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# Designing, Testing and Validating Collets for Tensile Testing Machine

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## ***Declaration of authenticity***

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 led to the award of a degree

Signed:

Date:

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## ***Abstract***

*This study is an investigation on wear on a collet that is used in a tensile testing machine, and how the wear can contribute to the production of inaccurate results of tensile testing. Experiments were carried out using two different types of collets and machines. One of the machines needed to be modified to carry out the experiments; the modification was achieved by designing a jig for the machine that was designed using the known engineering procedures. Also, for more valid results the collets were compared with a new set of purchased collets. The purchasing of the collet was attained using purchasing and supplied section process. The results of the experiments were compared, and the outcome was as expected in the hypothesis of the study.*

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## ***1.0 Introduction***

Many engineering applications are designed to perform as accurately as possible, to achieve good products, and determine if a defect or fault must occur. The source of the defect should be known to the operator, which will ease the repair process and trace and predict the occurrence of the problem in the future. This entirely depends on the purpose that it was designed for. Therefore, it could be argued that the two terms most crucial when using engineering measurement tools such as tensile test machines are ‘accuracy’ and ‘precision’. Tensile test provides information that is used in the design of a product, to ensure product safety and capability to carry out the job and withstand without failure. Tensile test is a mechanical test which can be divided into two types of test: quantitative and qualitative test. Quantitative testing is used to obtain data that can be used in the design process, and the qualitative test is used to obtain data that will be used for comparisons (Twi, 2017). An engineer can gain a great deal of valuable information from results obtained from such experiments. For example, the relationship between load and experimental are very different between Aluminium and Steel, therefore making sure all the experimental results are accurate will contribute to producing quality products and will provide the engineer with a good understanding of the behaviour of the different materials under various circumstances. According to (KalpaKjian, 2003), failure is one of the most important aspect of the material, because it is directly affect the selection process of the material for an application, the service life of the component, and the manufacturing method. Furthermore, there are many factors involved in the failure and fracture of materials, making it a complex area of study. Therefore, tensile test equipment must be inspected and validated at all times. This process sometimes can involve various processes to achieve such a goal, especially when a defect occurs as result of tensile testing machine usage over long period of time. (Groover, 2013) asserted that, when the machine tool is old and worn, it will perform below or above the tolerance value. However, to resolve this problem, different processes will be utilized to inspect and establish the problem, such as comparing data from two tensile testing machines using the numerical technique that includes finite element analysis and any suitable engineering method. Therefore, this study will facilitate various engineering techniques to forensically inspect wear on a collet that will be used in tensile testing.

## ***2.0 Aims and objectives***

- Identifying a problem with the collet function by investigating the effect of wear on the collet performance.

- Validate the collet function.

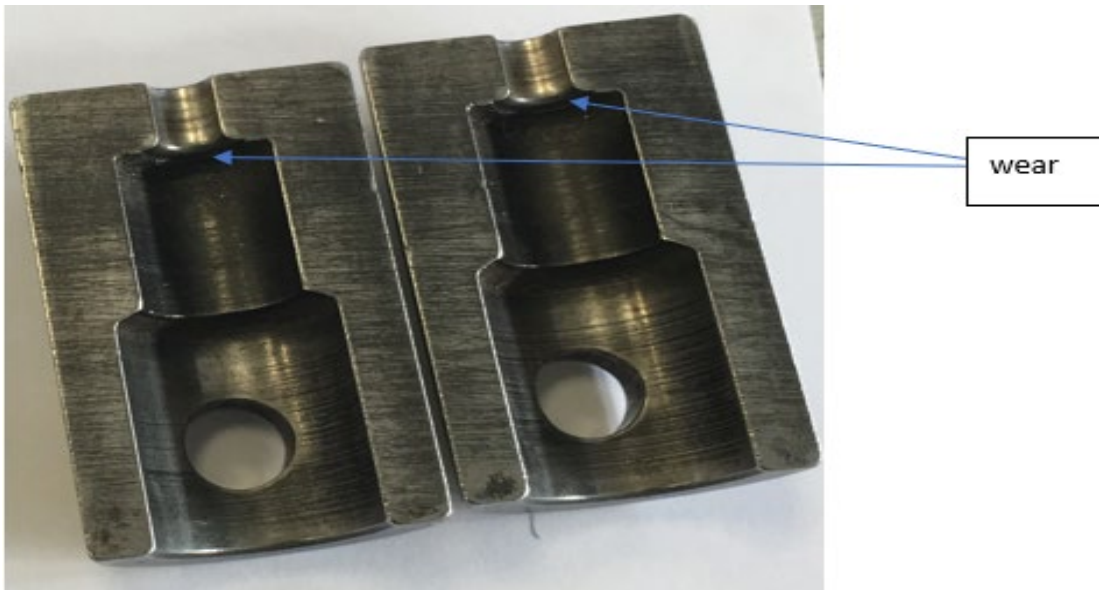


*Figure 1 shows wear on collet within the gripping area*

**2.1 Objective:** To design and manufacture a feature that will work in two different tensile testing machines, to produce accurate results which can be used in material testing for the University of Wales Trinity Saint David (Engineering Science Laboratory).

### ***3.0 Hypothesis***

Wear is affecting the performance of the collet by not allowing the collet to grip test specimens strongly enough during the tensile testing operation.

### ***4.0 Tensile testing***

Tensile testing is the process in which a force is applied incrementally to a specimen of material and, as a result, extension will occur on the specimen. This process will continue until the specimen breaks into two parts. The test is always achieved using a different types tensile testing machines. The result of the test can be plotted in a graph consisting of load against extension (Ross, 2015). The diagram below is representative of a typical graph for mild steel testing.

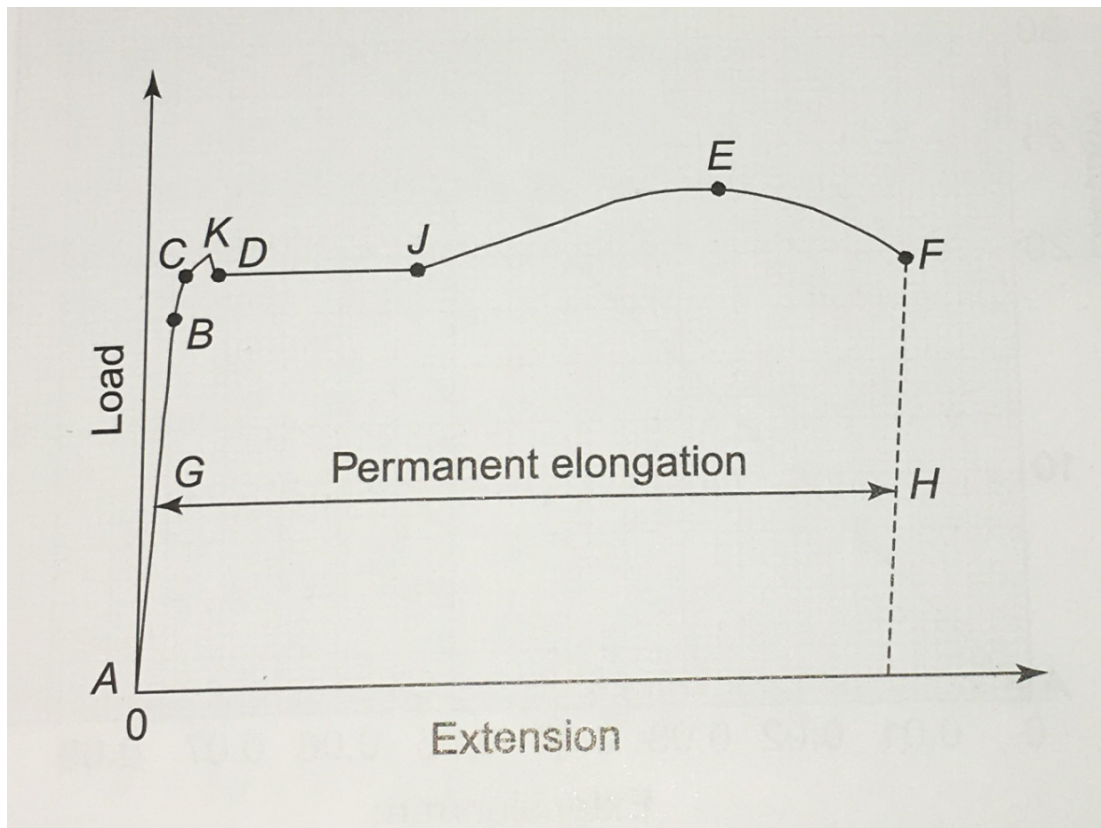


Figure 2 shows the tensile testing properties in a tensile testing graph

(Ross, 2015)

- Between point A and B is the elastic region, where Hook's Law applies. In this area stress is directly proportional to strain.
- The point B is the limit of proportionality where stress and strain are no longer experiencing the same relationship.
- The point C is the elastic limit, if the load is removed at this point the material will go back to its original length.
- The point D is the yield point, where a sudden extension of the specimen to the point J will occur without increase in force, yield stress of material can be determined using the following:

$$\text{Yield Stress} = \frac{\text{load where yield takes place}}{\text{original cross - sectional area}}$$

- Point E is the maximum load which can be applied to the specimen, and its value can be used to calculate the ultimate tensile strength (UTS) of the specimen, which is:

$$UTS = \frac{\text{maximum load}}{\text{original cross-sectional area}}$$

- Between points E and F, as result of extension, the cross-sectional area of the material will reduce, therefore necking will be formed. The specimen will break at point F.
- The distance GH is called the permanent elongation.
- Point K is the upper yield point. This occurs in some machines, such as the hydraulic machine, which applies constant load to the specimen, but it does not appear when constant strain is applied to the specimen, such as test that is carried out on Hounsfield machine. It is significant to our study because experiments will be carried out using both types of machine mentioned above.

The above tensile test properties are important to determine how a material will react under certain force, therefore any changes made to one of these properties will have a direct impact on the result of the tensile test (Ross, 2015).

#### 4.1 Importance of Tensile Testing

Tensile testing produces information about the safety and integrity of the materials, products and components, that will help manufacturers to make sure that the final product is delivered to a high quality, and that it will fit the purpose of the production process. Data that is obtained from the tensile test can be used in the following aspects:

- Reduction of material cost
- Assistance in the design process
- To make sure the product will fulfil the National and International standards
- Achieving consistency in production
- To obtain patch quality ( Azo Materials, 2010)

#### 4.2 Material Used in the Tensile Testing

There are many different material specimens, with different shapes and sizes, which were used in the experiments in the initial states, but due to collet dimension, especially when the new set of collets were brought in for comparisons purpose, the scope of the project was restricted to only one size collet, therefore a specific size specimen. However, two materials were used; specimens including Carbon-steel 0.15 % as drawn code B, and carbon-steel 0.54% - condition

O.Q. 840 °C, T. 550 °C . These two materials are part of most commonly used engineering materials.

Engineering material can be classified into four categories that include metals, polymers, ceramic and composite (Groover, 2013). The diagram below shows the classification of the four engineering materials.

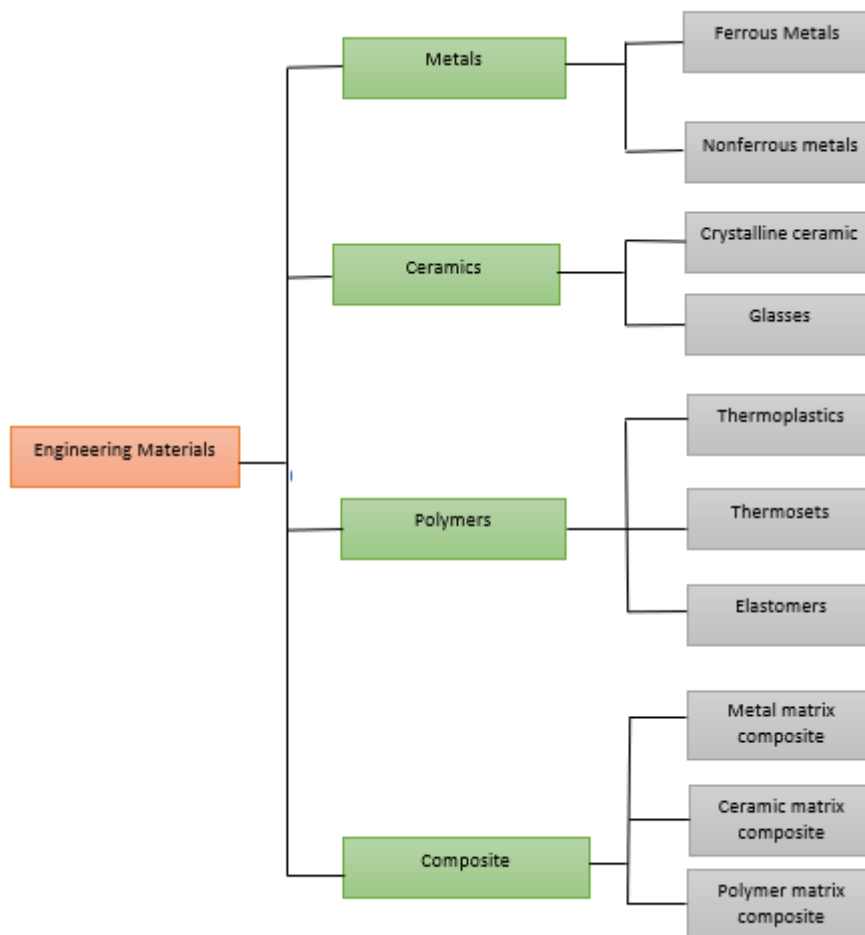


*Figure 3 shows the classification of engineering materials*

As the types of specimen used in the experiment are metals. Therefore, understanding the material properties of metals will enhance the experiment and the results obtained from the experiment.

### 4.3 Metals

Metals are a solid chemical component, good thermal electricity conductors, shiny, hard, durable, lustrous, opaque, and solid with a relatively high melting point. It could be argued that the term metal is vague and broad (Woodford, 2018), however, (Groover, 2013) attempts to

succinctly define metals used in manufacturing as usually alloy, which consist of two or more elements, with at least one being a metallic element. Therefore, in an effort to dispel some of the ‘vagueness’ and breadth of the material, metals and alloys can be split in to two groups: ferrous and nonferrous, as is stated in Figure 3.

**4.3.1.0 Ferrous metals** are based on Iron and includes Steel and Cast Iron. Although pure Iron has limited commercial use, when alloyed with carbon it has greater commercial value than any other metal, due to the alloys of carbon and iron having the ability to form steel and cast iron.

- **4.3.1.1 Steel** is an iron – carbon alloy containing 0.02% to 2.11% carbon, and it is considered one of the most important types of the ferrous metal group. Its importance is also valued within this study, as all materials used within the study contain carbon with different percentages (Groover, 2013).

