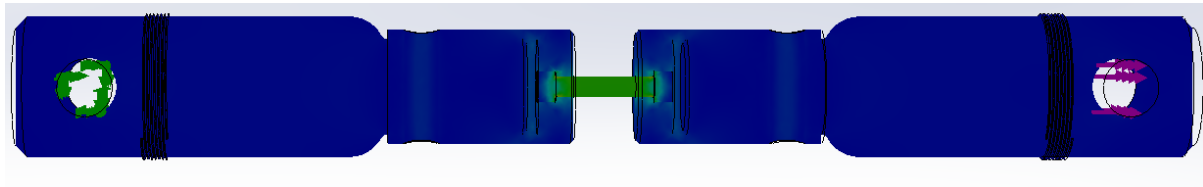


Figure 31 Denison jig design 1 simulation

Due to having to combine the parts together, we cannot see the effectiveness of the notch as Solidworks see this as one big part.

We have set this simulation up to run the same as it was with the Hounsfield machine the fixture, force, the contact sets, and the plot values.

Results

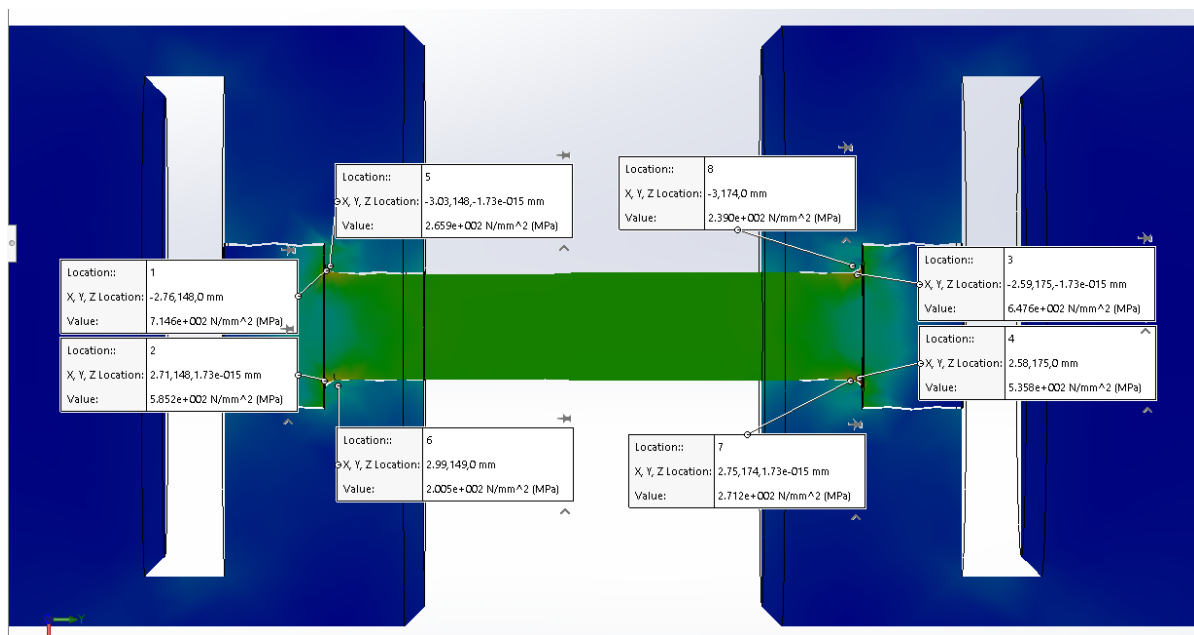


Figure 32 Stress probes on jig design 1

Probes 5, 6, 7 and 8 are the probes on the lips of the collet, from the values presented in the probes we can gather that the highest of all the stresses acting on the collet is $2.712 \times 10^2 \text{ N/mm}^2 (\text{MPa})$; this translates into $271.2 \text{ N/mm}^2 (\text{MPa})$; this to us is useful as we can determine we are well within the limits of the model, the yield strength of this material is 602.5 MPa .

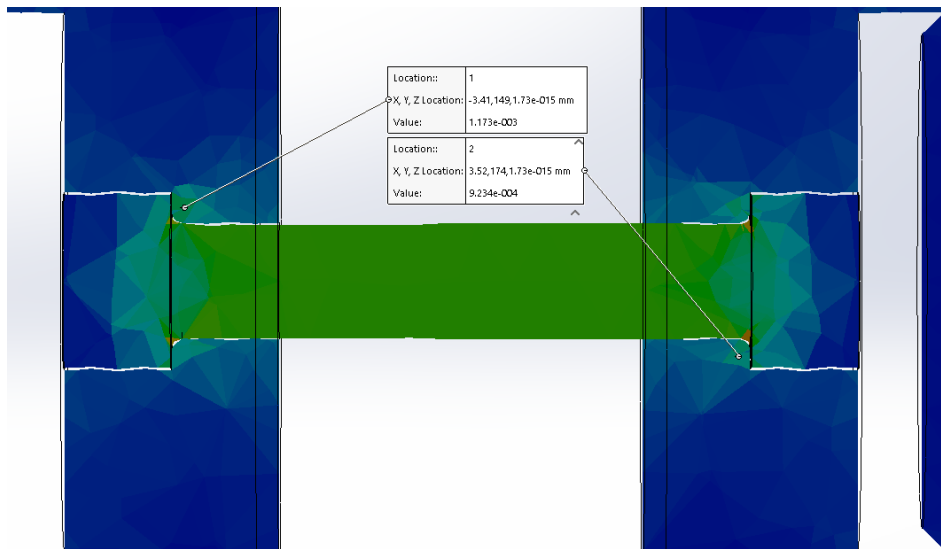


Figure 33 Strain 1 plot for Denison jig design 1

The strain plot for the Denison jig design 1 also showed us no reasons for concern around the lips of the collet, the values are so minimal they are of no concern.

