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APPENDIX GA36a

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Harley Dulton	Student ID number:	
Programme:	HNC Mechanical Engineering		
Module:	Materials		
Module code:	SGDM4003	Contribution to Overall Module Assessment (%):	50%
Lecturer:	Chris Davies	Internal Verifier:	Robert Rees
Assignment Title:	Assignment 1 Tensile Test to Destruction.	Word count (or equivalent):	2000
Submission deadline:		Return date of provisional marks & written feedback:	
Submission method:	All written assessments, where practical and possible, must be submitted via Turnitin unless otherwise instructed by the Lecturer. (Please DO NOT put this assessment specification into Turnitin or it will match many similarities with other students' submissions.) Alternative submission method (if applicable): Late submission of the assessment will result in a late penalty mark. Penalties for late submission: Up to one week late, maximum mark of 40%. Over one week late, 0%. Only the Extenuating Circumstances Panel may approve a change to submission dates.		
Academic honesty / referencing:	Academic honesty is required. In the main body of your submission you must give credit to authors on whose research and ideas your work is based. Append to your submission a reference list that indicates the books, articles, etc. that you have used, cited or quoted in order to complete this assessment.		

Module Learning Outcomes
(from module syllabus)

1. Demonstrate a detailed knowledge and understanding of the structure, properties, processing and subsequently the use of engineering materials;
2. Use standard materials testing apparatus and derive the mechanical properties of materials and analyse and understand the cause of materials failures.

STUDENT FEEDBACK FORM

This section details the extent to which the assessment criteria are demonstrated by you, which in turn determines your mark. The marks available for each category of skill are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Generic Assessment Criteria	Marks available	Marks awarded
1. Engagement with Literature Skills	20	
Clear engagement with wider and suitable literature. Appropriate points made to inform your report although some opportunities were missed (see 2 below).		14
2. Knowledge and Understanding Skills	30	
Very good knowledge and understanding demonstrated. Some opportunities missed (discussion of steel microstructure in relation to α , pearlite and ferrite).		20
3. Cognitive and Intellectual Skills	20	
Sound application of theory to determine property values. Good conclusions made from a well ranging discussion.		15
4. Practical Application Skills	15	
Some good points made about the importance of each property and the general use of the test. Some specific examples would have helped.		10
5. Transferable Skills for Life and Professional Practice	15	
Some minor issues noted but this is a well written and presented report with suitable referencing.		11

Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)

Late Submission Penalties (tick if appropriate)

Up to 1 week late (40% Max)

Over 1 week late (0%)

70 %



Tensile Test to Destruction

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Summary

This report sets out to perform tensile tests on 5 different samples of metal. Some of these samples have been heat treated and most are alloying of some kind. ✓

Tensile tests are used to gather a range of useful material properties, such as yield stress which can be used to calculate the Factor of Safety for a material. The accuracy of the tests could be greatly improved by having the data recorded by a computer and not noted down by hand. ✓

Annealing/normalising increases the ductility of a material by causing recrystallisation to occur within the microstructure of the material. New strain free grains develop at nucleation points within the microstructure and uniformly grow until there are only new strain free grains. Nuclei points are places where the internal stresses are the highest, such as dislocation build up at slip planes or grain boundaries (Bolton and Higgins 2015, p.66). Grain growth can occur if the annealed/normalised metals are heated for too long, causing larger grains to form that give poor mechanical properties. ✓

Alloying increases the strength of a material by substitutionally or interstitially adding secondary atoms to the lattice structure. These atoms distort the lattice and impede the flow of dislocations through the lattice, increasing the force required for slip. Ashby, M.F. and Jones, D.R.H. (1999, p101) ✓
"solute atoms interact with dislocations and make it harder for them to move". Adding more solute atoms increases the strength but lowers the ductility, as seen in the 0.4% steel sample, where no plastic deformation occurs. ✓

Good points made but it would have been good to discuss your results to highlight the points made.

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section number, system needed.

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Introduction

This assignment aims to evaluate and discuss the results gathered from tensile tests performed on 5 different sample materials, and state the significance of the tensile test in relation to material properties gathered and how they can be applied in real life applications.