#### **4.3.1.2 Types of steel and their application**

| Name of steel       | Carbon percentage % | Applications                                                    |
|---------------------|---------------------|-----------------------------------------------------------------|
| Dead mild steel     | 0.05                | Car bodies, sheet and strip for press work, wire rod and tubing |
| Mild steel          | 0.08 – 0.15         | Concert reinforcement bar, wire, rod for nails                  |
| Mild steel          | 0.15                | Case carburising quality                                        |
| Mild steel          | 0.1 – 0.3           | Structural work, sections and steel plate                       |
| Medium carbon steel | 0.25 - 0.4          | Bright drawn bar                                                |
| Medium carbon steel | 0.3 - 0.45          | High tensile tubing and shafts                                  |
| Medium carbon steel | 0.4 - 0.5           | Railway tyres, gears and shafts                                 |
| High carbon steel   | 0.55 – 0.65         | springs, railway rail, forging dies                             |
| High carbon steel   | 0.65 - 0.75         | Cylinder linings, saw, hammers                                  |
| High carbon steel   | 0.75 – 0.85         | Forging die blocks, cold chisels                                |
| High carbon steel   | 0.85 – 0.95         | Shear blades, high tensile wire                                 |
| High carbon steel   | 0.95 – 1.1          | Milling cutter, axes, screwing die and taps, knives             |
| High carbon steel   | 1.1 – 1.4           | Drill, metals and wood cutting, ball bearing, razor             |

*Table 1 show the different types of metal and their carbon percentage and applications*

(John, 2003)

- *4.3.1.3 Cast Iron* is an alloy of iron and carbon 2% to 4%, and it also contains other elements which are added to obtain the desirable properties in the cast parts used in casting such as sand casting.

*4.3.2.0 Nonferrous* metals include the pure metals and alloys of aluminium gold, magnesium, nickel and copper and other metals (Groover, 2013).

## *5.0 Wear*

Wear is the progressive loss of substance from the surface of a solid body caused by mechanical process, for example contact and relative motion with a solid or gaseous counter body. The study of wear is known as by the scientific term ‘tribology’ (Phase Trans, 2018). Therefore, the wear in the collet subject of this study has occurred because of contact between the collet and the specimens during the test procedure, by continuous testing over long period time, although the collet was heat treated.

## *6.0 Heat treatment*

Heat treatment is the process of heating and cooling metal to change their mechanical and physical properties, without allowing the object to change shape. This process is used to alter some mechanical properties such as machining, formability and improving, and can also be used in reinforcing materials. One of the most popular applications of heat treatment is metallurgical, but it can also be used in aluminium, steel, glass and many more different materials. However, according to (Sisson, 2001), heat treatment can be used to control the microstructure of the metal to make it easier to process, more machinable or formable. and to impart improved properties and performance to make it more durable. This is key in allowing the material to oppose wear, corrosion, fatigue, and in developing strength.

## *7.0 Hardening*

The process of hardening includes heating of the steel and keeping it at a suitable temperature until pearlite (or is softened). It is then transformed into austenite (changes of crystal structure), before quenching it quickly into water or oil. The temperature at which instantizing rapidly happens depends on the type of carbon content in the steel used (Sinit, 2011).

According to (New Age , 2018) hardening is a significant property for a material; it can act as wear resistance, along with resistance against scratching and abrasion. Although these collets used in the experiment were hardened, this did not prevent them from contracting wear; therefore, new sets of collets with no wear were bought to compare the two results from the two different types of collet and record the differences. To buy the collet, the guidance of purchasing and supplier selection process was followed.

## ***8.0 Purchasing and Supplier Section Process***

The process of buying or importing new parts or services in a company is known as purchasing or (procurement). As there are many different suppliers and venders trying to sell the same product with different quality and price, finding the one that will satisfy the company specification to the highest degree of accuracy is not an easy task, especially when it comes to buying the collet. However, the following steps make the selection process easier:

- the quality of the part
- the cost of the part must be within reasonable price
- Is it easy to work with supplier?
- supplier reliability and the part must arrive on time
- the supplier reputation

When the above questions are answered, the selection process will be optimum for the company (Mlibraries , 2016). It is worth noting, however, that the perspective of the company or buyer is not always coinciding with the perspective of the buyer, according to (Yoon, 2017). There are many different types of purchasing processes which include:

- **8.1 E-purchasing** in which the company use the internet to contact, compare and select suppliers, such as using the popular online selling companies including eBay (Mlibraries , 2016). It is also worth mentioning that the collet used for this experiment was bought using the e-purchasing method, which was via eBay, after the price was compared with the other companies, which were significantly more expensive. When the first manufacturer was contacted but after the price was compared the price was reduced from £925 to £18; a reduction of 166%. However, the excessive expensive could be due to the rareness of the collet.
- **8.2 Just in time production.** This is a traditional manufacturing concept which was first developed in Japan to eliminate the waste of materials, capital, machines, manpower

and inventory throughout the manufacturing system. The company will arrange delivery of the material to coincide for the material or part to be used as soon as it arrives in the company, a process discussed in the works of (KalpaKjian, 2003).

There are many other purchasing methods that companies can implement in their manufacturing system, however, in this stage, only the two purchasing methods discussed above are those that are relevant to our study. There are some important contradictions and considerations to be made, however, in the reality of the application of these purchasing processes. Where the e-purchasing method principle was applied, the box of collets included some collets that are not likely be to use in the machine, however were paid for, which can be considered as a waste of materials and capital, therefore contradicting with some of the JIT concept, and also as inefficient use of comparing, contrasting, selecting and acquiring products and sellers that meet the exact product or result requirements. The diagram below shows the collet purchased for the experiment flowing the purchasing procedure.



*Figure 4 shows one pair of the newly purchased collet*

## ***9.0 Designing the jig***

### **9.1 Engineering design process**

During this study two tensile test machine will be used to carry out the experiments, but the type of collet that will form the subject of this study is designed to work in only the Hounsfield Tensiometer machine. In order to make the collets work in the other tensile testing machine (Denison), a jig was designed. The design process was accomplished following the engineering design process. According to (Draper, 2009) the engineering design process is a method that turns theoretical ideas into a physical representation, which is developed to satisfy a specific need or to solve a problem. (Cross, 2008), however, went on to compare the way in which the designer and scientist approaches to solve the same problem. The scientist tends to use the strategy of systematically trying to understand the problem in order to generate and underline a rule that will enable them to establish an optimum solution, while the designers tend to make initial explorations and then propose multiple possible solutions until they have found one that is more suitable.

In contrast to the theory that the process of problem solving is unique to the practises of the beholder, however, (Khandani, 2005) stated that the problem solving and design process applies five general steps to solve an individual problem which include the following:

#### **1- Defining the problem**

The first step is that the problem must be described clearly, and an unambiguous definition of the problem must be available. Furthermore, the need to solve the problem must be found, therefore allowing a solution to satisfy the need. Nevertheless (Cross, 2008) argues that this stage of the design is regarded as a mysterious and creative part of the designing process, and also added that the ability to design depends partly on being able to visualize something entirely in the mind's eye, and more on making external visualisations.

(Khandani, 2005), however, remains steadfast in the belief that the definition of the design problem progresses through sequences as designers gain absolute understanding of the problem. This can be achieved by establishing and identifying the need, developing problem statements and establishing criteria for success, which means the design specification must meet requirement quality.

## 2- Search for existing design and information

Before starting the design process, the designer must search for an existing design to save time and money. This can be achieved using searching methods such as books, internet, experts... etc; this will make sure that time and money is not spent on something which already exists (Draper, 2009) . However, the energy spent on searching for information about the problem will pay significant bonuses in the later stages of the design process according to (Khandani, 2005).

## 3- Generating multiple solutions and Developing design

In this stage the brain storming of ideas occurs, before narrowing down solutions and design concepts. This is achieved by comparing the different types of concepts that have been developed previously. A crucial aspect of this process is in the designer becoming free to make mistakes and take risks. Studies show that there is no connection between creativity and intelligence, therefore people are creative because they are willing to make conscious attempts to think and act imaginatively.

## 4- Analysis of the design and selection of the best solution

After all possible solutions were developed, the design team must analyse all of these solutions to determine which is most suitable for implementation. Analysis will have involved mechanical, manufacturability, economic and market analysis, functional analysis and ergonomics.

## 5- Test and implementation of the solution

Here is where the selected design will undergo testing that can be made through different methods of implementation, such as prototyping, where the first working design is made. Also, concurrent engineering can be applied, which is the ability to apply similar design and analysis and compare manufacturability, marketability, safety, regulation compliance and serviceability. In modern times this can be done using computer aided engineering CAE.

The diagram below shows the five basic steps of the engineering design process:

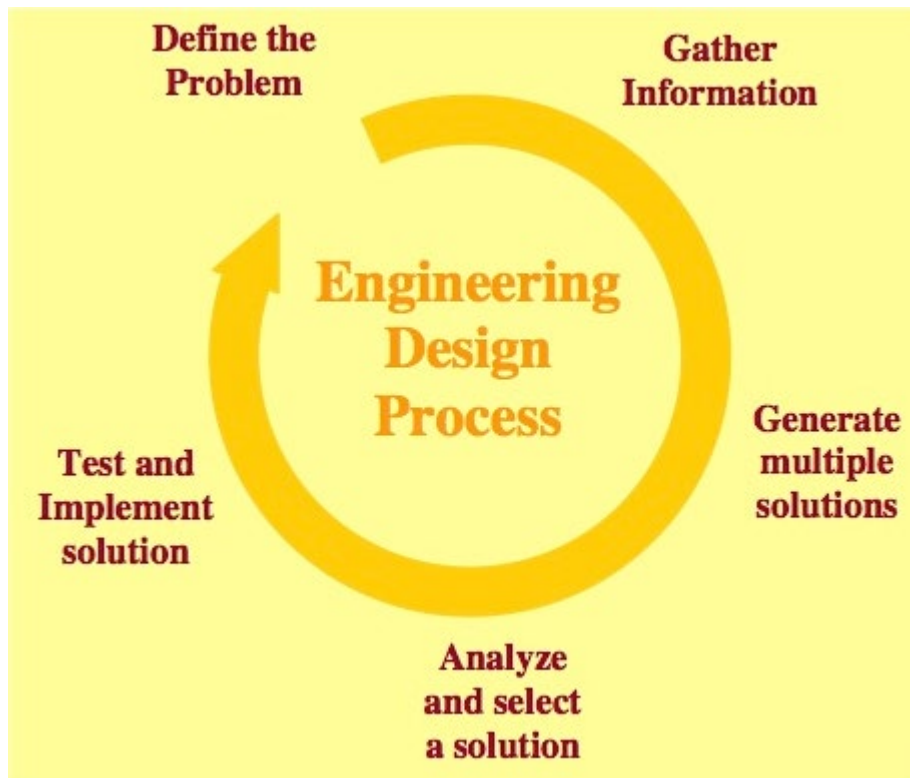


*Figure 5 engineering design process basic steps*

(Kassam, 2012)

The above five steps of the engineering design process were utilised to solve the problem, which was stated as the need for a feature that will adapt the Denison machine to carry out tensile testing using the same collet used in the Hounsfield machine. After the conceptual design of the jig was developed, the process of making the solid design began by drawing the jig using computer aided design (CAD). (KalpaKjian, 2003) stated that CAD is the use of a computer to create design drawings and geometric models of a product component. It can also analyse and evaluate engineering designs by deriving applications such as finite element analysis of stress and strain, and deflection. In addition, CAD can also examine potential problems such as interference mating surfaces, an excessive load or deflection during the assembly.

## 9.2 Jig sketch

The diagram below shows the CAD drawing using Solidworks.

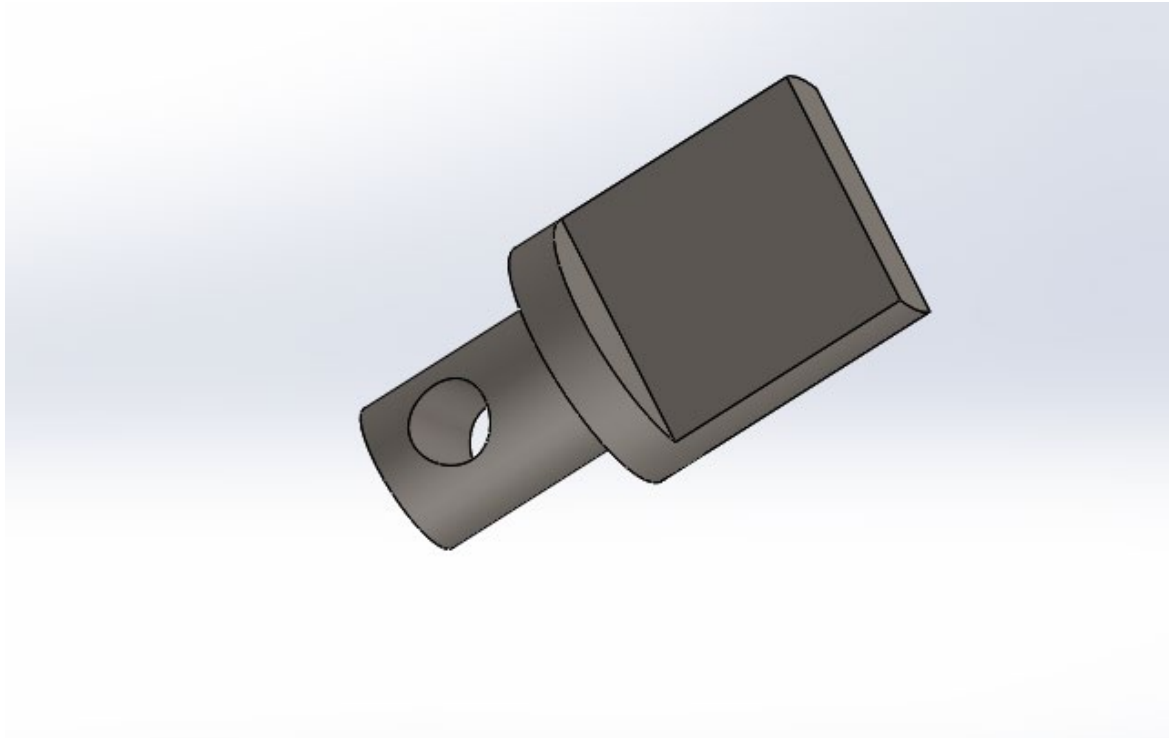


*Figure 6 shows feature of jig create in Solidworks*

This 3D model of the jig was created using Solidworks. It is 47 mm long, 23×8 mm on the flat side, middle circle 25mm in diameter, 8mm thick, 16mm long and the 8 mm diameter for the hole. This process facilitates the communication between users and makes the production process much faster; according to (Dassault Systemes , 2017), Solidworks visualise helps accelerate the approval process and deliver the product to the market six months faster than when there is no use of CAD to create the drawing, as it has saved time and money, and is also useful in eliminating error by testing the prototype using the Finite element analysis (FEA) in Solidworks.