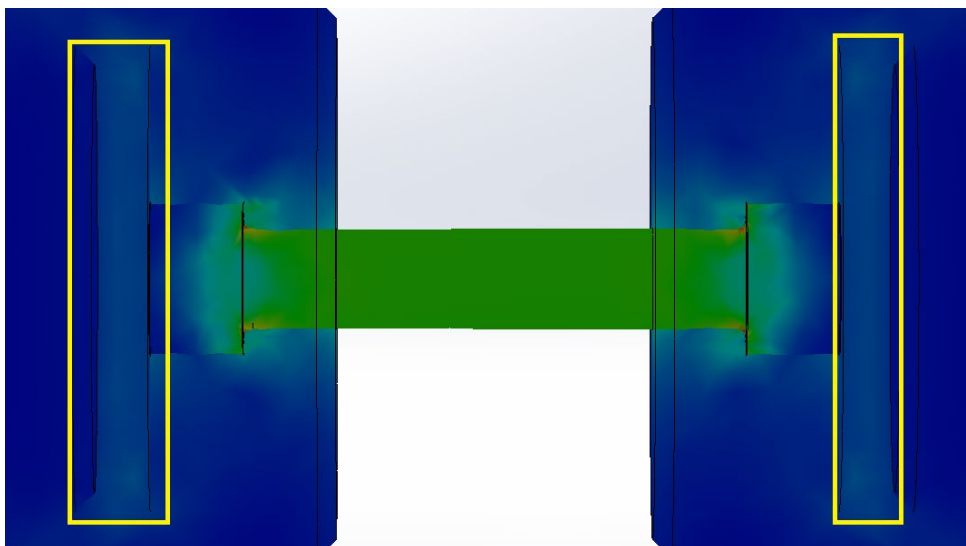


Figure 34 strain plot 2 for Denison design 1

However, the strain plot brought out our attention to the areas within the yellow rectangles, the strain in these areas could be problematic, they start from the ninety-degree angle; this confirmed our suspicions about the inner lip of collet that was discussed in the design considerations.

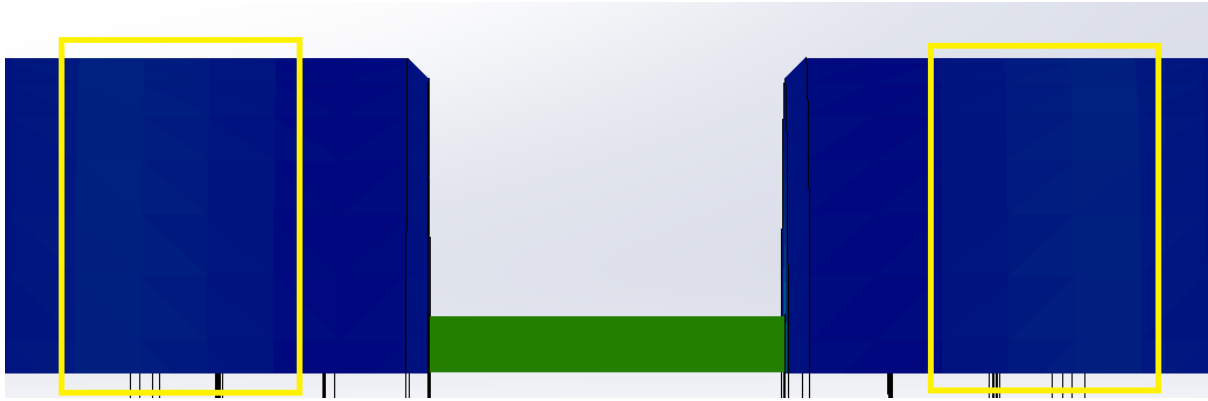


Figure 35 Back side of collet

In the yellow rectangles we can see that the strain is apparent through the back side of the collet, it is very faint but still needs to be taken into consideration. Although the strain is minimal, this could be problematic later when it is being used; if it causes the collet to fail it could be an issue, with the forces being used in tensile tests if it was to fail it could potentially hurt the user and destroy any other equipment.

Interpretation

The design of the Denison jig is good, but there are a few minor details that allow us to further improve on this design. The main body of the Denison looks to be performing as expected.

Design consideration 2

Inner lip of collet

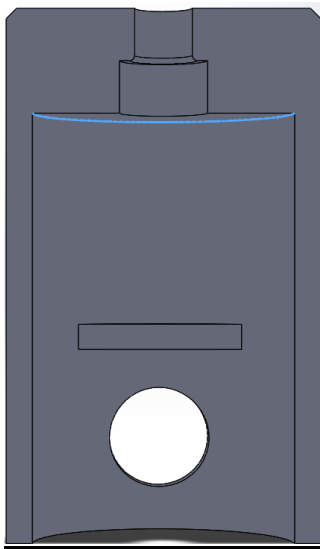


Figure 36 Weak inner lip(blue) of first collet consideration.

One concern with the first collet we considered was the lip highlighted in blue, with all the force being transferred downwards from the lips which hold the specimen, this would be a weak spot as it would easily deform under the upper limits of the collets capabilities.

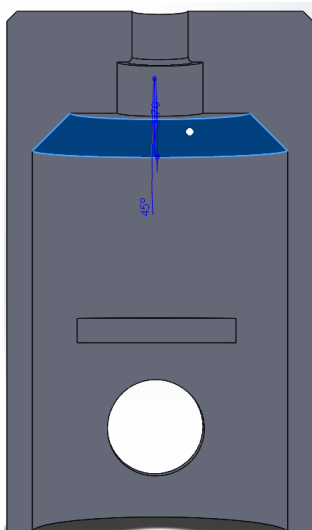


Figure 37 second collet consideration

A chamfer was added to better distribute the load and add rigidity to the structure of the collet; with a 90° angle on the first consideration for the collet, the risk of deformation is greatly increased. By adding a chamfer instead of the 90° angle we can reduce the risk of it deforming in that area and it also allow us to distribute the load more evenly across the entirety of the collet instead of a large amount of the load having to pass through a single lip.