- 70/30 Brass
- 70/30 Annealed Brass
- Annealed Copper
- 0.1% Normalised Carbon Steel
- 0.4% Carbon Steel

A comparison of the gathered results of the 5 samples will be made and the results compared to standard reference results to show any discrepancies in the test results.

Finally, a discussion on the effects of alloying of metals, microstructure of the materials and any heat treatment and how they affect the material properties.

Objective

The objective of this report is to gather results from tensile tests performed on 5 different materials, listed above. Once the results have been gathered, they will be plotted on Force/Extension graphs. These graphs will then be used to calculate the yield strength and the ultimate tensile strength. Following the test, an evaluation of the effects of heat treatment and alloying on the materials will be made.

Background

Tensile tests are a valuable destructive mechanical test to run on material samples, as it easily allows a number of useful material properties to be calculated from just one test. The data gathered from the test can be used to calculate the yield strength, the ultimate tensile strength (UTS), the reduction in area and the elongation at fracture. Young's Modulus is another valuable material property that is calculated using the results. By gathering these properties, engineers are able to identify what materials are most suitable for a certain task.

Tensile tests apply tensile forces to samples that extend the sample. How a material reacts to these stresses is governed by their Young's Modulus. Higher Modulus values usually indicate stronger but

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more brittle materials. Alloying and heat treatment may also affect how the sample behaves as they alter the microstructure of materials.