## 9.3 Finite element analysis (FEA) testing process

The finite element analysis (FEA) is a numerical technique which is utilised to determine an approximation solution for set of partial differential equations on a domain. The FEA has a

very good performance to solve the partial differential equations over complex domains which can be varied with time. The FEA has many different applications that include the following: nonlinear, linear, dynamic, thermal, fatigue and buckling analysis (Altair, 2015). However, according to (Bashetty, 2010) the FEA uses the numerical procedure to analyse the domain by using a complex system of points called nodes and elements which make a grid called a mesh. The mesh is programmed to contain the material and structural properties of the domain, such as yield strength, elastic modules and Poisson's ratio, which will determine how the domain will react under certain loading conditions. The mesh will act as a spider web in that, from each node, there will be an extended mesh element to the neighbouring nodes. This is to generate a limited number of finite calculations, and then to interpolate the result for the entire domain. Generating the result on a mesh also involves a degree of freedom which can be infinite in the domain, therefore FEA solvers reduces the degree of freedom (DoF) from infinite to finite. Nevertheless, meshing is an important part of the FEA and choosing the right mesh element is crucial. Below is a diagram which shows the meshing process in the primary stage of FEA testing in SolidWorks during the jig design.

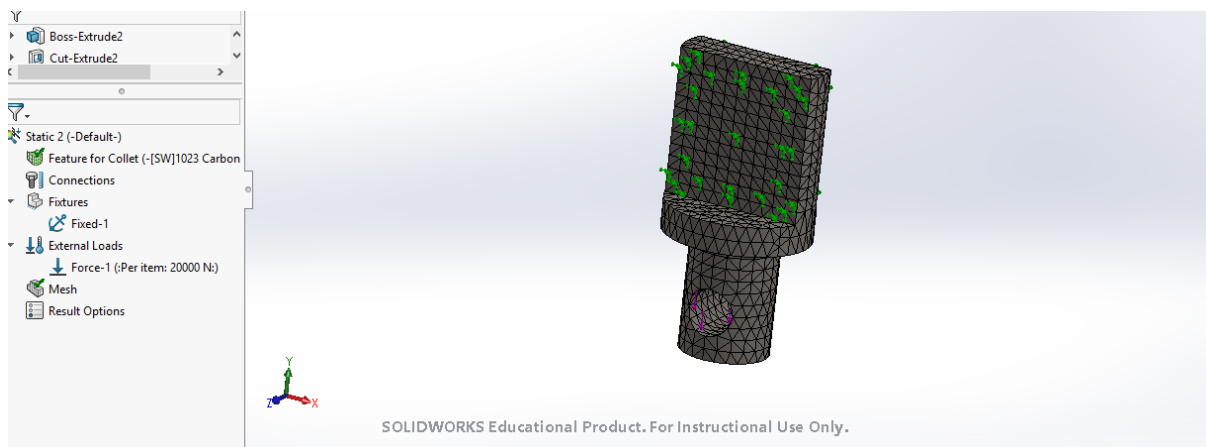


*Figure 7 shows meshing process during Finite element analysis*

After the meshing is generated in Solidworks FEA the following step is to run the study, which means running the FEA calculation. After the calculation was completed FEA show the results as a coloured jig including yield strength of the jig and maximum Von Mises of  $3.803 \times 10^8$  in a coloured bar, where colour in the colour bar corresponds to the colour in the jig, whereby red shows a high concentration of stress. Stress varies depending on the colour as it is going down in the coloured bar. In addition the maximum stress is shown by the von Mises because it is considered to be one of the best theories, among the other five theories of the material failure according to (Hearn, 1997), and it was suggested that this theory has received wide

verification from practical and regarded as reliable for the design. Von Mises theory is also known as the maximum shear strain energy per unit volume theory and is also known as distortion energy theory. The diagram below shows the von Mises stress on the jig.

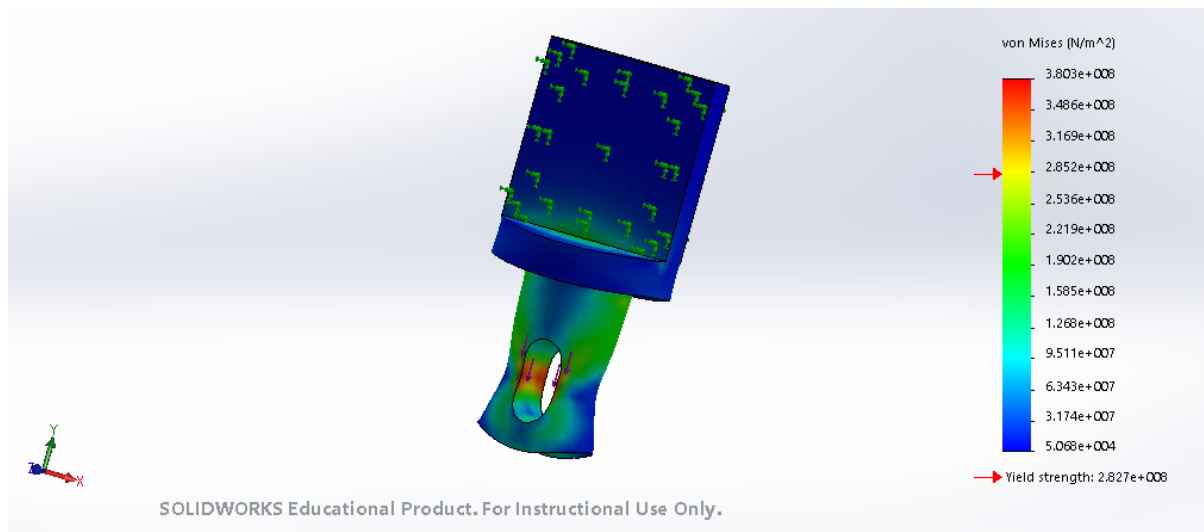


*Figure 8 shows the von Mises and yield strength of the jig in FEA*

Beside the von Mises stress, the solid works FEA has shown a maximum displacement of  $1.134 \times 10^{-002}$  mm of the jig the displacement, corresponding to the applied stress. This value of the displacement under this load is almost negligible. According to (Botting, 2011) the URES is U, commonly known as a vector that represents the resultant displacement in a domain; this vector has the component  $U_z$ ,  $U_x$  and  $U_y$ , these are Value Solved by FEA for each orthogonal direction. The diagram below shows displacement as URES in the colour bar.

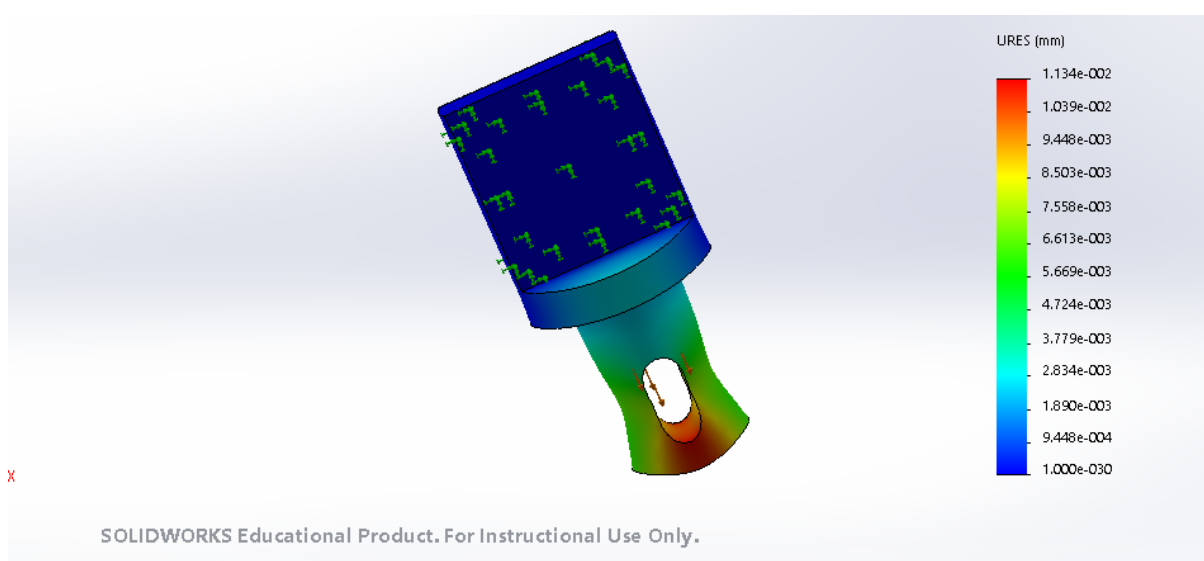


*Figure 9 shows the resultant displacement in the jig when tested in FEA*

After the Solidworks design was created and tested using Finite Element Analysis method, and the feature proved its capability to withstand the required forces of 20 KN which is well below the yield strength of the material of  $2.88 \times 10^8$  and the displacement of  $1.134 \times 10^{-002}$  mm as it shown in FEA. Although Solidworks FEA made design testing easier, it also has its limitations. According to (Altair, 2015), when using FEA linear solver it will never show visualized breaking on the domain, it will only show the area coloured in red as a high stress concentrating area but some FEA solver such as Abaqus can visualise breaking . However, FEA was followed by creating the physical model. The physical part of the model of the jig was made using different types of machines include the following.

#### 9.4 Lathe machine

A rounded bar of mild steel was used to create the jig; first it was shaped in the Lathe machine, which is a conventional material removal machine that works by spinning at high speed whilst a cutting tool will remove the material. A workpiece (rounded metal bar) was placed in a chuck that was attached to a spindle. As the part starts rotating the cutting tool, which is made from very strong material, will be moved until it touches the workpiece, therefore the material will be removed until the desired size is obtained. In this operation the circular shape of the jig was formed. As it can be seen in below figure 10.

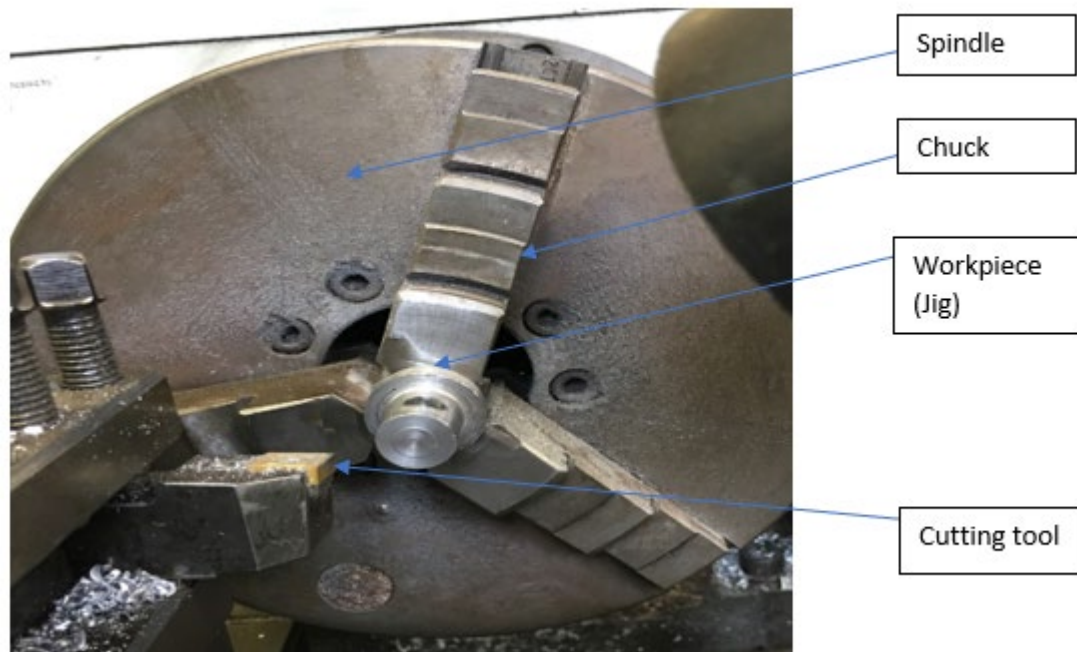


*Figure 10 show the jig in the lathe machine during material removing process*

## 9.5 Milling machine

To create the flat shape in the jig the milling machine was used. According to (Groover, 2013) the milling in machining operation is the process in which a workpiece is fed past a rotating cylindrical tool with multiple cutting edges; the axis of rotation of the cutting tool is vertical to the direction of the feed. The jig was placed in the worktable of the milling machine and tightly held in the table, then the worktable was moved with a controlled feed against the rotating cutter which is mounted in the spindle of the milling machine. The cutter rotation was fixed in one place; when the jig approaches the cutter teeth the material will be removed from the surface of the jig and the anticipated shape is produced, which was how the flat surface of the jig was shaped. The picture below in figure 11 shows the Jig during the milling process.

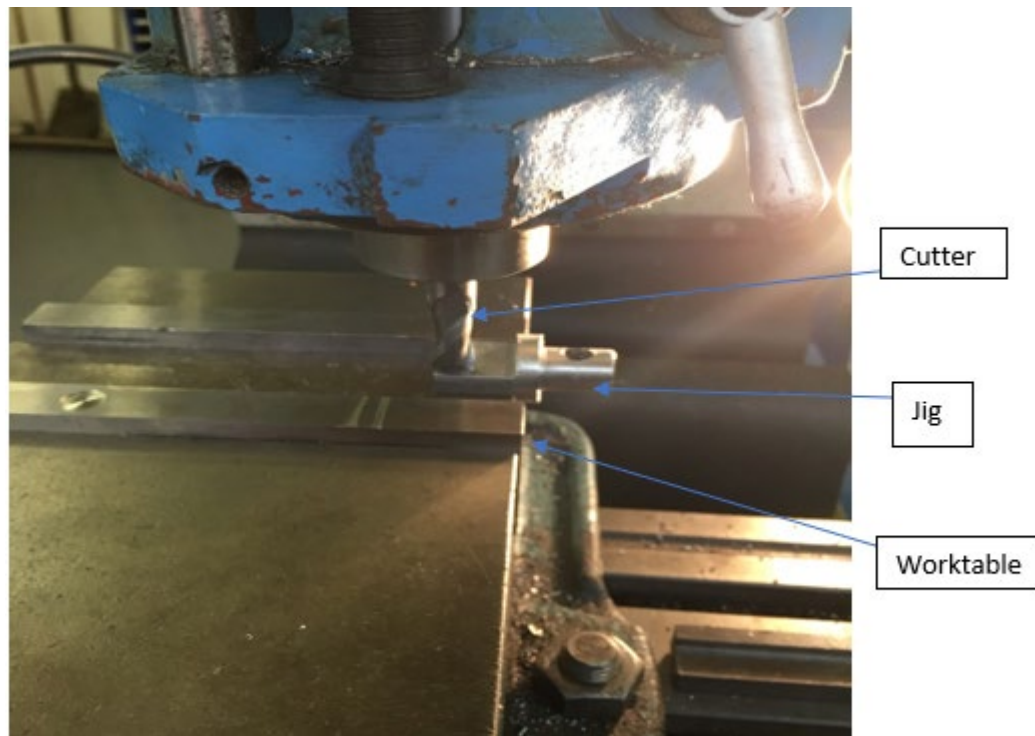


*Figure 11 shows jig in the milling machine during material removal process*

## 9.6 Drilling machine

Drilling is a machining operation that is utilised to make holes in the work piece. It is operated using a rotating cylindrical tool that has two cutting edges on the operational end. The tool is called a 'drill bit' or 'drill'. Drilling works by rotating a drill bit that is gripped by a spindle; the rotating drill bit is fed in to the workpiece until a desirable hole is created. These procedures were applied to drill the hole in the jig. By placing the jig on the drilling work table, the size of the drill bit was selected and inserted in the drill spindle, before the spindle was advanced in the jig slowly for safer drilling and to remove the unwanted waste materials. The process was continued until the desired hole was created. The picture below in figure 12 shows the process of drilling the hole in the jig.