Design consideration 2 FEA

In the second design, we added a chamfer to the inner lip to add a structural rigidity to the lip that is seeing strains. The main body was also bored through the centre to reduce the amount of material being used if it was to be produced.

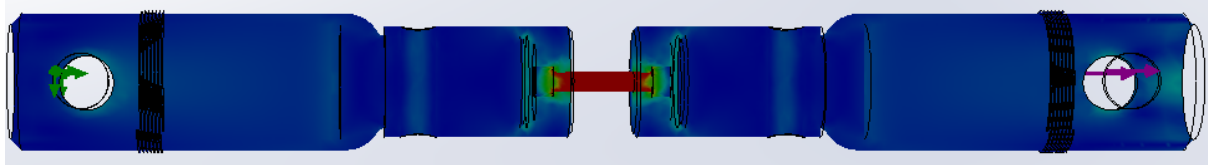


Figure 38 Denison jig second design setup.

The set up for this was a little different to the first design, the fixtures and forces applied was applied to two different pin holes rather than a solid channel. We tried to keep this simulation as close to the previous ones to be able to receive similar results.

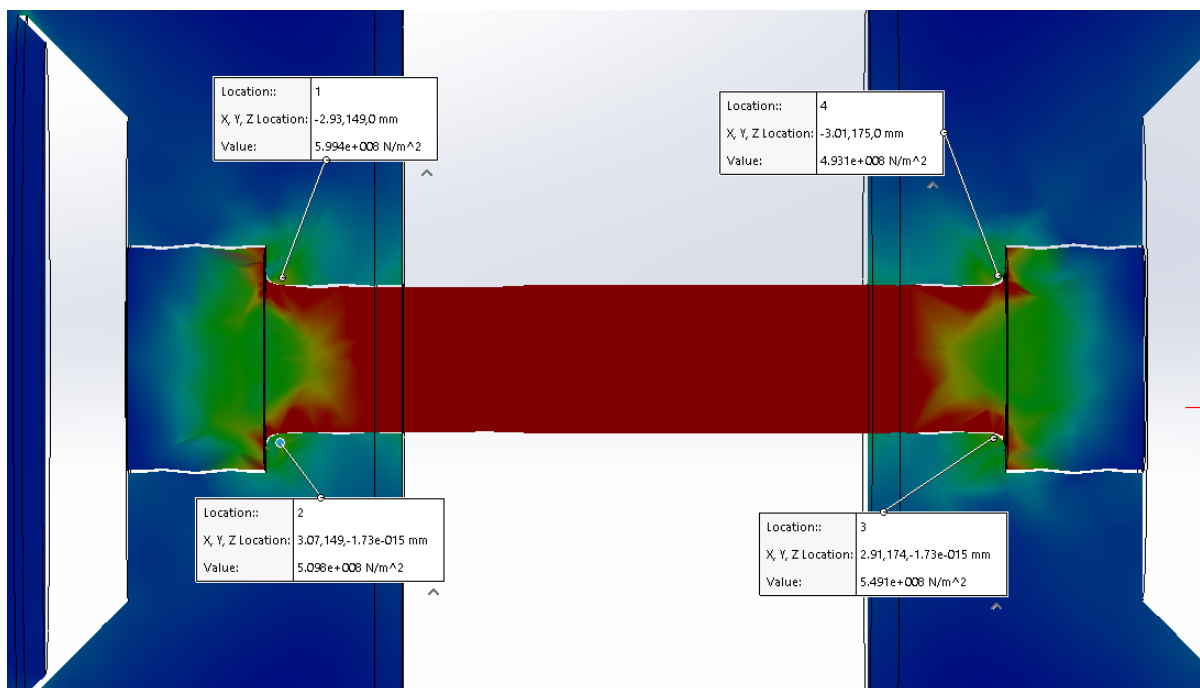


Figure 39 Denison design 2 stress plot.

We can see from the stress plot that the forces are more predominant in the lips of the collets now than before; this is down to the chamfer that has been added to the inner lip of the collet. This doesn't allow the collet flex and distributes the force better by having it spread over a small section rather than a single edge.

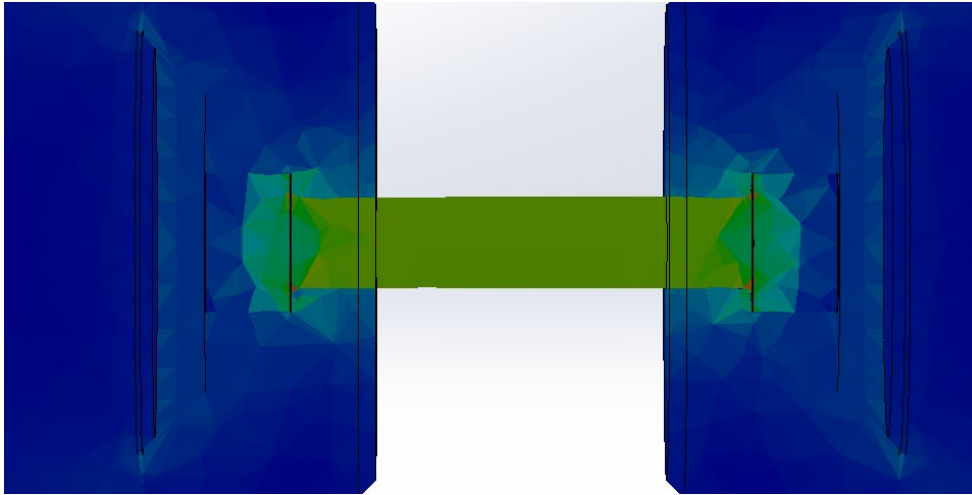


Figure 40 Strain plot for Denison design 2

This shows the strain being distributed more evenly throughout the area of adding the chamfer, this should relief the lip of a lot of stress and strain.

