Material Testing

Name

Institution

Test 1: Material testing of different metals

Purpose

The objective of this exercise is to determine mechanical properties of three specimens; aluminum, brass and steel before and after being heat-treated. The analysis was to check the behavior of the specimens in terms of strain and application of loads.

Abstract

This exercise entails mechanical properties of three metallic specimens; aluminum, brass and steel. The investigation is to find out how heat treatment processes such as annealing and quenching affect structural and mechanical properties of the three specimens. This is done by examining how the treated and untreated specimens behave under applied forces. When the load is applied, the beams behave differently as observed from the force-strain graph. Heat treatment encompasses alteration of the crystalline structure and microscopic composition of metallic elements by heating the specimens to high temperatures and then cooling them down either rapidly (quenching) or slowly. The difference in heating and cooling patterns results in different products that are either brittle or tough.

Theory

Different materials exhibit mechanical properties that are varied during testing and field applications. The most important parameters that have been studied in-depth include tensile strength, yield strength, ultimate tensile strength, and ease of failure or fracture and weight/strength ratio (Atanackovic & Guran, 2000). These are just few elements that metallurgists consider when designing which is the correct material to use in a specific location and environment. Metallic specimens such as steel, aluminum and brass have unique properties that suit them to be used in specific areas within the industry. However, engineers and materials scientists have devised ways of improving structural and mechanical properties of the said materials to ensure they perform better under diverse and dynamic conditions. Through heat treatment processes, the microscopic and crystalline structure of these materials are altered to perform either well or poorly as will be shown in this experiment. For example, a steel material can be heat-treated to produce a Martensite product or annealed but the performance of these two products are totally different because the former exhibits brittleness while the latter shows more resistance to wear or failure (Ashby, 2005).

To conduct the investigation, the following specimens were used; aluminum, un-treated brass, annealed brass, normal steel, annealed steel and steel martensite. The main object was to compare how the treated specimens behaved under the applied force in relation to their percentage elongation (strain). The specimens' dimensions remained the same and the force was applied gradually by using turns with the help of a handle on the material testing equipment. Using the force-strain graph, it is possible to know which of the specimen is suitable for higher loads and effects of brittleness as portrayed by steel martensite materials.

Introduction

It is important to understand metallurgical properties of metal elements because they are usually used in various industrial applications. The conditions which affect performance of these metals include loads applied, temperatures, tension forces, pressure, strength-to-weight ratio, service life and corrosion. Engineers and scientists conduct a process known as heat treatment to either harden or toughen the original specimens so as to perform optimally in extreme conditions mentioned above (Stonecypher, 2011). Therefore, an analysis of the mechanical properties of these elements is requisite to understand various parameters and the reasons why such the said treatments are necessary. In order to perform this analysis, the specimens will be subjected to point loads in a gradual manner using a tensile testing apparatus/machine.

Using a turning handle to exert tensile force on the specimen, the extension of the specimen will be monitored on a computer software analysis. It is important to note that the specimens have similar dimensions hence only micro-structural effects influence the behavior of specimens under investigations. From the observation, annealed specimens exhibit different properties from the original specimens as can be seen on the force-percentage strain graph (Abdul & Salit, 2013).

Heat treatment effects on the mechanical properties of steel, aluminum and brass are observable as shown on the graphs. Annealing of respective metals increases their strength and toughness. For instance, the yield strength or yield point of an annealed brass material is higher than that of an untreated brass specimen. A higher force is required to elongate an annealed brass material compared to an untreated specimen for the same percentage strain. This is well illustrated in the results section below.

Procedure

- Six round bars of similar lengths and diameters were selected for analysis. This was to ensure that not dimensional factor affected the results of the exercise
- The apparatus was set up comprising of a digital tensile testing machine connected to a computer for data collection and analysis
- Using the tensile testing machine, loads were applied axially on the specimens on gradual basis using a turning knob as follows; 0 turns, 6 turns, 10 turns up to 80 turns with each of the turn corresponding to readings. The total number of readings was 10 as shown on Table 1.
- The force in KNs was recorded on the computer software and the net movement or extension of the specimens noted for each number of turns or reading.