Equipment

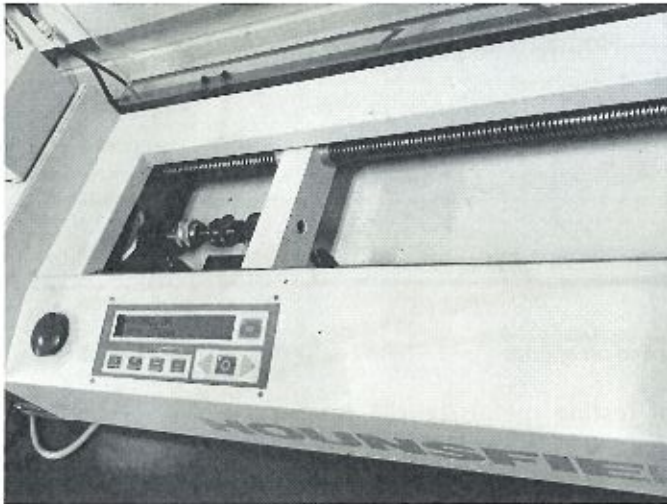


Figure 1 : Hounsfield Tensile Tester

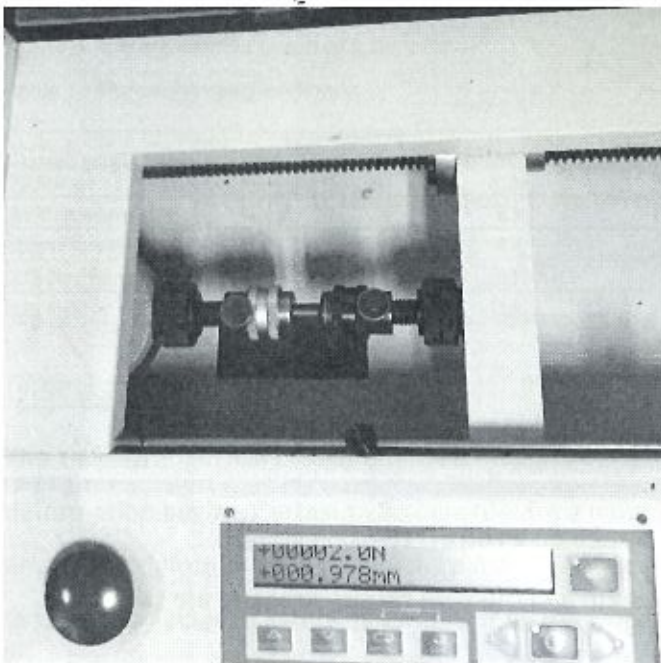


Figure 2: Sample Loaded in Tensile Tester and Display Screen

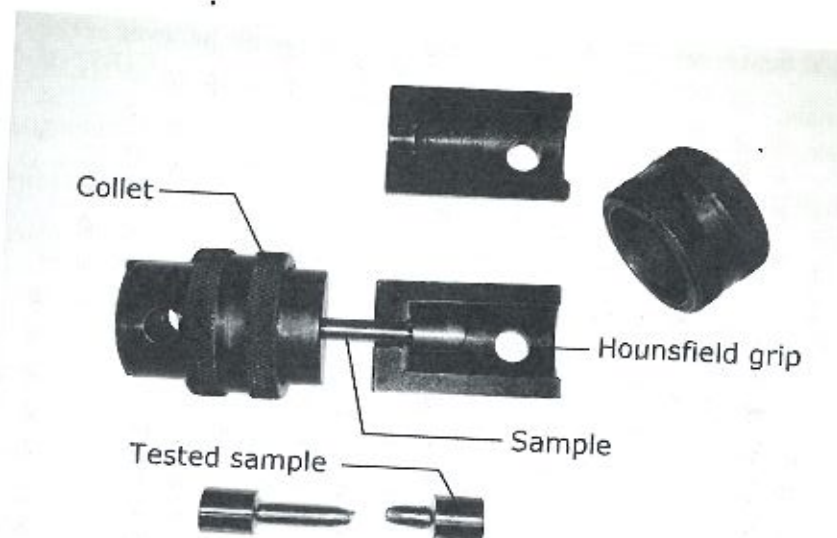


Figure 3 : Static image showing a typical tensile specimen and set of grips

https://www.doitpoms.ac.uk/tlplib/mechanical_testing_metals/tensile_testing.php

Method

The equipment used to perform the tensile testing was a Hounsfield Tensile Tester, shown in Figure.1.

1. The samples are loaded into the grips, a collet is placed over the grips and held in place with a screw. The collet and grip are shown in Figure. 3 (Doitpoms, 2019)
2. The machine is zeroed before the test begins
3. The force is applied slowly, and results are recorded
4. The sample fails and is removed from the machine
5. Following removal, the final gauge length and cross-sectional area are measured and recorded
6. The results are imputed into Excel and plotted on a Force/Extension graph
7. Other values, Tensile Strength, Yield Strength and Ultimate tensile strength, are calculated using the results