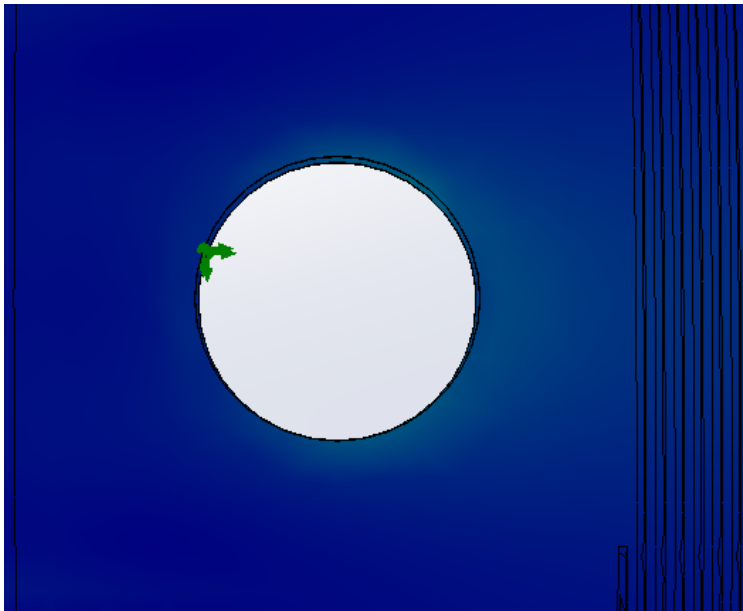


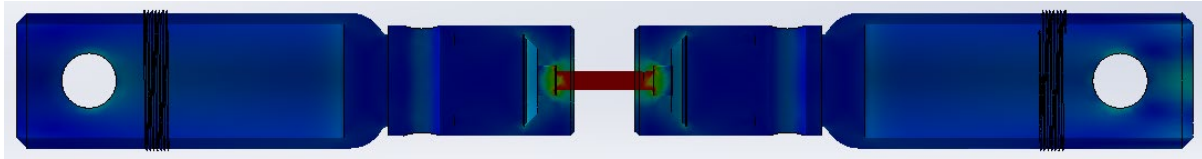
Figure 41 Pinhole stress plot.

After boring the centre of the main body, we can see that the stresses have not greatly increased and what has changed is minimal.

Interpretation

After adding the chamfer to the lip and boring the centre of the main body we can see that the distribution of load has changed drastically; the forces that are meant to be against the lip of the collet are now apparent and are remaining in the area where the specimen is pressed against the collet.

Final design for the Denison jig



This simulation will be different for the final jig, we will be simulating the jig in an assembly; This will tell the software that all the parts are individual parts and not one big part. This will give us more accurate results.

When putting together an assembly for simulation, every mate and restraint added will influence the results; therefore, when running a simulation for an assembly; attention to detail is key, if one mate is unnecessary or incorrect it can give you inaccurate results; they may look realistic and feasible, but the slightest error can change all the results.

For this simulation, the same materials, fixtures and forces will be used; the biggest difference is the restrains. There are now 7 parts in this simulation as opposed to 4 in the previous simulations.

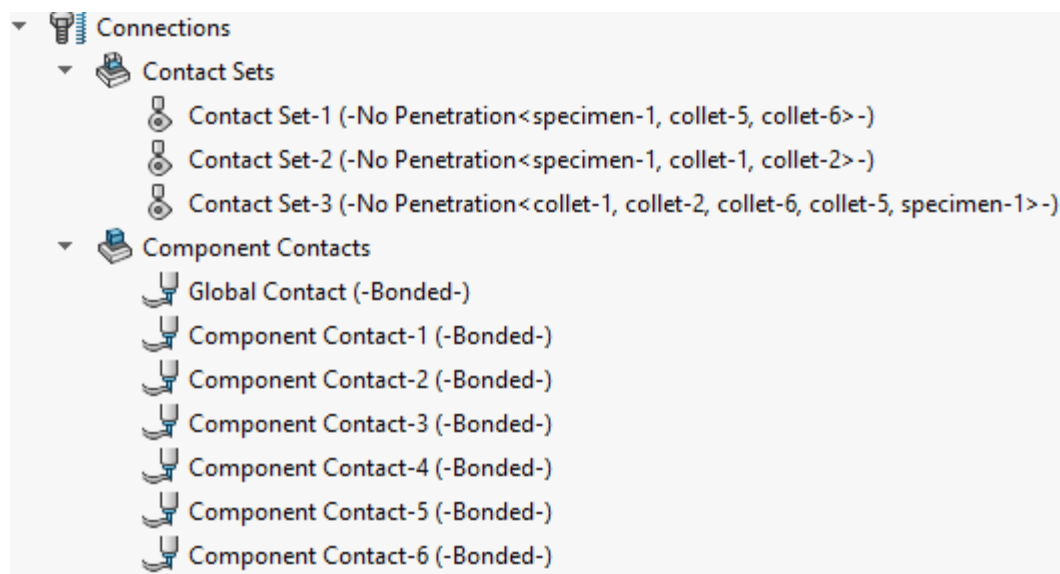


Figure 42 Restraints for assembly.

The contact sets remain the same and restrict the specimen from penetrating the lip. However, the component contacts are added between the inner faces of the collets and the main body and then added between each collet in the set to simulate the collar which would hold them to the main body.



Figure 43 Stress plot for Denison final jig.

As we can see from probe location 1 we are just passing the yield strength; for the testing of the samples provided to us we wouldn't see forces this great. The forces used in this simulation are just a guideline as to how much the jig would be able to handle.



Figure 44 Strain plot for Denison final jig.

As we can see in the stress plot, the strain has increased greatly in comparison to the simulation of the Denison design 2. This also matches up with stress plot; the increase on both plots confirms that we are starting to see higher pressure in the lip of the collet.