- The graph of Force, KNs against percentage strain was then generated as shown on Figure 1.
- The same process was repeated for brass and steel but with a different number of turns as shown on Tables 2 to 4.
- The force applied that caused fracture/failure of specimens was recorded.

Results

Table 1 shows data for Al as received

Reading	Turns	End beam position	End beam deflection thouinch	End beam deflection mm	Force kN	Movement mm	Net movement = Extension	Strain %
0	0	0	0	0	0	0	0	0
1	5	0.0035	0	0.0001	0.0008	0.4233	0.4232	1.69
2	10	0.0055	0	0.0001	0.0013	0.8467	0.8465	3.39
3	15	0.006	0	0.0002	0.0014	1.27	1.2698	5.08
4	20	0.006	0	0.0002	0.0014	1.6933	1.6932	6.77
5	30	0.0065	0	0.0002	0.0015	2.54	2.5398	10.16
6	40	0.0065	0	0.0002	0.0015	3.3867	3.3865	13.55
7	50	0.007	0	0.0002	0.0016	4.2333	4.2332	16.93
8	60	0.007	0	0.0002	0.0016	5.08	5.0798	20.32
9	70	0.0075	0	0.0002	0.0017	5.9267	5.9265	23.71
10	80	0.007	0	0.0002	0.0016	6.7733	6.7732	27.09

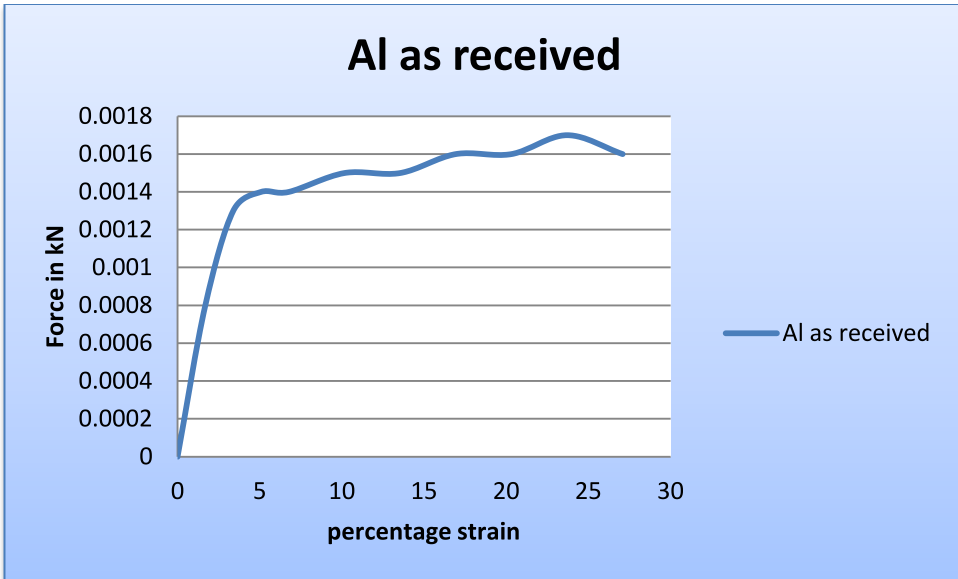

Figure 1 shows force-strain for untreated Al

Table 2: data for annealed brass

Annealed Brass								
Reading	Turns	End beam position	End beam deflection thouinch	End beam deflection mm	Force kN	Movement mm	Net movement = Extension	Strain %
0	0	0	0	0	0	0	0	0
1	5	0.005	0	0.0001	0.0011	0.4233	0.4232	1.69
2	10	0.008	0	0.0002	0.0018	0.8467	0.8465	3.39
3	15	0.0085	0	0.0002	0.0019	1.27	1.2698	5.08
4	20	0.009	0	0.0002	0.0021	1.6933	1.6931	6.77
5	25	0.0095	0	0.0002	0.0022	2.1167	2.1164	8.47
6	30	0.01	0	0.0003	0.0023	2.54	2.5397	10.16
7	35	0.01	0	0.0003	0.0023	2.9633	2.9631	11.85
8	40	0.0105	0	0.0003	0.0024	3.3867	3.3864	13.55
9	45	0.0105	0	0.0003	0.0024	3.81	3.8097	15.24
10	50	0.0105	0	0.0003	0.0024	4.2333	4.2331	16.93
11	55	0.0105	0	0.0003	0.0024	4.6564	4.6567	18.63
12	60	0.011	0	0.0003	0.0025	5.0797	5.08	20.32