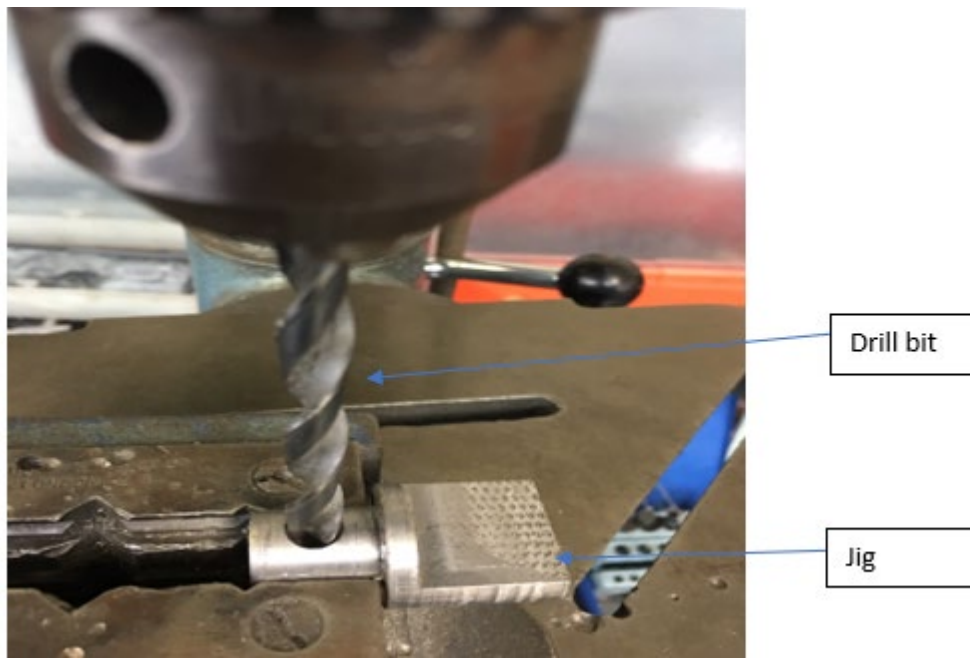


*Figure 12 shows the jig during the drilling process*

### 9.7 Deburring

During the initial testing of the jig, obstacles were faced, including misalignment between the jig, pin and collet pin due to burr resulting from the machining process. These problems were overcome by deburring the jig. According to (KalpaKjian, 2003) burr is thin ridges that develop along the edges of the work piece during the machining, trimming, forging, and casting. Because burr is sharp they can pose a safety hazard for personnel, especially when associated with the jig, which requires sufficient personal handling. The jig was deburred using a machine that holds an abrasive disc in one side and an abrasive belt on the other side. The jig was held manually and advanced to the rotating disc. Both discs were used in deburring the jig until the desired surface finish was achieved. The picture below in figure 13 shows the deburring operation.

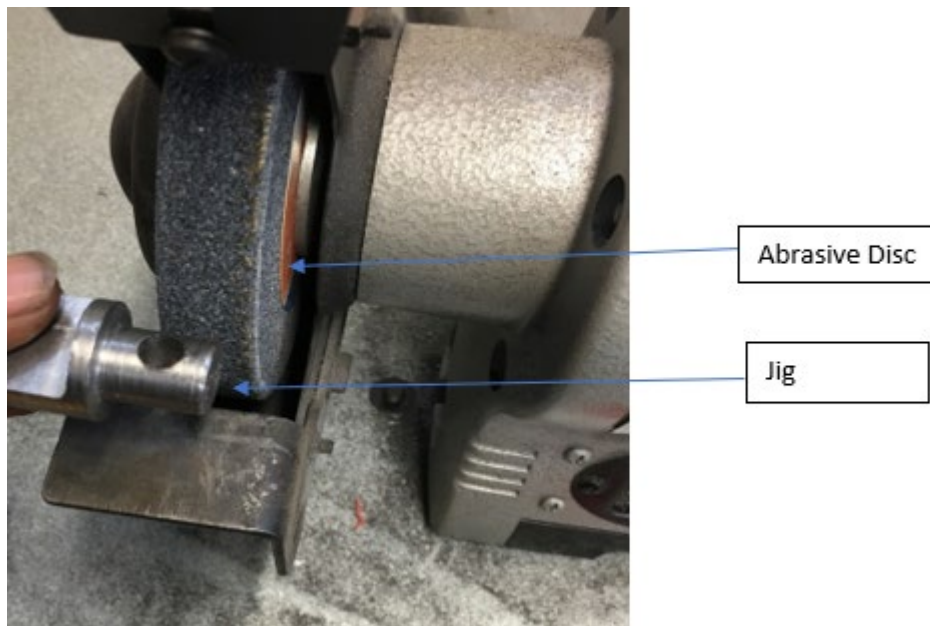


*Figure 13 shows the jig during the deburring process*

After the jig had been designed it was tested multiple times in the Denison machine, and it passed all tests, therefore the newly developed jig fulfilled the design specification in which to modify the Denison machine to use the Hounsfield's collets also to be use for verification and validation of results from both machines. Nevertheless, the usage of the jig will help users not only by working in the Denison machine but also by validation and comparing the test that is carried out using the Denison machine, therefore the quality of determining the tensile test result. The picture below in figure 14 show the final design of the jig.



*Figure 14 shows the jig created using different machining processes*

## 10.0 The experiment

### 10.1 Equipment /apparatus Hounsfield machine



*Figure 15 shows the Hounsfield tensile testing machine (Tensiometer)*

- Hounsfield H20 – W capacity 20 KN tensile testing machine (Tensiometer)
- Pair of HT19 collet grips including pair of collet pins
- 20 Dumbbell shape test specimens various of material available in this study carbon steel was used
- Vernier calliper
- Computer device
- HTE W-series terminal Computer software
- Stopwatch
- AMCap camera

### 10.2 Experimental procedure

In this study, as mentioned previously, there were two types of machines that were used to carry out the experimental work, therefore there will be two experimental procedure explained as the following:

#### 10.2.1 Hounsfield Machine Experimental Procedure

- 1- At the beginning of each test, after the desired specimen was selected, the specimen was measured manually using the Vernier calliper, and its length and cross-sectional area were recorded.
- 2- The specimen was placed between one set of the split collets, then the collet ring was inserted in between to hold the split part for tight gripping. The collet was attached to the nose piece and a pin was inserted to stop the collet from moving.

- 3- Step two was applied in the left-hand side collet that will pull the specimen during the test.
- 4- Vernier calliper was used to measure the distance between the two collets while they are holding the specimen after slack is being removed, to achieve same starting point for each experiment.
- 5- On the machine control panel, the force and extension were zeroed.
- 6- On the computer connected to the testing machine the HTE W-series terminal computer software was open and a new file was selected.
- 7- On the machine control panel, the test button was pressed. Before starting the test, the time was monitored using the stop watch, which started simultaneously with the test and stopped when the specimen was broken
- 8- The specimen was observed while the test was running, and time and machine was stopped at the same time when the specimen was broken.
- 9- After the specimen was broken, all the test results were displayed on the computer, including maximum force and extension and breaking point, and automatically a graph was generated.
- 10- After the specimen was broken in to two parts, the broken parts were joined together and firmly held using the Vainer calliper and the new length was recorded.

Note: the speed of the machine during the test was 5 mm /second.

## 10.3 Equipment/apparatus Denison machine

### 10.3.1 Denison vertical tensile testing machine



*Figure 16 show the Denison tensile testing machine*

- Vertical Denison tensile testing machine
- Pair of Jigs
- Pair of HT19 collet grips including pair of collet pins
- Computer device including Denison max test software
- 20 Dumbbell shape test specimens
- Pair of Jigs
- AMCap camera

### 10.3.2 The Denison machine experimental procedure

Unlike the Hounsfield horizontal machine, the Denison machine is operated vertically using jaws rather than a collet, therefore the jig in figure 14 was used to adapt the machine to ensure that the same collet used in the Hounsfield can be used in the Denison machine. However, the experimental procedure involved the following:

- 1- Specimen length and diameter were measured
- 2- Specimen was placed in the collet and collet was attached to the jig.

- 3- Denison machine jaw size 7 ~ 14 was used
- 4- The assembly of collets, jigs and specimen was attached to the Denison machine main jaws
- 5- Slack was removed and distance between two collets was measured using Vernier calliper
- 6- On the computer software a new file was created, and all previous calculations were deleted. A speed of 5 mm per second was selected.
- 7- The test command button was clicked to start the test
- 8- After specimen was broken, a graph was generated showing maximum load, extension and all data including time displayed and recorded on the computer screen.
- 9- Test piece was removed and put together and the new length was recorded.

Note: after every test the broken parts were put back together, and the consistency was achieved using AMCap camera computer software, which uses a camera to magnify objects.

## ***11.0 Results***

The experiments results were used to compare two sets of data. All of the data obtained from the Hounsfield tensile testing machine were compared against data obtained from the Denison tensile testing machine. Two collets were used to carry out the experiments, one collet is referred to as the old collet. This collet has been identified as having wear, which is the subject of the study. Another collet is referred to as the new collet, which was purchased from a supplier and has no wear identified within the collet. The finding from both collets was also compared. The graphs and tables below represent the data from both machines and collets, using two different samples: sample K (carbon steel 0.54 %) and sample B (carbon steel 0.15%).

Results obtained using the new collet from the Hounsfield testing machine

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | K           | 90.05                 | 28                   | 4.288                  | 31                 | 53       | 0.1071   | 0.153    | 15.87         |
| 2       | K           | 90.05                 | 28                   | 4.193                  | 31                 | 48       | 0.1071   | 0.149    | 16.35         |
| 3       | K           | 90.05                 | 28                   | 3.778                  | 31                 | 47       | 0.1071   | 0.135    | 16.78         |
| 4       | K           | 90.05                 | 28                   | 3.944                  | 31                 | 47       | 0.1071   | 0.141    | 13.72         |
| 5       | K           | 90.05                 | 28                   | 3.631                  | 31                 | 45       | 0.1071   | 0.129    | 16.73         |
| Average |             | 90.05                 | 28                   | 3.967                  | 31                 | 48       | 0.1071   | 0.1414   | 15.89         |

*Table 2 test results generated from Hounsfield testing machine using the new collet*

The above table was filled using information from each test, in the table number test and sample code are referred to as the number and code of a single specimen. Vernier calliper is the distance between two collets holding the specimen, and original length is the length of the specimen measured before the test. Extension machine is the extension recorded by the testing machine from the start of the test until the sample breaks. Length manual is the length measured manually after sample breaks by putting two pieces together, and time is the time taken from the start of the test until the sample breaks. Strain 1 is the strain obtained from the manual and Strain 2 is the strain calculated automatically as an extension. The maximum load is the load that the specimen can withstand before it breaks. The strain was calculated using the following equation:

$$Strain = \frac{change\ in\ length - original\ length}{original\ length}$$

$$\varepsilon = \frac{\Delta l - l}{l}$$

Before we begin a full comparison between all results, it is important to highlight some discrepancy in the table above. It was noticed that, when using the new collet, the length calculated manually is the same, hence no differences in the manual strain1 calculation. The extension obtained from the machine, however, was dissimilar, resulting in difference in results for Strain 2. Therefore, the difference in average of strain 1 is 24% lower than strain 2.

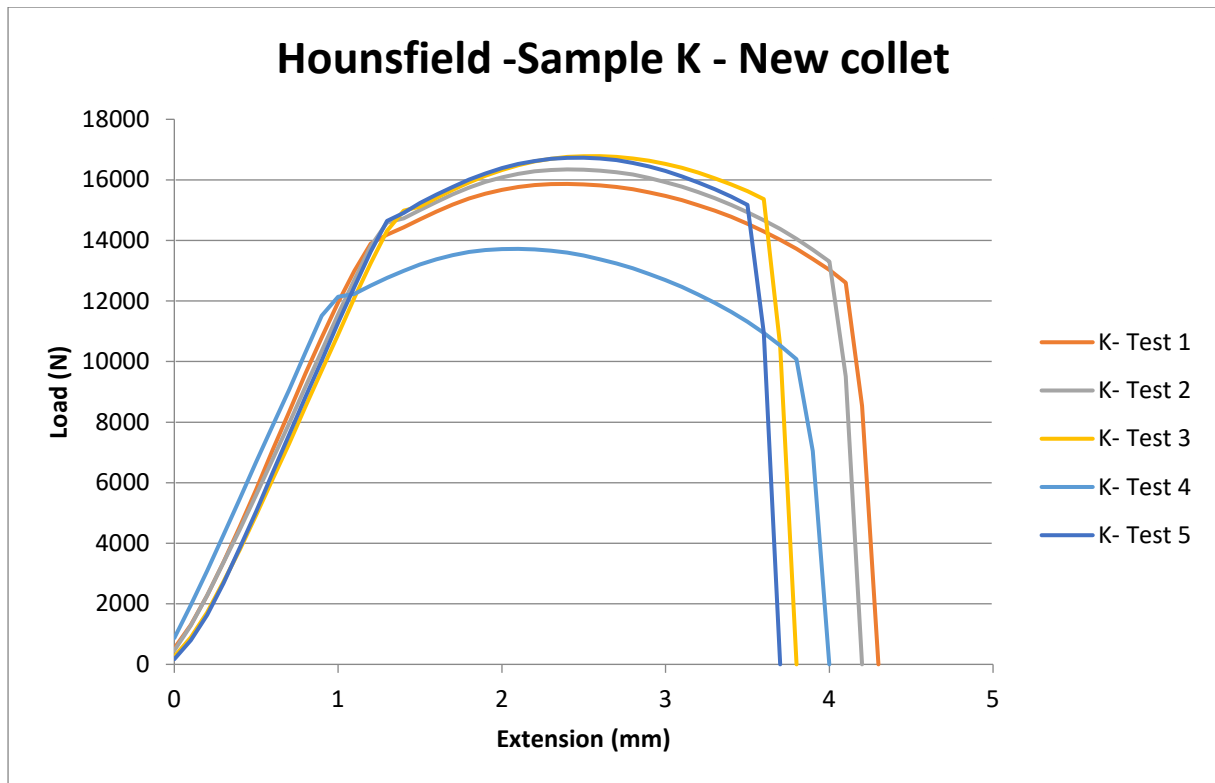


*Figure 17 show graphs for sample K using new collet in the Hounsfield machine*

The graph above visualises the relationship between Load in Newtons and Extension in Millimetres, and each colour represents the number of a test. The data for the graph in figure (17) was obtained from table (2). It shows that when the new collet was used in the Hounsfield machine, the graph is almost similar, although there was a dead load at the beginning of each test that varies from 170 N to 869 N total of 699 N. The variation is in a distance between 3.7 mm to 4.3 mm in the extension line which in total is 0.6 mm. Also, it was noticed that all specimens behaved similarly until the elastic limit points where reached, then bigger differences will occur as the sample reaches breaking points.