Results

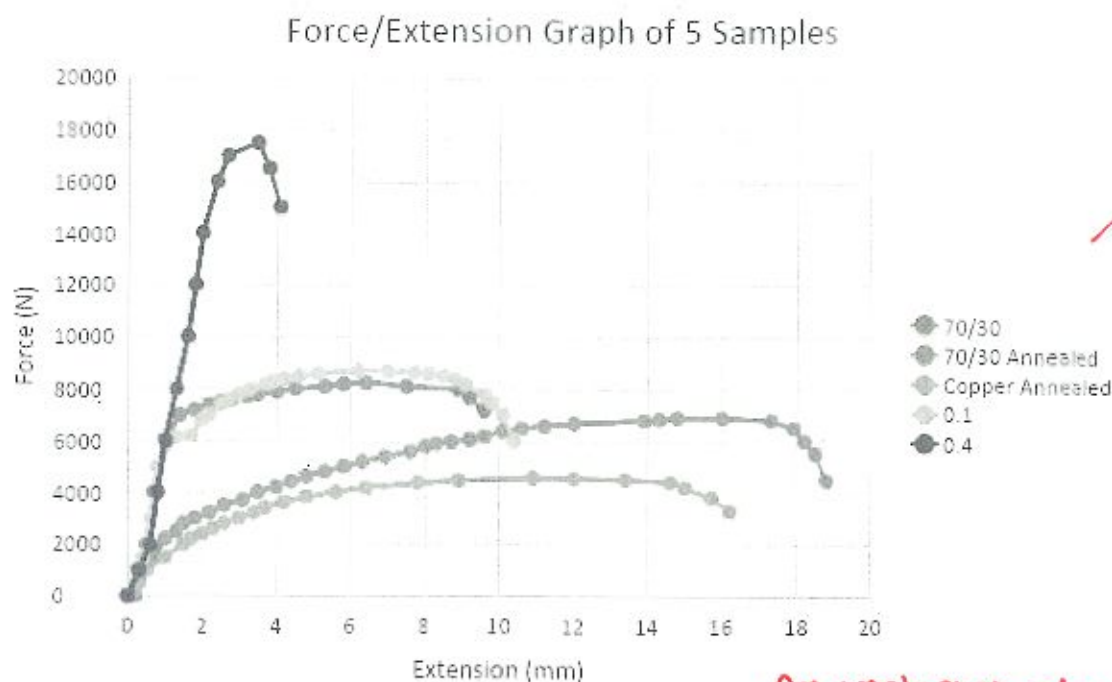


Figure 4: Force/Extension Graph of 5 Samples

Table 1: Material Properties Results

Material	Yield Force (kN)	Maximum Force (kN)	Yield Stress (MPa)	UTS (MPa)	Reduction in Area (%)	Elongation at fracture (%)
70/30 Brass	7	8.25	350	412.5	60	41.6
70/30 Brass Annealed	2.2	6.9	110	345	70	76
Copper Annealed	1	4.6	50	230	72	64.8
0.1% Steel Normalised	6.15	9.7	307.5	435	45	45
0.4% Steel	17	17.5	850	875	25	17.2

An inclusion of a typical calculation for each would have been good.

Discussion

The Yield strength is a measure of how much stress a material can withstand before plastic deformation begins. Certain tasks may require a material to withstand a high stress and not allow any plastic deformation, as a structure may fail if plastic deformation occurs. Yield Strength is used to calculate Factor of Safety by dividing it by the working load. A high Factor of Safety is crucial in certain industries and situations. Of the samples tested, 0.4% Steel will be the most suitable to withstand a high stress without plastically deforming as it has a high Yield strength. Certain tasks may require a material with similar strength to a high carbon steel, such as 0.4% steel, but require a lower density/weight. Ti-6 Al4 V alloys of titanium have yield strengths of 800-900MPa and UTS of 900-1000MPa. The results of 0.4% Steel fall within these ranges but the titanium alloy has a density of 4.4Mgm^{-3} compared to high carbon steels density of 7.8Mgm^{-3} . This lighter material is ideal for use in aerospace applications.

Comparing the gathered mechanical properties to standard reference values and some inconsistencies between the two are visible.

Table 2: Properties of the Generic Metals (taken from Bolton and Higgins. 2015, p.12)

Metal	Cost (UK£ (US\$) tonne ⁻¹)	Density (Mg m ⁻³)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)
Iron	100 (140)	7.9	211	50	200
Mild steel	200-230 (260-300)	7.9	210	220	430
High-carbon steel	150 (200)	7.8	210	350-1600	650-2000
Low-alloy steels	180-250 (230-330)	7.8	203	290-1600	420-2000
High-alloy steels	1100-1400 (1400-1800)	7.8	215	170-1600	460-1700
Cast irons	120 (160)	7.4	152	50-400	10-800
Copper	1020 (1330)	8.9	130	75	220
Brasses	750-1060 (980-1380)	8.4	105	200	350
Bronzes	1500 (2000)	8.4	120	200	350

The values for Yield Stress and UTS of the Copper sample were similar to the generic values shown in Table. 2, 50Mpa compared to 75MPa and 230MPa compared to 220MPa. The Copper sample did not have a clear yield point and a lower yield force may have been chosen, resulting in the lower value for Yield Stress.

Both the Brasses had very different Yield Stresses than what is indicated on Table.2. The 70/30 Brass also had a larger UTS than the generic value, while the annealed 70/30 Brass had almost the same value, 345MPa compared to 350MPa.

The 0.1% Normalised Steel had a higher yield stress value than generic Mild Steel but the value for UTS was similar. 0.4% steel is a high carbon steel, on the lower end of the carbon wt%. Both the yield stress and UTS fall within the property ranges indicated on Table.2.

The discrepancies seen between the gathered results and a generic table may be due to the heat treatment performed on some of the samples or the inaccuracy of the testing method.

The first samples to be discussed are Annealed Copper, Annealed 70/30 Brass and 70/30 Brass. These 3 materials are all non-ferrous metal with FCC crystal structures, see Figure.5.