Interpretation

After running the simulations for the final jig, we can see we are now passing the yield strength limit; this is another reason as to why we decided to run a simulation in the form of an assembly. When running an assembly there are many more factors that come into play, and if all the inputted information is accurate/correct then it makes for a more accurate result.

Finite element analysis (FEA)

FEA is a method of solving mathematical equations usually approximations, mainly used for problems with no exact solution, usually expressed in a mathematical series of equations (Modlen, 2008). This helps us obtain an understanding as to why/how certain parts/components react in a certain environment with certain loads and displacements present.

FEA is usually integrated into a computer aided design (CAD) package; this allows the user to easily access it without having to worry about converting different models or equations to different formats.

Prior to the use of FEA the user would have developed a model on an AutoCAD package; this will dictate the accuracy of the final results.

The FEA process is split into three sections; (Roylance, 2001)

- ❖ Pre-processing: At this point the model developed by the user will be broken down in to small regions typically known as 'finite element' or just 'elements', the size of the element will be dictated by the user (assuming compatibility with the proposed model); Each of these element will be connected at a given point called 'nodes', certain nodes will contain fixed displacements and some will contain prescribed load, these values will depend on the users FEA setup. This process is called "meshing". Some CAD packages will contain a software that will give you the option to have a mesh optimised to what level or accuracy you want in your model.
- ❖ Analysis: At this point, the CAD software will be generating equations (usually differential or partially differential equations) using the 'finite element code' being used by the company who has generated the software of use. The software will then input the variable gathered form the model and the values entered by the user, this will then generate a series of wither linear or non-linear equations. An advantage of FEA code is that many types of problems can be solved/approximated with a single code.
- ❖ Post-processing: At this point, the used will see a graphical display which will contour the different stresses and strains; depending on the software package the user will be shown an option of plots, each plot will represent a different aspect of the model being analysed (these plots can be defined by the user). There are also options that allow the user to view the different equations used and to view the desired values in a numerical value (charts, tables, reports etc. can also be developed).

Conducting FEA

For This stage of the design process, we used a software package call Solidworks; at this stage we modelled all of design considerations and ran them through a simulation (FEA).

All information used in these simulations are as accurate as we can possibly make them; from the materials to the setup of the simulation, this will allow us to retrieve the most accurate results for analysis.

Software package

Solid works is a CAD package that helps engineers visualise models in 3D and 2D without any complexity, quicker and in a cost-effective manner. Solidworks allows us to not only visualise but run motion simulations whilst adding many different variables from surface texture to gravity. It allows us to achieve very accurate approximations on our simulations, which in turn will allow us to prototype in virtual space.

Material selection analysis.

In the process of designing a new product there are multiple stages to go through before we can come to a decision of what material we chose; we must consider all the element of the material and what are the most important properties to us, that can be the cost or the stiffness of the material. We must analyse the use of this product to determine our requirements, which has been discussed earlier in the report.

For the material selection, it will be carried out in 4 steps; (ASHBY, 1999)

- Requirements: Determination of what the requirements are for the material based on the information we have and any assumptions which will be made.
- Preselection: In this section we will rule out any “class” of materials which will not be used for this application, or any specific material we won’t use for clear reasons.
- Fine selection: This section will compare the few materials we are left with; this will focus on the fine details such as (cost, machinability) and weigh up the pros and cons of each of the materials.
- Selection: This will be the final section which will be our final choice of material for the application at hand. This section will contain the reason we have chosen the material; this will justify why we have chosen this material and what it offers us in this application for the material.

Material details and assumptions

The requirements for this material depend on many factors; This product is being used for tensile testing, but what will it be testing? What are the factors we need to consider? Etc.

We need a guide line for the limits of this product which will depend on; what are the samples we will be using? We can design a jig to test a 25% hardened steel; but this isn't what we require, if we use the best possible material available to us it could run up costs and it is unnecessary.

These are the 3 samples we will be testing with this jig.

1 N/mm ² is exactly equivalent to 1MPa

Plain carbon steel, cold drawn

- Tensile strength: 460N/mm² / 460MPa
- Yield strength: 310N/mm² / 310MPa

60/40 Brass

This brass is called 60/40 brass because it is almost entirely made up of copper (58%) and zinc (39%) with only 3% lead.

- Tensile strength: 410N/mm² / 410MPa
- Yield strength: 200N/mm² / 200MPa

Aluminium

- Tensile strength: 290N/mm² / 290MPa
- Yield strength: 250N/mm² / 250MPa

In this case we will be designing this product purely around these samples; with the information we have above, we know the maximum tensile strength and yield strength of the materials we will be testing; but we also must consider what other factors come into play when running a tensile strength test.

When running a tensile strength test we must consider the hardness of the material and the stiffness of the material alongside the tensile and yield strength as these are the core factors that may affect the performance of the jig; as we have seen in the analysis of the original Hounsfield collets, we saw a divot on the inner edge of the pin hole and excess ware on the lip of the collet where the specimen sits whilst under tension. Although we are unsure of the

cause of this, we can take this into consideration and try to design it not to fail in such a way or reduce the chance of this happening again.

From the three samples we will be testing the 'plain carbon steel, cold drawn' is the strongest/toughest so we will use this as our base line for the requirements. We will be able to acquire the guidelines for the material requirements for our final material using the information and assumptions which will be made.

We have been given the tensile and yield strength for the material but not the full data sheet, so we have found a very similar material which is "AISI 1018 steel, cold drawn" the information available for this material is as follows;

AISI 1018 steel, cold drawn

- Tensile strength: 450MPa
- Yield strength: 310MPa
- Hardness: 136Hv (Vickers hardness test)
- Modulus of elasticity: 200GPa

These are the four variables which were relevant to us in the data sheet; the tensile strength is 10MPa off our 'plain carbon steel, cold draw' whilst the yield strength remains the same. The reason we wanted this information is for the hardness of the material, the hardness of this material scored 136Hv in the Vickers hardness test, and for the modulus of elasticity.