Test result obtained using the old collet in the Hounsfield testing machine

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | K           | 87.05                 | 28                   | 3.631                  | 29                 | 36       | 0.035    | 0.129    | 16.08         |
| 2       | K           | 87.05                 | 28                   | 2.855                  | 30.5               | 35       | 0.089    | 0.101    | 11.75         |
| 3       | K           | 87.05                 | 28                   | 3.536                  | 29.5               | 48       | 0.053    | 0.126    | 16.73         |
| 4       | K           | 87.05                 | 28                   | 3.172                  | 29.3               | 44       | 0.046    | 0.113    | 16.31         |
| 5       | K           | 87.05                 | 28                   | 4.195                  | 30.5               | 48       | 0.085    | 0.149    | 15.85         |
| Average |             | 87.05                 | 28                   | 3.478                  | 29.76              | 42.2     | 0.0616   | 0.124    | 15.34         |

Table 3 show table created by using data from the Hounsfield machine using old collet

Using the old collet in the Hounsfield machine, the data in Table 3 was generated. It is clearly noticeable that the length of the specimen measured manually were dissimilar, and as a result there is also a difference in Strain 1. When the average strain is compared Strain 1 was lower than Strain 2 by 50.3 %.

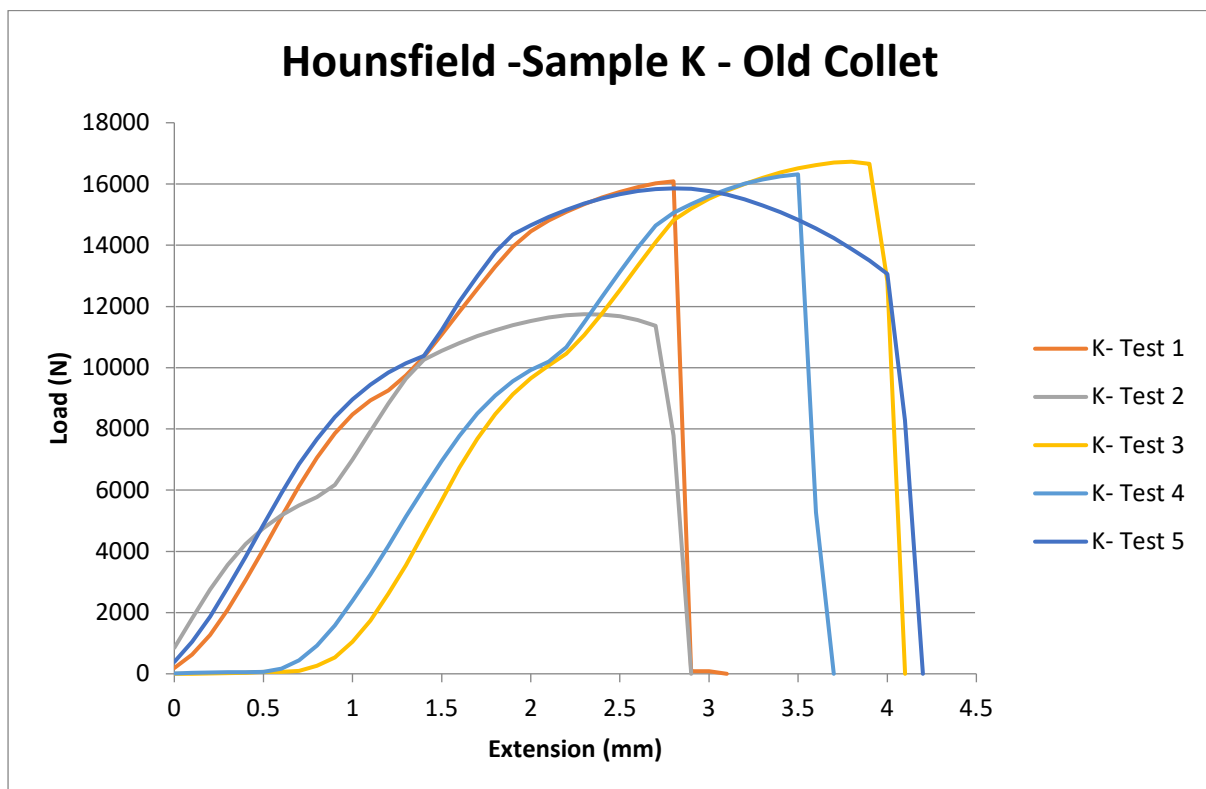


Figure 18 shows graphs of sample k using the old collet in the Hounsfield machine

The graph shows a visualisation of the old collet data, which appear to be different from each other. Although careful measurement was taken to achieve a similar start point by introducing the Vernier Calliper before each test, a similar start point was never accomplished. There was a bend in the middle of each graph, in the area of the elastic limit, that indicates that the wear on the collet is affecting the results by contributing to the lack of constant gripping during the experiment while force is applied to the specimen. The different breaking points start from 2.9 mm to 4.2 mm, a difference of 1.3 mm in extension, while the difference in load starts from 46 N to 844 N; the load difference is 798N.

Result data obtained using the Denison machine with the new collet

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | K           | 90.05                 | 28                   | 4.604                  | 31                 | 53       | 0.107    | 0.1644   | 11.30         |
| 2       | K           | 90.05                 | 28                   | 4.610                  | 31                 | 56       | 0.107    | 0.1646   | 12.81         |
| 3       | K           | 90.05                 | 28                   | 4.065                  | 31                 | 49       | 0.107    | 0.1451   | 15.80         |
| Average |             | 90.05                 | 28                   | 4.426                  | 31                 | 52.7     | 0.107    | 0.158    | 13.3          |

*Table 4 table created using sample K and the new collet in the Denison machine*

For this test only 3 sample K specimens were used due to a shortage in the number of samples available. The difference between Strain 1 and Strain 2 shows that Strain 1 was 32.2% less than Strain 2.

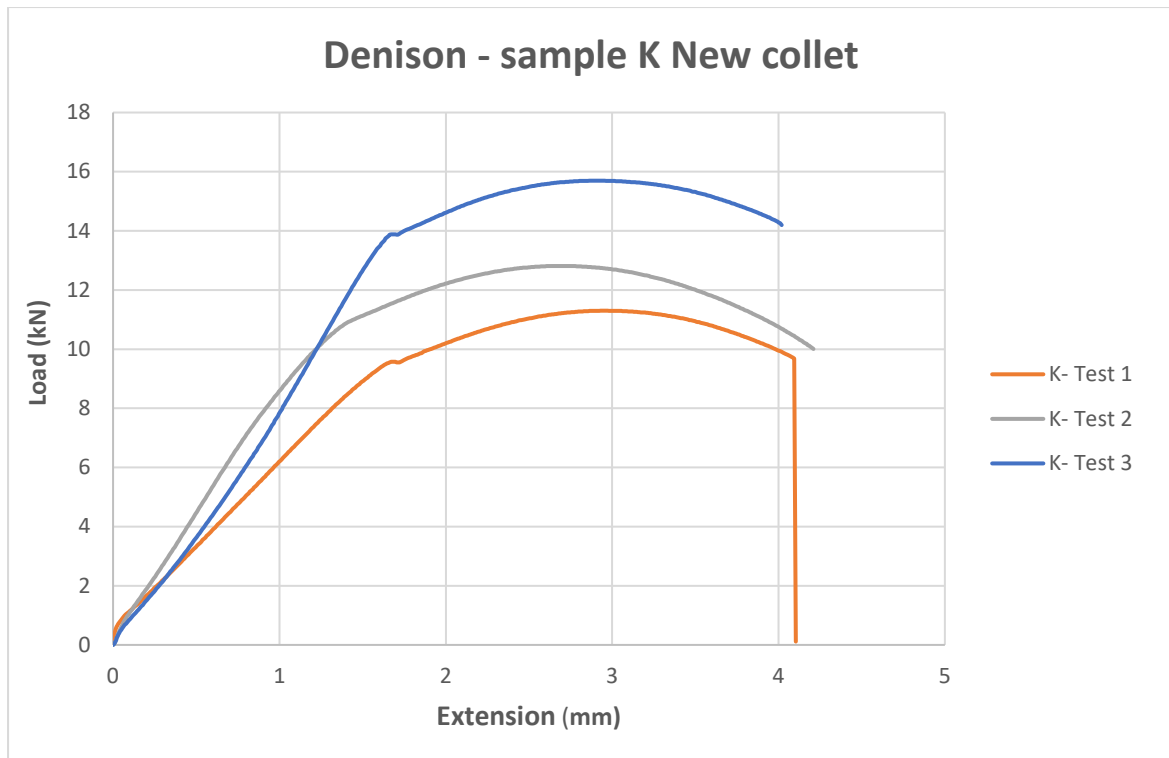


Figure 19 graphs from sample K in the Denison machine using new collet

In the graph displayed in Figure 19, representing data from the Denison, it was noticed that all samples started from almost the same sample points, but as the test progressed to the yield and maximum load, the gap increased from 11.295 kN to 15.685 kN. It is noted, however, that the gap was reduced towards the breaking points from as low as 4.10 mm to 4.21 mm.

Result obtained from the Denison using the old collet

| Test No  | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (kN) |
|----------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1        | K           | 87.05                 | 28                   | 5.272                  | 30.05              | 67       | 0.073    | 1.882    | 16.050        |
| 2        | K           | 87.05                 | 28                   | 3.80                   | 31                 | 85       | 0.107    | 1.357    | 16.265        |
| 3        | K           | 87.05                 | 28                   | 3.520                  | 29.05              | 43       | 0.037    | 1.257    | 12.70         |
| Averages |             | 87.05                 | 28                   | 4.197                  | 30.033             | 65       | 0.073    | 1.498    | 15.01         |

Table 5 is created using sample k and the old collet in the Denison machine

Again, according to data shown in Table 5, the old collet is showing differences in the length measured manually and also in the length measured by the machine. This resulted in significant differences in Strain 1 and Strain 2 calculation, where Strain 1 average is 0.073 and Strain 2 average is 1.498, which is approximately a 95.13% difference in strains.

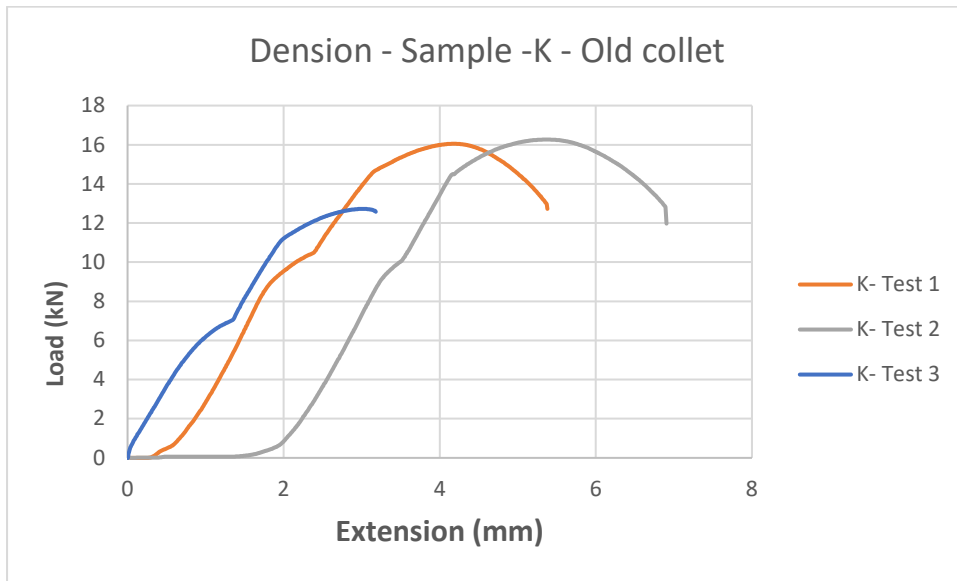


*Figure 20 shows graphs for sample K created in the Denison machine using the old collet*

The graph in Figure 20 represents the data shown in Table 5, obtained using the old collet. This shows a significant gap between the three samples used. This includes the difference at the starting and breaking points; break points start at point 3.18 mm and end at 6.90 mm, the difference being 3.72 mm. This is due to the test, again, failing to start from the same point. Although careful measurement was taken using the Vernier Calliper to ensure one starting point, due to the wear on the collet the specimen is always unstable when a load is applied.

Data from Hounsfield tensile testing machine using new collet

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | B           | 90.5                  | 28                   | 2.81                   | 30.5               | 35       | 0.089    | 0.100    | 6.634         |
| 2       | B           | 90.5                  | 28                   | 3.02                   | 30.5               | 36       | 0.089    | 0.107    | 9.645         |
| 3       | B           | 90.5                  | 28                   | 3.27                   | 30.5               | 38       | 0.089    | 0.116    | 8.315         |
| 4       | B           | 90.5                  | 28                   | 3.71                   | 30.5               | 43       | 0.089    | 0.133    | 10.566        |
| 5       | B           | 90.5                  | 28                   | 3.60                   | 30.5               | 43       | 0.089    | 0.128    | 10.410        |
| Average |             | 90.5                  | 28                   | 3.28                   | 30.5               | 39       | 0.089    | 0.117    | 9.114         |

Table 6 created using sample B and the new collet in the Hounsfield machine

From the data in Table 6 obtained using Sample B and the new collet, Strain 1 was the same in all tests, which resulted from identical manual length calculation, but there was a difference in the Strain 2 calculations as a result of extension calculated by the machine. The different in both strain averages is 23.9% between the two strains. It was also noticed that there was proportionality between times taken for the sample to break and the maximum load applied to the specimen.