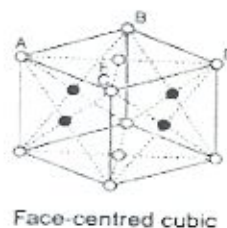


Figure 5: FCC Crystal Structure (Bolton and Higgins 2015, p.43)

Both the Copper and the Annealed 70/30 Brass were the most ductile of the 5 samples, with Percentage elongations of 64.8% and 76%. Little to no elastic region was seen in either of the samples, indicating that only a low stress was needed to plastically deform the samples. This factor contributed to their yield strength being the lowest among the other samples. Brass is an alloy of Copper and Zinc. While the Brass sample contains a large amount of Copper (70%) and has the same structure as Copper, it had a higher UTS and percentage elongation than Copper. These increases in material properties are due to the effects of alloying.

Brass is a substitutional alloy of Copper and Zinc. Substitutional alloying can only occur between atoms of similar size (Bolton and Higgins 2015, p.96). Substitutional alloying is governed by a set of rules known as the Hume-Rothery Rules:

1. The radius of the solute and solvent atoms cannot differ by more than 15%

$$\% \text{ difference} = \left(\frac{r_{\text{solute}} - r_{\text{solvent}}}{r_{\text{solvent}}} \right) \times 100\% \leq 15\%.$$

Equation 1: % Difference Equation

2. Similar Crystalline structure
3. Have complete solubility when their valency is the same
4. Similar electronegativity

The Zinc atoms are substituted into the lattice, replacing Copper atoms. The Zinc atoms are larger than Copper atoms, leading them to distort the lattice, Figure.6 (Bolton and Higgins 2015, p.43).

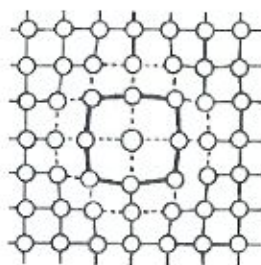


Figure 6: Large Substitutional Atom Distorting Lattice (Bolton and Higgins 2015, p.97)

The increase in distortions within the lattice, as more solute atoms are substituted, increases the strength of the material. Slip within the material becomes more difficult, as dislocations within the microstructure must travel around or through the distortions, thus requiring a greater force to produce slip (Bolton and Higgins 2015, p.99). Simply put by Ashby, M.F. and Jones, D.R.H. (1999, p101). "solute atoms interact with dislocations and make it harder for them to move". Although slip

is initially more difficult to occur within the alloy, it does still occur and the material maintains the ductility of Annealed Copper. This is shown well in the Force/Extension graph of 70/30 Annealed Brass, as it has a higher percentage elongation than Copper.

The results for the 70/30 Brass sample were largely different from the Annealed 70/30 Brass samples. It had a much greater elastic region and higher yield stress (350MPa) and a much smaller percentage elongation (41.6%). The UTS was larger than that of the Annealed 70/30 sample but not as drastically as the difference in yield stress. The difference in yield stress and ductility are effects of the heat treatment that the Annealed sample underwent. Ashby, M.F. and Jones, D.R.H. state (1999, p55), annealing occurs "when cold worked metals are heated to about $0.6T_m$ and new strain-free grains nucleate and grow". Annealing is also known as recrystallisation.

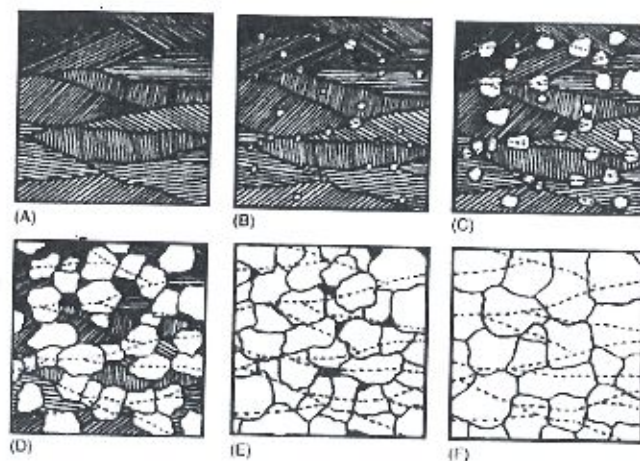


Figure 7: Stages of Recrystallisation (Bolton and Higgins 2015, p.67)