Tensile strength

Tensile strength is defined as the maximum tensile load a component or body can handle before failing or breaking, this force is a force trying to stretch the material. This is sometime known as ultimate tensile strength (UTS).

The equation for tensile strength is as follows

$$\sigma = \frac{F}{A}$$

Where σ is the tensile stress, F is the force being applied at failure, and A is the original cross-sectional area. (Roylance, 2008)

Yield strength

The yield strength is defined as the stress at which a predetermined amount of permanent deformation occurs, or a point on the stress-strain curve where there is a sudden increase in

strain but not an equal increase in stress. The yield strength is usually the stress at which the material's deformation moves from 'elastic' to 'plastic' and this occurs before complete failure is reached (tensile strength). (Roylance, 2008) This gives us an indication as to how much load the material can withstand before deforming permanently, but not failing completely.

Hardness

The basic principal with a hardness test is to observe a materials resistance to plastic deformation. With regards to the hardness we will be referring to, it will be measured in the by the Vickers hardness test. This will allow us to understand how resistant the surface of the material is to indentation or ware.

The Vickers hardness test is conducted in this manner; indentation of the material with a diamond tipped indenter, the shape of the indenter is very important to us; it is a square based pyramid, so we have very identical indentations, so we can compare between them. The indentations are done at an angle of 136° and are subjected to a force between 1gf and 100kgf. The full load is usually applied between 10-15 seconds and sometimes can be for longer, and if it applied for longer then it will be mentioned in the final value. The diagonal lengths are measure with a microscope and averaged. After this, the area of the sloping sides of the indentation is calculated; The Vickers hardness is then obtained by dividing the load applied by the area on the indentation. (Rebouças Filho, 2010)

The hardness of the material is important to us as it is an indicator to us as to how easy the surface will scratch which will allow us to maintain the surface finish we chose or require. This will also allow us to determine if the specimen has the capability of creating divots in the collets whilst in use.

Modulus of elasticity

The modulus of elasticity is equivalent to the young's modulus; this measures the stiffness of the material and therefore is one of the most important properties of a material.

This is equivalent to the stress applied divided by the elastic strain.

Material requirements

Therefore, based off the information we have now, we can set an outline for the requirements of the materials we can/will consider. The requirements for this specific application of material would require a material which would be able to withstand these stresses, strains and should either match the hardness and modulus of elasticity of our samples or be greater.

Tensile strength must be greater than 460N/mm^2 / 460MPa .

Yield strength must be greater than 310N/mm^2 / 310MPa .

Based off the similar material we found (AISI 1018 steel, cold drawn);

The hardness of the material must score higher than 136Hv in the Vickers hardness test.

The modulus of elasticity must be either equivalent or greater than 200GPa .

Preselection

During the preselection phase of the material selection we will be identifying which materials will not be compatible for our product. We will look at the different classes of materials (polymers, enhanced polymers, ceramics etc.) which we wouldn't consider for this application. (ruling out)

Polymers and enhanced polymers

These materials are unsuitable for this specific application as they have low moduli of elasticity; Epoxies have a high tensile strength and excellent hardness properties, but a low modulus of elasticity; this means it will deform under relatively low forces, and this isn't suitable for this specific application.

Ceramics

Ceramics are predominantly made up of ionic bonds; this means that the atoms in the molecular structures cannot easily move past each other. So, when they do tend to move they develop a fracture which then continues to grow, and we stress the material more. This is why ceramics are considered to be brittle and metals to be ductile.

These are the two main 'classes' of materials we needed to address, although there are some polymers and ceramics with tensile strength's and hardness's that may outperform our final material we select, we must have a material that is applicable to our application.

There are many more classes of materials that we can consider; but the main 2 are those above, these materials are widely used, and engineers are trying to incorporate them into many different applications, but unfortunately that wouldn't be possible in this instance.

Fine selection

For this section we will review the materials we have found that would fit for our application; for this selection of material selection we used an application called CES selector EDUpack, this application contains a thorough database of materials and processes information. This application also contains references to all the information they have and if there any assumptions or approximations made, they will be noted and justified. This application allows us to search for materials based on material properties; this has a large range, from tensile strength to thermal expansion. With this tool, we can narrow down thousands of materials to a select few based on how specific our search criteria is.

In this case, our search criteria is fairly simple; we based our search on our requirements which were;

Tensile strength must be greater than 460N/mm^2 / 460MPa .

Yield strength must be greater than 310N/mm^2 / 310MPa .

Based off the similar material we found (AISI 1018 steel, cold drawn);

The hardness of the material must score higher than 136 in the Vickers hardness test

The modulus of elasticity must be either equivalent or greater than 200GPa .

After we ran our search we found approximately 13 materials; not all of these materials were suitable for our application, some of the materials were far more than we required which also increased the price. For example;

Tungsten Alloy

Price	①	* 46.7	-	47.9	GBP/kg
Young's modulus	①	310	-	380	GPa
Yield strength (elastic limit)	①	525	-	800	MPa
Tensile strength	①	720	-	3e3	MPa
Hardness - Vickers	①	280	-	600	HV

Figure 45 material properties for Tungsten Alloy

As we can see from figure(X) all the mechanical properties meet our criteria and exceed it; but the price is very expensive. In comparison it is approximately 95 times the price of all the other materials on the lower end and almost 90 times the price of all the other materials on the higher end. (more expensive per kg)

The reason we chose this Tungsten as an example is because it is a very well-known material. Also, it wasn't the cheapest material that came up within our search results; this gives us an indication of where the cheaper materials would be priced and where the mid-range to higher range prices lie. This shows us why it is important to understand where our limits are in regard to what we require.

Four materials were taken into consideration after eliminating the materials that we know would be out-of-reach, mainly due to the cost justification; in this case, the properties of the other materials along with the Tungsten Alloy would have been suitable for this application but would have been 'overkill' and too expensive.