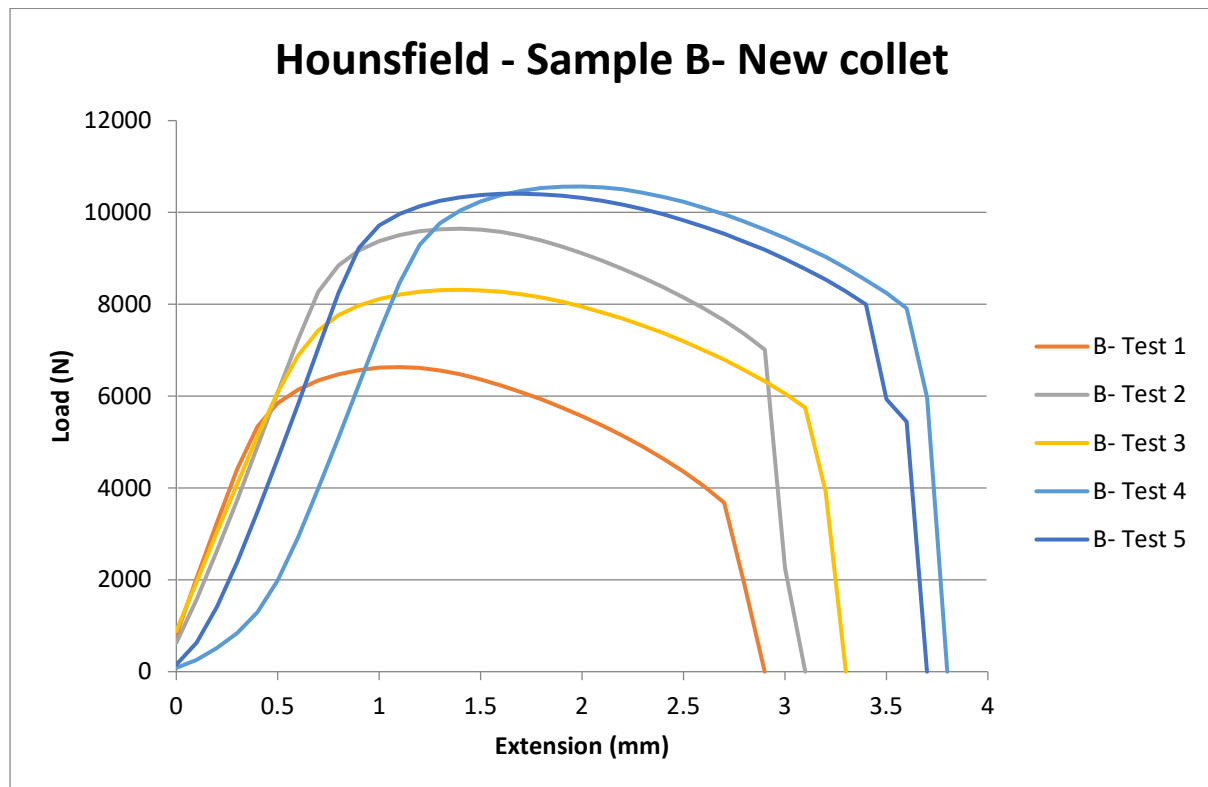


Figure 21 graphs generated using sample B and new collet in the Hounsfield machine

The graph in Figure 21 shows the results obtained from Table 6. It was noticed that, at the beginning, there was load but no extension. This can be considered as a dead load that varies from 155.3 N to 886 N. The dead load translated in the extension producing gap 0.9 mm, which is between 2.9 mm and 3.8 mm.

Data from Hounsfield tensile testing machine using old collet

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | B           | 87.5                  | 28                   | 3.112                  | 30                 | 35       | 0.0714   | 0.111    | 8.38          |
| 2       | B           | 87.5                  | 28                   | 3.55                   | 30                 | 42       | 0.0714   | 0.126    | 10.22         |
| 3       | B           | 87.5                  | 28                   | 3.54                   | 30.5               | 42       | 0.089    | 0.126    | 10.19         |
| 4       | B           | 87.5                  | 28                   | 3.90                   | 30.2               | 43       | 0.078    | 0.139    | 10.51         |
| 5       | B           | 87.5                  | 28                   | 3.747                  | 30.1               | 45       | 0.075    | 0.133    | 10.43         |
| Average |             | 87.5                  | 28                   | 3.56                   | 30.16              | 41.4     | 0.077    | 0.127    | 9.95          |

*Table 7 data obtained from the Hounsfield machine using old collet and sample B*

From the data in Table 7 for sample B using the old collet in the Hounsfield machine, extension machine and manual both failed to produce similar extension, which reflects the averages of Strain 1 and 2 results that experienced a difference of 39.4 %.

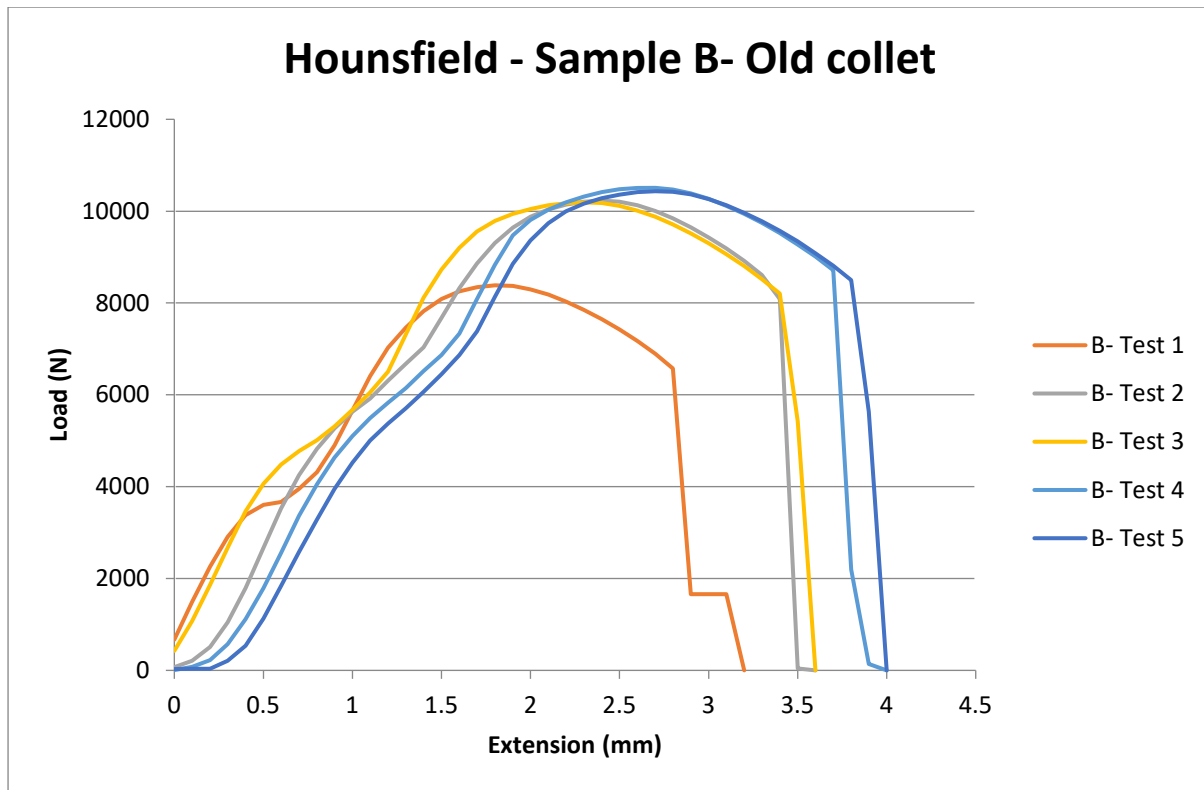


Figure 22 shows graphs generated using sample B and the new collet in the Hounsfield machine

The graph in Figure 22 was created using the old collet. It was noticed that there was an improvement in the performance of the old collet. The four graphs were almost identical, but still there was a small extension, and the load was observed at the beginning of the last two tests. Also, the difference in the breaking point started from 2.8mm to 3.8mm, therefore all breaking occurred in the region of 1mm.

Test results from Denison machine using New Collet

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | B           | 90.5                  | 28                   | 4.74                   | 30                 | 59       | 0.0714   | 0.170    | 11.07         |
| 2       | B           | 90.5                  | 28                   | 4.43                   | 31                 | 60       | 0.107    | 0.160    | 10.62         |
| 3       | B           | 90.5                  | 28                   | 3.70                   | 31                 | 46       | 0.107    | 0.132    | 8.92          |
| 4       | B           | 90.5                  | 28                   | 3.90                   | 31                 | 49       | 0.107    | 0.140    | 9.91          |
| 5       | B           | 90.5                  | 28                   | 4.30                   | 31                 | 52       | 0.107    | 0.154    | 10.55         |
| Average |             | 90.5                  | 28                   | 4.214                  | 30.8               | 53.2     | 0.1      | 0.150    | 10.21         |

Table 8 data created using sample B and the new collet in the Denison machine

The data in Table 8 was obtained using the new collet in the Denison machine. From the data it was noticed that the difference between the average strains is 33.3 % increase in Strain 2.

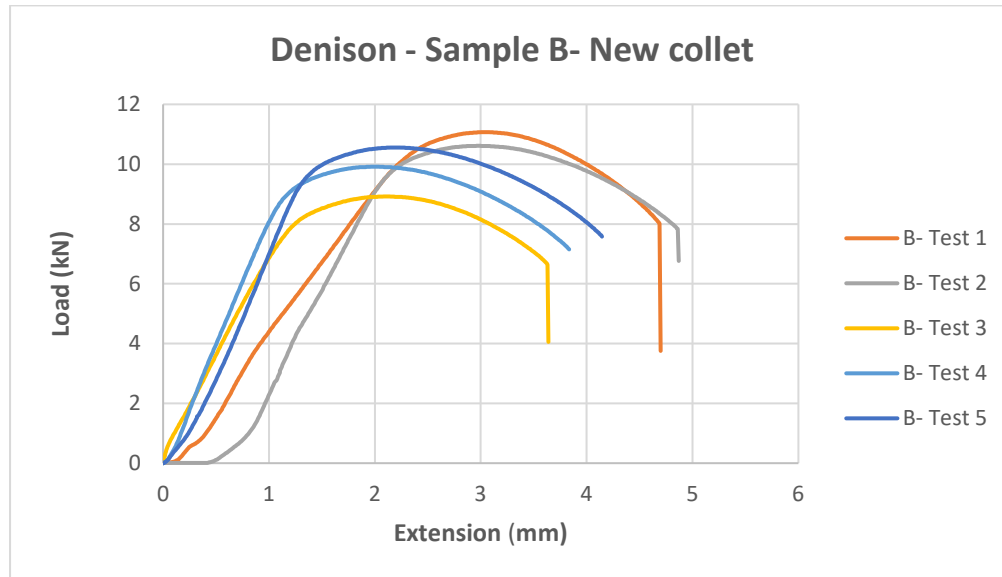


Figure 23 shows graph for sample B and the new collet using the Denison machine

The graph in Figure 23 highlighted that all graphs started from almost the same points, apart from one which was extended without a load applied to it. However, all samples broke in a different position; the first sample was broken at 3.63 and the last at 4.8. All samples broke in the region of 1.17mm.

Test results obtained from the Denison machine, old collet:

| Test No | Sample code | Vernier Calliper (mm) | Original length (mm) | Extension Machine (mm) | Length manual (mm) | Time (s) | Strain 1 | Strain 2 | Max load (KN) |
|---------|-------------|-----------------------|----------------------|------------------------|--------------------|----------|----------|----------|---------------|
| 1       | B           | 87.5                  | 28                   | 4.0                    | 29.5               | 60       | 0.054    | 0.143    | 9.985         |
| 2       | B           | 87.5                  | 28                   | 3.60                   | 30                 | 49       | 0.071    | 0.129    | 8.650         |
| 3       | B           | 87.5                  | 28                   | 3.10                   | 30                 | 39       | 0.071    | 0.110    | 8.020         |
| 4       | B           | 87.5                  | 28                   | 2.80                   | 29.5               | 34       | 0.054    | 0.10     | 8.345         |
| 5       | B           | 87.5                  | 28                   | 3.73                   | 29.3               | 50       | 0.046    | 0.133    | 10.20         |
| Average |             | 87.5                  | 28                   | 3.446                  | 29.7               | 46.4     | 0.059    | 0.123    | 9.04          |

Table 9 generated using sample B and the old collet in the Denison machine.

From the data in table 9, obtained by using the old collet in the Denison machine, it was noticed that there was variation in the extension measured manually and machine measurements, which resulted in variation in the strain 1 and strain 2. The average difference between the two strains was 52.8% increase in strain 2.