Figure 7 shows the stages of recrystallisation within a cold worked material. A) shows cold worked grains that have been deformed and are elongated horizontally. Cold worked grains are more compact and defects are closer together, making dislocation movement more difficult, lowering ductility. In B) "new strain free grains grow from nuclei formed in the deformed matrix" (Smallman and Ngan 2016, p.351). Nuclei points are places where the internal stresses are the highest, such as dislocation build up at slip planes or grain boundaries (Bolton and Higgins 2015, p.66). The strain free grains continue to grow uniformly, C) and D), within the microstructure, as atoms are transferred across the grain boundaries. At stage E) almost all the cold worked grains have been removed and finally in F) the strain free grains are replaced the strained grains.

These new grains are smaller and more uniformly shaped, allowing them to slip and slide across one another easier. Dislocation are able to travel more easily through this microstructure as the defects are not as densely packed as in a cold worked metal. These factors are what cause an annealed metal to have a greater ductility than a cold worked metal.

The final 2 samples that are to be discussed are 0.1% Normalised Steel and 0.4% Steel. Both these samples are ferrous metals with the BCC structure.

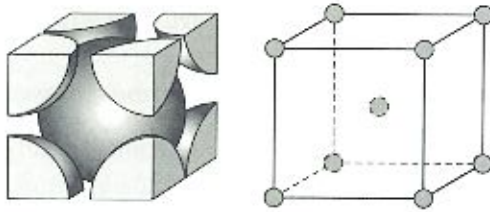


Figure 8: BCC Structure (Callister & Rethwisch 8e, p.49)

Both the samples are alloys of Iron and Carbon. Carbon interstitially alloys within the lattice of Iron. It cannot substitutionally alloy as the carbon atoms radius is smaller than 15% that of Iron's and does not obey rule 1 of the Hume-Rothery substitution rules, stated earlier. Interstitial alloys follow a different set of Hume-Rothery rules, known as the Interstitial solid solution rules:

1. Solute atom radius no larger than 15% of the solvent atoms
2. Similar electronegativity
3. Wide range of compositions
4. Same/similar valency

Could have discussed in terms of Ferrite, Pearlite and Fe₃C.

As interstitial atoms do not replace the solvent atoms within the lattice, they instead sit within interstices in the lattice, Figure 9. Similar to substitutional atoms, the interstitial atoms distort the lattice and increase the strength of the material by disrupting dislocation movement. Increasing the wt% of Carbon within a steel, greatly increases the strength of a steel, as more distortion, more force required for slip. Increasing the wt% of carbon does drastically lower the

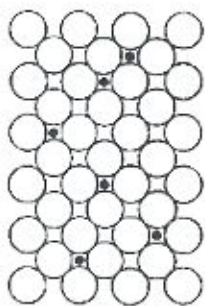


Figure 9: Interstitial Atoms within a lattice (Bolton and Higgins 2015, p.97)

ductility of Steel though. 0.4% Steel underwent little to no plastic deformation following the yield stress being passed. This is caused by the extra interstitial carbon atoms within the lattice. The dislocations travel through the lattice and build up at slip planes and grain boundaries as the metal is strained. The interstitial atoms become more densely packed and tensile stress is applied to the sample.

The increased density further increases the force required for slip to occur, and it reaches a critical point after the yield stress, where no plastic deformation or slip can occur and the sample undergoes a brittle fracture.