The materials taken into consideration are;

- Low carbon steel
- Medium carbon steel
- High carbon steel
- Low alloy steel

the properties of each are as follows;

Low carbon steel (table 1)

	Values	Average	Units
Tensile strength	345-580	462.5	MPa
Yield strength	250-395	322.5	MPa
Young's Modulus	200-215	207.5	GPa
Hardness	108-173	140.5	Hv
Cost	0.493-0.531	0.512	GBP/kg

Medium carbon steel (table 2)

	Values	Average	Units
Tensile strength	410-1.2*10 ³	805	MPa
Yield strength	305-900	602.5	MPa
Young's Modulus	200-216	208	GPa
Hardness	120-565	342.5	Hv
Cost	0.493-0.539	0.516	GBP/kg

High carbon steel (table 3)

	Values	Average	Units
Tensile strength	550-1.64*10 ³	1095	MPa
Yield strength	400-1.16*10 ³	780	MPa
Young's Modulus	200-215	207.5	GPa
Hardness	160-650	405	Hv
Cost	0.493-0.531	0.512	GBP/kg

Low alloy steel (table 4)

	Values	Average	Units
Tensile strength	550-1.76*10 ³	1155	MPa
Yield strength	400-1.5*10 ³	950	MPa
Young's Modulus	205-217	211	GPa
Hardness	140-693	416.5	Hv
Cost	0.531-0.577	0.554	GBP/kg

All four of these materials have great hardening qualities; hardening is used to strengthen, stiffen and harden a material, this process is very useful to us; this process is used in the materials for oilrigs, skyscrapers, hardened drill bits, etc.

Hardening is the process of heating up the steel to the point where carbon is able to dissolve into the steel (usually around 800°C), then dropping or dipping (quenching) the part/component into a liquid (usually water or a specific oil which will reshape the molecular structure). Once the component has been quenched, it is brittle and known as 'martensite'. The part is again heated, but to a lower heat and kept at this temperature, this happens for a certain amount of time (tempering); depending on the heat and the length of time for tempering, it will restore the toughness, stiffness and bring down the hardness of the material; this is very good for engineers, because we can control the heat and duration of time to achieve the properties we desire.

Comparison

This 'class' of steel is some of the most widely used hardened materials we see in our day and age; Carbon steel is becoming one of the most widely used steel's in the construction industry, from construction of buildings to the crane which builds them; The core support which erect these structures to steel beams to reinforce the concrete, this class of steel is becoming more apparent in the applications across all engineering industries from automotive to aerospace.

Due to the 'hardenability' of carbon steel this makes it useful to make core supports and even rolled sheets of steel. This material is readily available and very cheap in comparison to its alternatives which may be used for applications that vary away from ours.

In the case that we are reviewing, we aren't concerned with the operating temperature as we will be conducting our tensile tests usually at room temperature. The most important information to us is the mechanical properties; this will dictate to us the applicability of this material for our part.

(All values used in this section will be averages seen in the tables (1, 2, 3, and 4))

Low carbon steel

Low carbon steel meets the requirements and just exceeds it.

Low carbon steel usually contains less than 0.25% carbon, meaning the hardening process for this material is easier to conduct than that of high carbon steel.

The hardness however is not much greater than that of our original, on average Low carbon steel only scores 4.5 more than our sample, and this could prove to be problematic in the long-term use of our product.

Medium carbon steel

Medium carbon steel meets our requirements and exceeds them by a fairly large margin; just under double the tensile and yield strength.

Medium carbon steel usually contains between 0.25%-0.7% carbon. This allows the steel to be hardened more, but this means it will take more time when hardening; as this process must be precise to meet our desired properties.

The tensile strength and yield strength are just under double our requirements; this will give us a great amount of room to what the limits of this component or part could/shall be. The Young's modulus also exceeds what we desire although not by a large margin, it will be able to handle the stresses and strains present in our testing. The Vickers hardness score exceeds our requirements by 206.5 which can be very useful to us in our application.

High carbon steel

High carbon steel exceeds our requirements by a very large margin; the properties the high carbon steel presents is far more than we require.

High carbon steel usually contains between 0.5%-1.7% carbon. This allows the steel to be hardened by a substantial amount, but this also presents an issue known as 'uneven-hardening' this is where too much carbon has been presented to the material that is trying to be hardened and it causes the part or component to have soft and hard spots.

The tensile strength and the yield strength of high carbon are more than double our requirements, this is great for our application; but unnecessary. The young's modulus exceeds our requirements by a small margin. The Vickers hardness is approximately triple our requirements and double that of the medium carbon steel, which again would work for us but is unnecessary in this application

Low alloy steel

Low alloy steel again exceeds our requirements by a substantial amount, this is again unnecessary in our application.

Low alloy steel can contain up to 2.5% carbon, but this is not the only thing which makes it such a strong material. Other metals and alloys can be added to enhance the properties of the material such as manganese, nickel, molybdenum, chromium and vanadium. Depending on the application of the low alloy steel, there will be different batches which may be used for

different applications on the percentage of alloys used in certain batches or by different companies.

The properties of low alloy steel fall within the same category as High carbon steel; it exceeds the properties of the high carbon steel, this makes it unnecessary for us to use. This material may be used for tensile testing materials with higher requirements than the samples that we will be testing.

Final selection

After comparing the Four materials, one of them stood out to us more for our application than the rest; our choice of material for this application is medium carbon steel and this will be discussed in further detail.

Although the Low carbon steel met our requirements; we didn't choose it because we wanted to take into consideration a safety factor the new material would have to meet, and that was 15% for the tensile strength, yield strength and hardness.

Although both the high carbon steel and low alloy steel met the requirements and 15% factor of safety they were excessive, producing our product from these materials could increase cost significantly. Because these are harder materials, we would need harder machining bits to machine with, and with the increase in the percentage of carbon and other alloys it would require a very specific order.