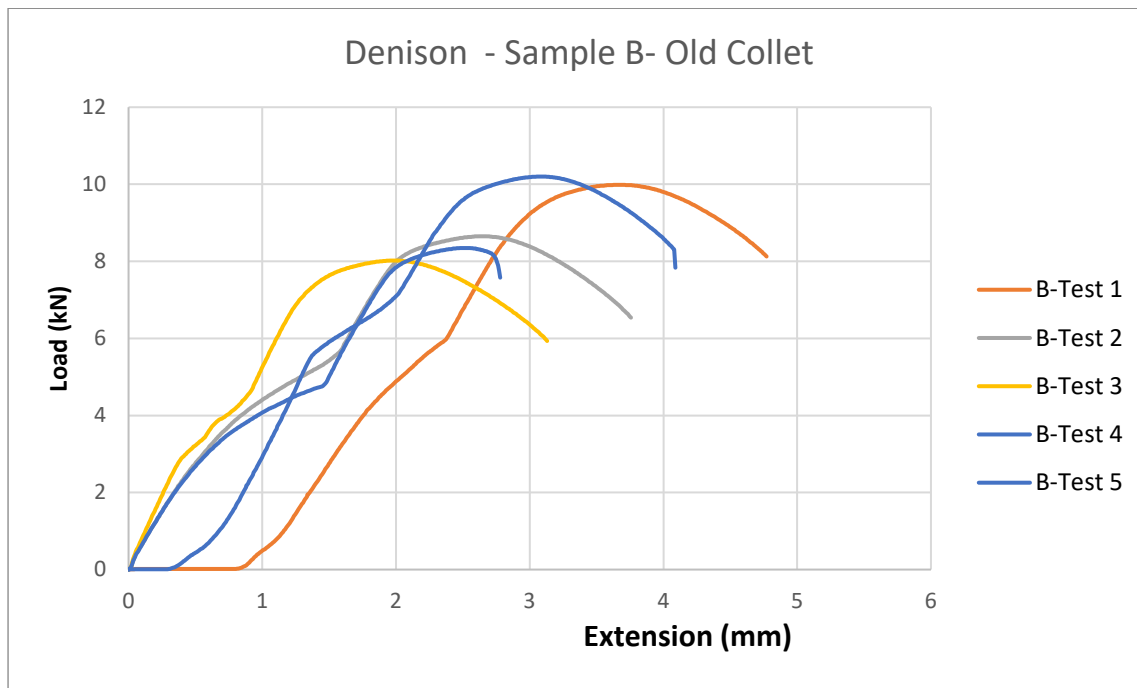


*Figure 24 shows graphs created using sample B and the old collet in the Denison machine*

From the graph in figure 24 it was noticed that two samples encountered extension without load, although the remaining samples started from the same points, but broke at different locations. The first sample was broken at 2.75mm and the last sample broke at 4.8mm, the breaking occurred in the region of 2.05mm.

## ***12.0 Discussion***

To draw a conclusion from the experiment results, there will be three stages of comparisons between the all results. Comparisons will be undertaken between the data from Hounsfield machine and the Denison machine, the new collet against the old collet, and, finally, the sample K (carbon steel 0.54%) and sample B (carbon steel 0.15%).

Comparisons between the Hounsfield tensile testing machine and Denison tensile testing machine were made using the new collet. When looking at data in Table 2 sample K, the average maximum stress was 15.89 KN and the difference in strains averages were 24.3%, but in the Denison machine the average maximum load sample K was 13.3 KN and the average difference in strains were 32.2%. In this test only three samples were used in the Denison machine and five samples were used in the Hounsfield machine. Therefore, the difference between the two machines measurement was 2.55 KN in load and 7.95% strain. When we look at the graphs obtained from the two tables, however, although there were variations in the breaking points among the graphs, the maximum load points were fairly good. According to (Shimadzu, 2018) if there was a variation in the tensile testing results at breaking points or elongation and tests produced repeatable maximum load which is similar, the result would be acceptable.

When comparing the Hounsfield and the Denison testing machines using the old collet sample K from Table 3, the data obtained from the Hounsfield machine highlighted that the average maximum load was 15.34 KN and the average difference in strains was 50.3%. However, when using data in Table 5 obtained using the Denison machine with sample k and the old collet, it was noticed that the average in maximum load was 15.01 and the difference in strains average was 95.13 %. Therefore, when comparing data from the two machines, the average maximum load was almost similar, but the difference in average between two strain averages was 44.83% difference. In additional graphs (Figures 18 and 20) there is a wider breaking region shown among specimens.

The comparison between the Hounsfield and Denison tensile testing machines using the sample B from Table 6 created using the Hounsfield and new collet with sample B, highlighted that the average load was 9.11KN and the difference in strain averages was 23.9%. A similar pattern was produced within graphs, although the breaking occurred in the region of 0.9mm. However, in Table 7 and Figure 27, data obtained from the Denison machine, the average maximum load was 10.2KN, and the difference in average strains was 33.3% while the region

of breaking was 1.17 mm. Therefore, to compare the data from the two machines using the new collet the difference in maximum load was 1.09KN and percentage strain difference was 9.4%, while the difference in the breakage region was 0.27 mm.

Finally, comparison between the two machines using the old collet sample B from the data in Table 7 and Figure 22 made clear that the Hounsfield machine has the average maximum load was 9.95 KN and the strain average difference was 39.4%; the sample breaking region being 1.0 mm.

In addition, the data in Table 9 and Figure 24 obtained using the Denison machine, new collet sample B, highlighted that the average maximum load was 9.04 KN, while the difference in strain was 52.8% and the breaking region was 2.05 mm. When comparing between the two, the difference in maximum load is 0.91KN, while the difference in average strain is 13.4% and the breakage region is 1.05mm.

### ***13.0 Analysis***

From the data presented above it was noticed that the difference in strains percentage was always high. When comparison involved the old collet in the Hounsfield and the Denison tensile testing machines, it was 13.4% strain difference between the two machines using the sample B and the old collet, and 44.83 % strain difference between the two-machine using the sample K with the old collet. This figure is lower when comparisons involved the new collet. However, the increase in the percentage difference of 44.83% in sample K is due to it being made from hard material which requires more force to break, therefore sample slip inside the collet during the test would contribute to an unstable result of extension in the sample; hence the change in extension effecting the strain calculations, since strain is the change in length divided by the original length. (Gedney, 2002) stated that wear or dirt in a collet can result in specimen slippage, which always makes the stress and strain diagram ineffective. (Gedney, 2002) also added that misalignment in a collet or jig during the test can also affect the result by giving lower tensile stress, therefore strain can be affected. Furthermore, it is recommended by the same author that the grip face (collet) should be inspected periodically and worn collets should be replaced and dirt should be cleaned; adding that proper alignment is vital for each test.

To further validate his claims and provide tangible evidence for his hypothesis, two years after making such statements, the author (Gedney, 2005) provided a diagram to show the effect of sample slippage on the stress and strain result. The diagram below shows the effect of slippage on the tensile test result.

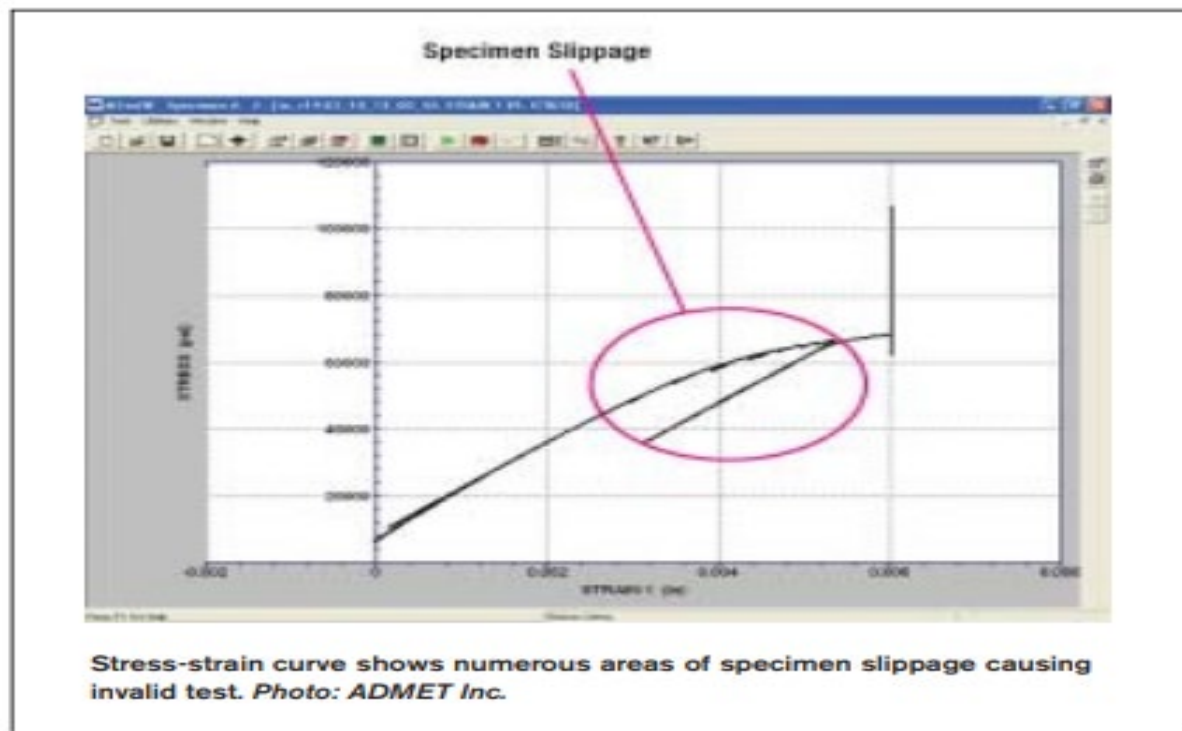


*Figure 25 created by slipping specimens*

(Gedney, 2005)

From the diagram above in Figure 25 it was noticed that the irregular curve shown in the graph was produced due to slippage during the test. It is crucial to note that similar graphs were produced by the old collet in the Hounsfield and in the Denison tensile testing machines, as shown previously in Figures 18, 20, 22 and 24.

Although the irregular curves were not as sharp as those in Figure 25, they are not regular and do not display typical tensile test graph results as shown in Figures 17, 19, 21, and 23, which were obtained using the new collet.

It was also suggested by (Malcolm S Loveday, 2004) that bad gripping during the tensile testing can be responsible for a substantial difference in the outcome of the test. This would be due to the system being unable to apply uniform strain across the sample, cross-sectional or along the length. It could also be argued that the effect of deficiency in clamping or misalignment and precision of grip components can include the following;

- The gripping system will introduce a nonlinear element in the load train, and this would be responsible for unexpected departures from the rate of strain during the test.

- Side to side variation in the pinning or clamping arrangement.

These two points could have been applied in both machines, because the gripping can be used in the Hounsfield machine and both the gripping and clamping can be used in the Denison, since the jig is involved in the operation.

Form the result obtained using the new collet it was noticed that the specimens break from the middle, as illustrated below in Figure 26, however this was different when the old collet was used, wherein the specimens do not break from the middle when using both machines, as illustrated in Figure 27. Furthermore, the stress on the specimen was concentrated in the middle when finite element analysis simulation was carried out, according to picture in Figure 28.

The picture below shows the breaking points on samples using the new collet in both machines.



*Figure 26 shows samples broken from the middle created by the new collet from both machines.*

The picture below shows the breaking point in specimens in the Hounsfield and Denison machine using the old collet.



Figure 27 shows samples broken from near the specimen's shoulder, created by the old collet from both machines.

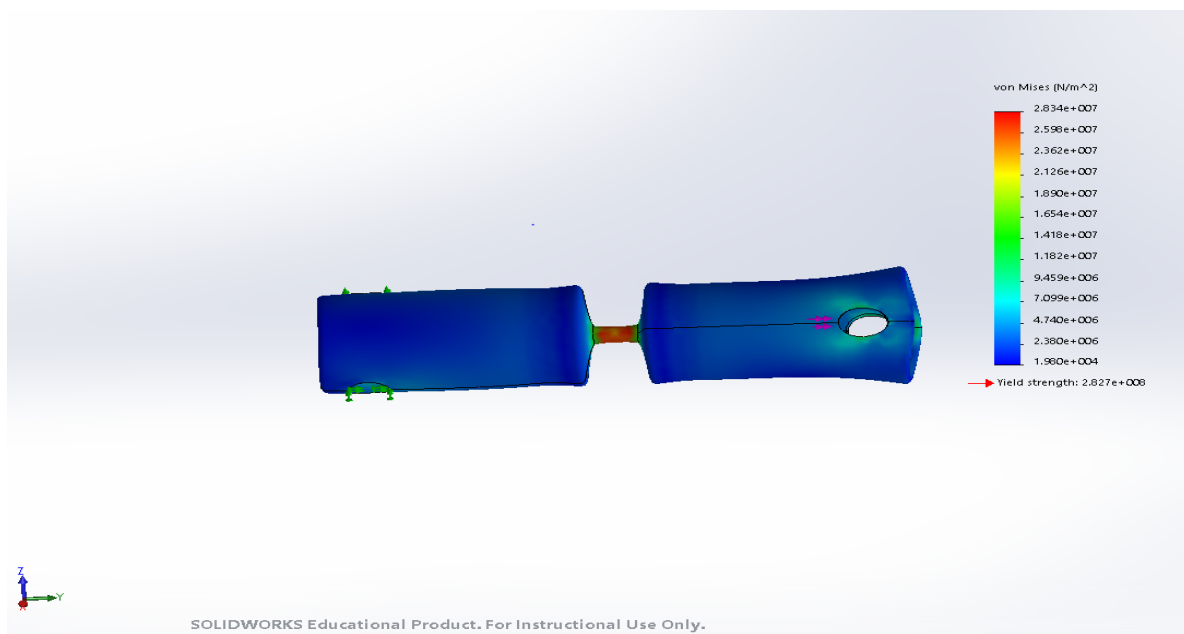


Figure 28 Solidworks FEA simulation shows the area with concentrated stress in the middle.

Therefore, if specimens are not breaking from the middle this indicates that there is problem associated with the load distributions resulting from the wear in the collet, which effects the gripping and holding of specimens, and produces the tensile testing collet misalignment phenomena. According to (Chen, 2018) it could be argued that, when the collet grip is off centre, it produces misalignment that will concentrate the stress away from the centre of the specimen, causing it to break near the shoulder of the specimen. It was also suggested by (Thomas, 2015) that, when the specimen breaks from near the shoulder and not in the middle, the outcome of this test should be avoided, and that one should consider the test as a field test that will cause stress and strain curve data lower than expected. It was strongly recommended by (Thomas, 2015), that the sample should break from the middle of the gauge length. (Bayfield, 2017) agrees with both the above statements in which it is asserted that the specimen in a tensile test should break from the middle.

Therefore, from the physical and theoretical evidence presented above, and the research carried out, it can be stated that the old collet failed to produce correct and valid results of tensile testing because of wear effecting the performance. Whilst it could be argued that such wear could produce a slightly acceptable result, it cannot maintain accurate results when a series of tests are undertaken.

## *14.0 Conclusion*

This project aimed to investigate how the wear on a collet would affect the outcome of tensile testing operations. To accomplish such a goal a research plan was established. First research was carried out on the tensile test properties on a typical tensile test graph of a mild steel. Also, research was carried out on the type of material that can be used in tensile testing typically, and the specimen's material of mild carbon steel and high carbon steel. Further research was undertaken in to the operations surrounding those metals such as wear, heat treatment and Harding, and the impact of those types of operations on the collet and the specimens used in the experiment.

To validate the practical experiments a new set of collets were purchased from a supplier. In order to achieve this, the purchasing guidance was followed, and the new collet was bought using the e-purchasing system.

To gain more accurate results, validation of the results was needed. Therefore, the use of different machines was necessary. The Denison tensile testing machine was to be used for more validation, which works differently to the Hounsfield, therefore modification was needed. To modify the Denison machine the engineering design process was followed. After multiple options were established, only one of these options was selected, which was to design a jig. Therefore, the conceptual design of the jig was drawn in Solidworks and its functionality was assessed using Solidworks FEA. Finally, the jig was created in the workshop using the conventional machining operations that include lathe, milling, drilling and deburring machines.