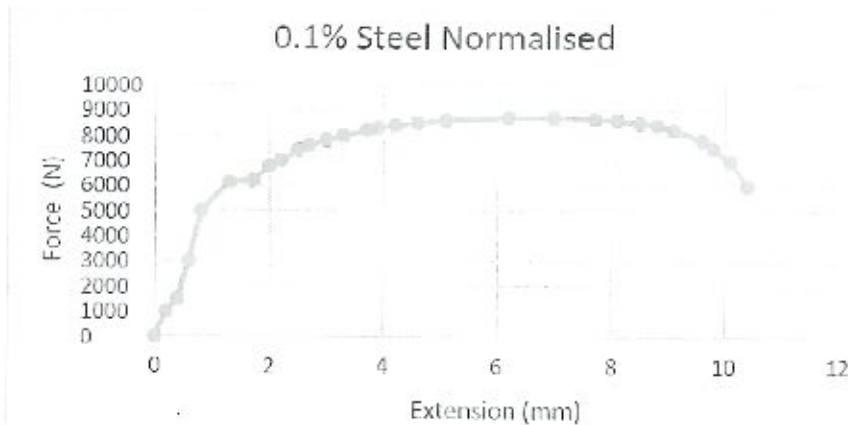


Figure 10: Force/Extension Graph for 0.1% Normalised Steel

Unlike 0.4% Steel, 0.1% Normalised Steel does not plastically deform following the yield stress. Mild steels like 0.1% Normalised steel have a lower and upper yield stress. Following the lower and upper yield stress the material undergoes a small region of slip, known as Luders strain. This region of slip has an increase of extension but no increase in force. This is caused as the Luders bands travel from the shoulders of the sample towards the centre and evenly out, causing the force needed to cause extension to rise again.

The 0.1% Steel sample underwent the heat treatment process of normalisation. This heat treatment process is similar to annealing as it causes the grains within the microstructure to recrystallise and for new strain free grains to grow. The difference between the two treatments is how the metals are cooled. Annealed metals are allowed to cool slowly within a furnace, while normalised metals are air cooled. This change gives a much faster rate of cooling, and a lower ductility compared to annealings' controlled rate (Metal Supermarkets UK - Stainless Steel, Aluminium, Bright, Black, Engineering, Bronze, Copper, Brass, Tool, Galvanized, 2019).

As the rate of cooling is quicker, there is less chance of grain growth following recrystallisation. Grain growth occurs as grain boundaries migrate, larger grains increase in size and smaller grains shrink as their atoms diffuse into the larger grains (Callister, D. W. and Rethwisch, D.G. 2018, p.224). Grain growth in the microstructure can lead to unwanted material properties, as larger grained materials are less ductile and weaker. If grain growth occurs in a material, it must be plastically deformed and annealed/normalised again.

Conclusions

In conclusion tensile tests are used to gather a range of useful material properties, such as yield stress which is used to calculate the Factor of Safety for a material. The accuracy of the tests could be greatly improved by having the data recorded by a computer and not noted down by hand.

Annealing/normalising increases the ductility of a material by causing recrystallisation to occur within the microstructure of the material. New strain free grains develop at nucleation points within the microstructure and uniformly grow until there are only new grains. Grain growth can occur if the annealed/normalised metals are heated for too long, causing larger grains to form that give poor mechanical properties, requiring the material to be plastically deformed and annealed again to obtain the desired mechanical properties.

Alloying increases the strength of a material by substitutionally or interstitially adding secondary atoms to the lattice structure. These atoms distort the lattice and impede the flow of dislocations through the lattice, increasing the force required for slip. Adding more solute atoms increases the strength but lowers the ductility, as seen in the 0.4% steel sample, where no plastic deformation occurs.

List of References

Bolton, W. and Higgins, R.A. (2015). *Materials for engineers and technicians*. London: Routledge, Taylor & Francis Group ; New York, Ny.

Elsevier Science Publishers, Ashby, M.F. and Jones, D.R.H. (1999). *Engineering Materials 2: An Introduction to Microstructures, Processing, and Design*. [online] Butterworth-Heinemann. Available at: <https://www.elsevier.com/books/engineering-materials-volume-2/jones/978-0-08-054565-3>.

Callister, D. W. and Rethwisch, D.G. (2018). *Materials science and engineering : an introduction*. Hoboken, Nj: Wiley.

Metal Supermarkets UK - Stainless Steel, Aluminium, Bright, Black, Engineering, Bronze, Copper, Brass, Tool, Galvanized. (2019). What Is Normalising? | Metal Supermarkets UK - Stainless Steel, Aluminium, Bright, Black, Engineering, Bronze, Copper, Brass, Tool, Galvanized. [online] Available at: <https://www.metalsupermarkets.co.uk/what-is-normalising/>

Smallman, R.E. and Ngan, A.H.W. (2016). *Physical metallurgy and advanced materials*. Amsterdam: Butterworth-Heinemann.