However, Medium carbon steel met our requirements and also exceeded our 15% safety factor; this also allows us to have a material which wouldn't cost a lot of money to machine in comparison with the low alloy steel. With that in mind, the cost of medium carbon steel is very reasonable in our application and would allow us a decent profit margin for our finished product which will be discussed further into the report.

With the properties of the Medium carbon steel, this would allow us to test other specimens which meet our safety of factor, the capability to test many more different specimens will also make it more appealing to buyers.

Manufacturing processes

When considering a manufacturing process there are many variables to consider, these variables vary from the intricacy of the product to the amount wanting to be produced. For our specific application, we know all the details except how we would produce it.

Our requirement is only a single piece of this product, so trying to make a mould of some sort would not be justifiable and would increase the time taken to manufacture our product. The material we have chosen is readily available and can be CNC machined which is a very widely available process; many small companies are based off making one off machined parts.

Although it is not a cheap process, it is a lot cheaper than having to make a mould to cast our product.

CNC machining

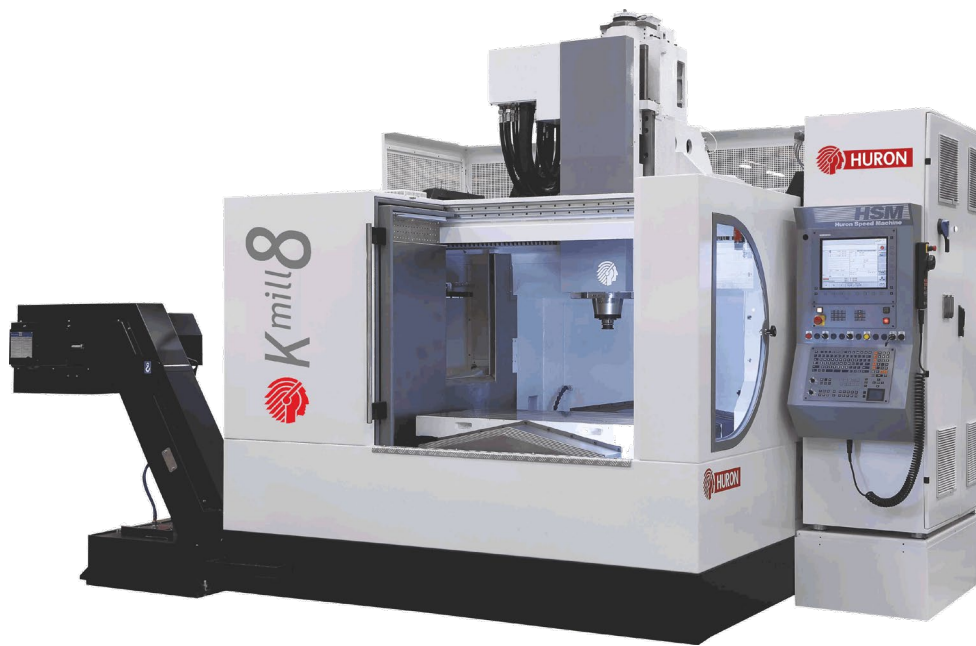


Figure 46 Huron CNC machine.

CNC machining means computerised numerical controlled machining, this means a computerised code will guide a machine that will produce our product; this could mean a mill, a lathe or a multi axis automated mill.

Modern day machining needs to be very precise, and to achieve the level of precision that is required manually is difficult, if not impossible. Doing this process manually takes a very long time, it required the user to constantly double check measurement frequently and if the user isn't experienced at machining, accuracy will be an issue.

How CNC machining works

A CNC machine typically uses numerical values that is fed to it through the machine control unit (MCU), these values are either written as a code or can be quickly developed with the assistance of 2D and 3D CAD software's. The numerical values which have been fed to the machine will then be interpreted as either a location, spin speed, feed rate or a point along the X and Y axis; the machine will then move the cutting tool to a specific location on the workpiece to begin the cutting of the model (EdiHermawan, 2017).

Advantage and disadvantages

With every process there are advantages and disadvantages, this section will discuss the pros and cons of choosing this process.

Advantages	Disadvantages
CNC machines can work 24 hours a day throughout the year and only need to be turned off for maintenance.	High start-up costs, although the price has reduced it is still more expensive than traditional manual machines.
CNC machines are consistent, the same product can be produced thousands of times and the tolerances won't change.	Maintenance costs are high.
A single person can operate multiple CNC machines, but a single person can only operate a single manual machine.	The product is only as accurate as you make it. The user input is the level of accuracy seen on the model.
A code can made on many different software platforms for the same machine.	
CNC machining is easy for beginners to learn. Manual machining requires many months/years of experience.	

For us this is an advantage; because it is such a widely used process, we can have our part made very quickly and the market price will be competitive. This allows us not be stuck to a single price, have the flexibility to negotiate and also we have the choice of many different parties.

Conclusion

To conclude, our initial suspicions of the collets being the reason for inconsistencies was confirmed by our analysis of the divot on pin hole and the ware on the lip of the collet; this was a key first step to redesigning the collets, this was a step in the right direction as we now know what was causing all the inconsistencies. This allowed us to ensure that we designed around this and hopefully avoid this issue in the future. By going through the design considerations, it allowed us to develop an initial model which acted as the foundation for us to improve upon; this allowed us to correct our mistakes and improve on our design; this resulted in us producing a jig that is suitable for its intended use. Conducting a material selection analysis allowed us to consider the options that were available; the material requirements gave us our baseline which then gave us the knowledge to gather 4 different material. From these four materials we compared and contrasted them to see which one best suited us and from that we came up with our final selection. The FEA allowed us to prove what we thought or considered to be correct; through setting up the Solidworks simulation and using accurate values we were able to determine if the jig we designed was a feasible option.

Resources

For the FEA/simulations and renderings we used Solidworks

For the material and manufacturing selection we used CES EDUpack

For the materials we also used matweb.com

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