All tools needed to carry out the investigation were made available; therefore, it was followed by the experiments that were carried out using two different types of materials: samples B and K, with 20 samples from each specimen. The experiment was undertaken in both the Hounsfield machine and the Denison machine using the old and new collet, and the results from those experiments were compared to each corresponding machine or collet. The outcome of these experiments was that the old collet had wear which made it unable to produce accurate results. Therefore, the wear on the old collet effected the result of tensile testing, which satisfied the hypothesis of the project.

## ***15.0 Recommendation***

There are two areas of recommendation, first when using the collet only in the Hounsfield machine, and when using the collet and the jig in the Denison machine. When carrying multiple or single tests, the position of starting must be from one location to prevent creating a dead load or extension without load in both machines. When using the Denison machine, when a jig is used, make sure that the two collets are properly aligned, or that a sample aligner can be introduced, which is a small piece of metal that attaches directly to the collet. Also, when using the Denison machine, the collet ring can slip down during the test. To prevent this, a thin piece of paper (about 20 mm long and 5mm wide) can be inserted between the collet and its ring.

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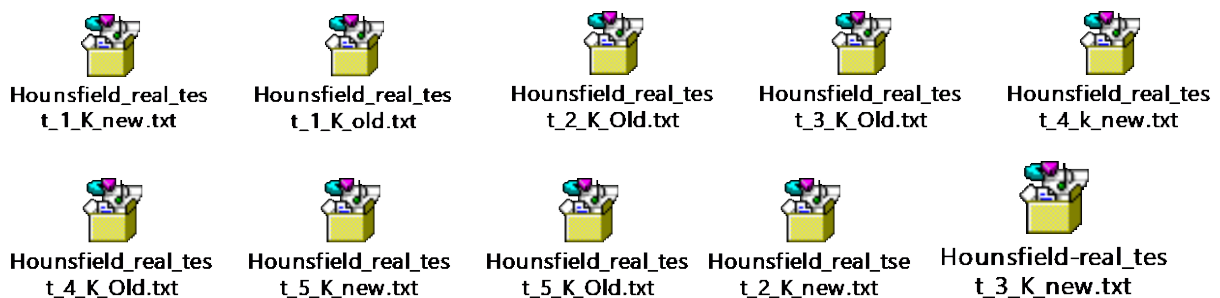
## 17.0 Appendix

Some appendices of the experiments raw data were only inserted as icons due to the large amount of raw data, which exceeds the maximum display required in the final year project report, therefore this raw data can be viewed by double clicking any icon blew when viewing this report in a computer screen. If you are reading the hard copy, you can access the raw data using the One Drive link below and typing it into google search engine.

<https://uwotdsd->

[my.sharepoint.com/:f/g/personal/ifadul\\_148243\\_student\\_uwotdsd\\_ac\\_uk/EhidiuPZ4atCmQ-8vH7yE7sBGbc0GqqnXROrQ1JUq4WXrA?e=5%3a0v7N8W%3aorigemail](https://my.sharepoint.com/:f/g/personal/ifadul_148243_student_uwotdsd_ac_uk/EhidiuPZ4atCmQ-8vH7yE7sBGbc0GqqnXROrQ1JUq4WXrA?e=5%3a0v7N8W%3aorigemail)

### 17.1 Appendix: raw data from the Hounsfield machine sample K, new and old collets



## 17.2 Appendix: graph from the Hounsfield machine, sample K, new and old collets



1\_Hounsfield\_1\_rea  
l\_test\_1\_k\_new.xlsx



2\_Hounsfield\_2\_rea  
l\_test\_2\_k\_new.xlsx



3\_Hounsfield\_3\_rea  
l\_test\_3\_k\_new.xlsx



4\_Hounsfield\_4\_rea  
l\_test\_4\_K\_new.xlsx



5\_Hounsfield\_5\_rea  
l\_test\_5\_K\_new.xlsx



6\_Hounsfield\_1\_rea  
l\_test\_1\_K\_Old.xlsx



7\_Hounsfield\_2\_rea  
l\_test\_2\_K\_Old.xlsx



8\_Hounsfield\_3\_rea  
l\_test\_3\_K\_Old.xlsx



9\_Hounsfield\_4\_rea  
l\_test\_4\_K\_Old.xlsx



10\_Hounsfield\_5\_rea  
al\_test\_5\_K\_Old.xlsx

## 17.3 Appendix: raw data from the Denison machine, sample K, new and old collets



1\_Denison  
\_real\_test\_1\_k\_Data\_



2\_Denison  
\_real\_test\_2\_K\_Data\_



3\_Denison  
\_real\_test\_3\_K\_Data\_



4\_Denison  
\_real\_test\_1\_k\_Data\_



5\_Denison  
\_real\_test\_2\_k\_Data\_



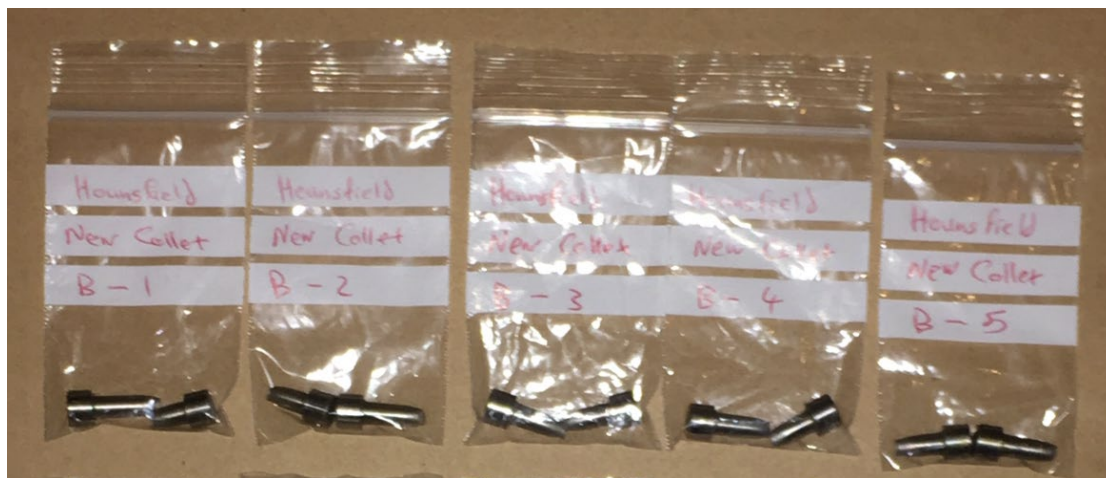
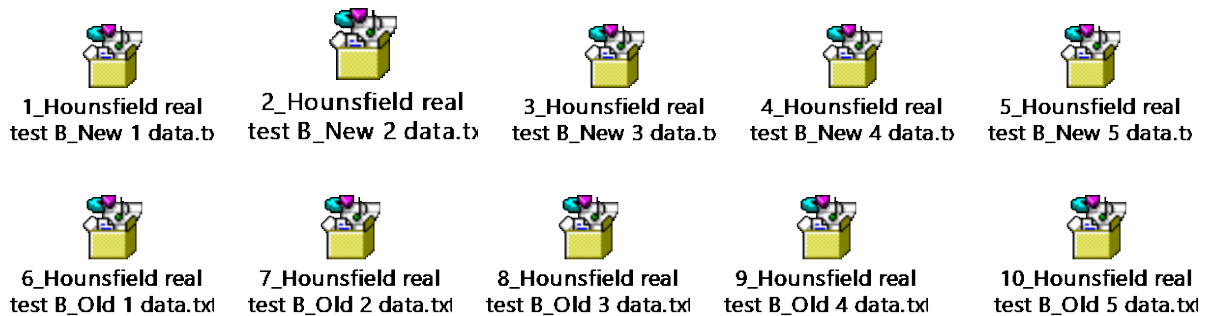
6\_Denison  
\_real\_test\_3\_k\_Data\_



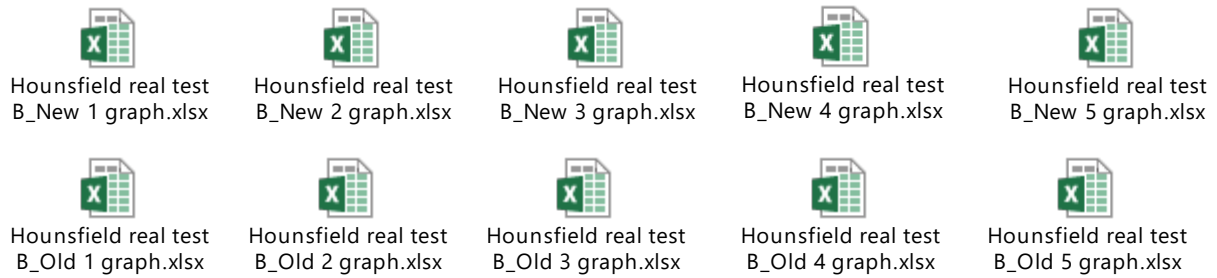
#### 17.4 Appendix: graphs from the Denison machine using sample K, new and old collets



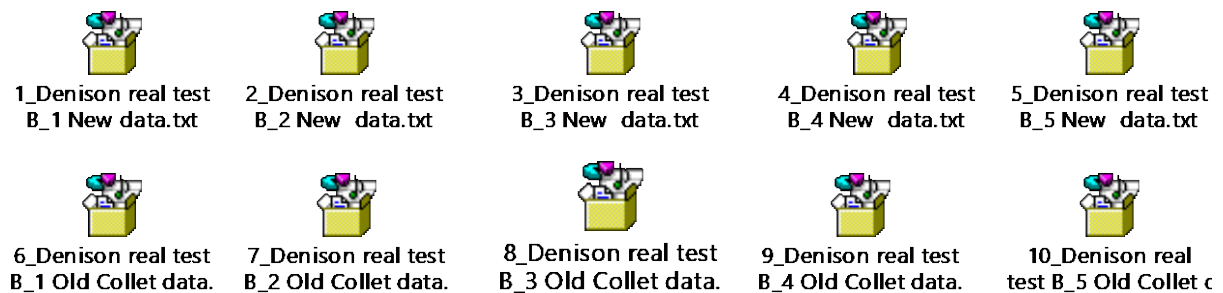
#### 17.5 Appendix: raw data from the Hounsfield machine, sample B, new and old collets



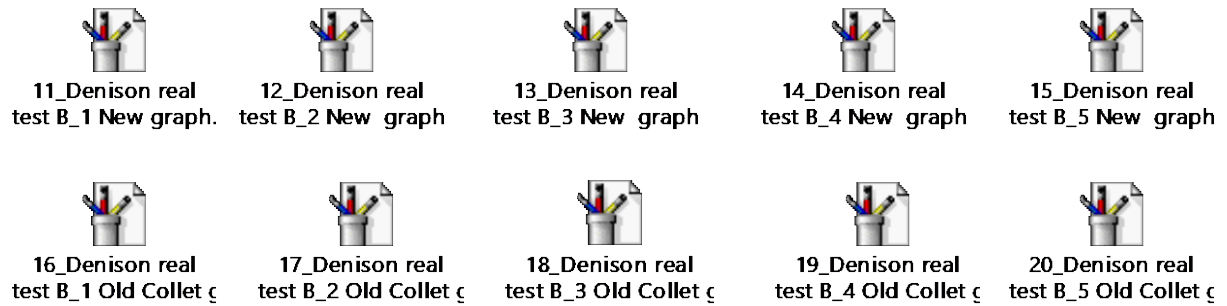
## 17.6 Appendix: graphs from the Hounsfield machine, sample B, new and old collets



## 17.7 Appendix: raw data from the Denison machine, sample B, new and old collets



### 17.8 Appendix: graphs from the Denison machine, sample B, new and old collets



### 17.9 Appendix: broken specimens placed together under the AMCap camera

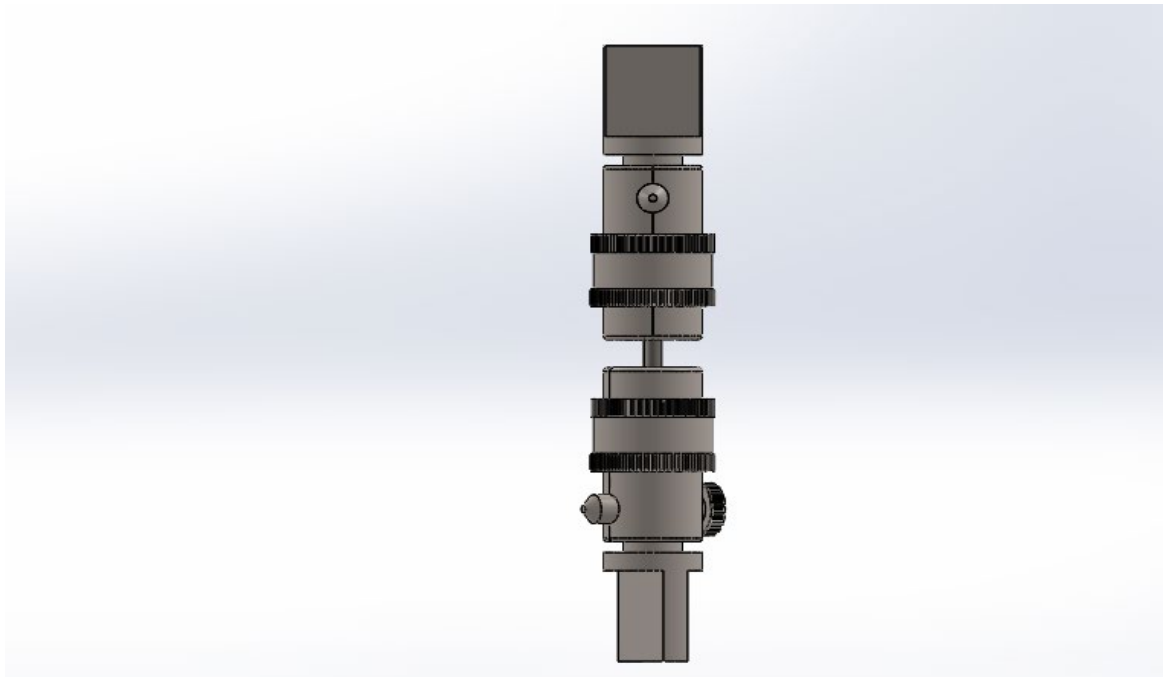




18.0 Appendix: show the metal bar used in the jig design



18.1 Appendix: shows the jig during trial in Solidwork and the Denison machine





18.2 Appendix shows the usage of Vernier calliper before the test in the both machines