Table 3; Brass as received

Brass as received

Reading	Turns	End beam position	End beam deflection thouinch	End beam deflection mm	Force kN	Movement mm	Net movement = Extension	Strain %
0	0	0	0	0	0	0	0	0
1	5	0.0015	0	0	0.0003	0.4233	0.4233	1.69
2	10	0.0025	0	0.0001	0.0006	0.8467	0.8466	3.39
3	15	0.0035	0	0.0001	0.0008	1.27	1.2699	5.08
4	20	0.0045	0	0.0001	0.001	1.6933	1.6932	6.77
5	25	0.005	0	0.0001	0.0011	2.1167	2.1167	8.47
6	30	0.005	0	0.0001	0.0011	2.54	2.6399	10.16
7	35	0.0055	0	0.0001	0.0013	2.9633	2.9632	11.85
8	45	0.006	0	0.0002	0.0014	3.81	3.8098	15.24
9	55	0.0065	0	0.0002	0.0015	4.6567	4.6565	18.63
10	65	0.007	0	0.0002	0.0016	5.5033	5.5032	22.01
11	75	0.007	0	0.0002	0.0016	6.35	6.3498	25.4
12	85	0.0075	0	0.0002	0.0017	7.1967	7.1965	28.79

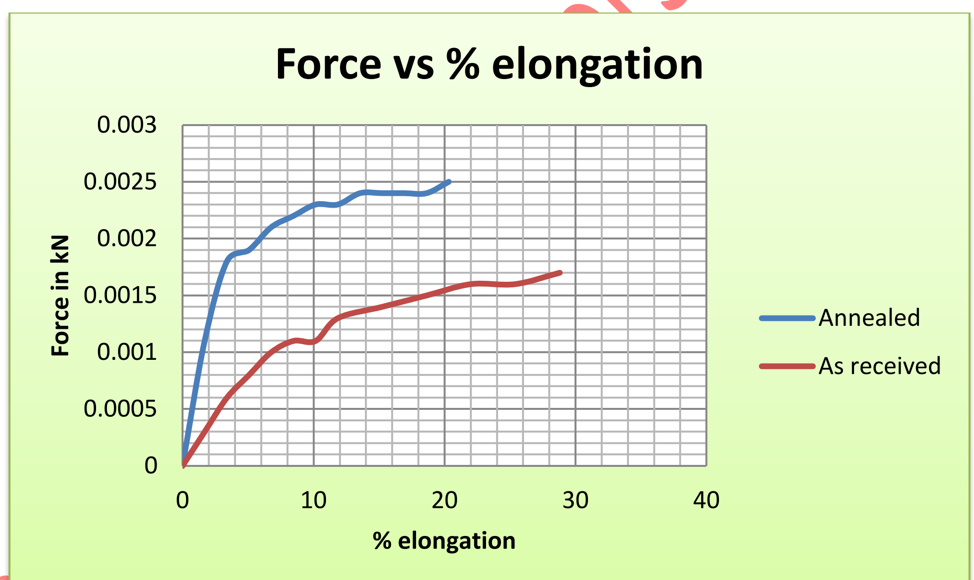

Figure 2: graph of annealed and untreated brass

Table 4: data for martensite

Martensite								
Reading	Turns	End beam position	End beam deflection thouinch	End beam deflection mm	Force kN	Movem ent mm	Net movement = Extension	Strain %
0	0	0	0	0	0	0	0	0

1	3	0.0025	0	0.0001	0.0006	0.254	0.2539	1.02
2	6	0.004	0	0.0001	0.0009	0.508	0.5079	2.03
3	9	0.006	0	0.0002	0.0014	0.762	0.7618	3.05
4	12	0.0075	0	0.0002	0.0017	1.016	1.0158	4.06
5	15	0.0085	0	0.0002	0.0019	1.27	1.2698	5.08
6	18	0.009	0	0.0002	0.0021	1.524	1.5238	6.1
7	21	0.01	0	0.0003	0.0023	1.778	1.7777	7.11
8	23	0.011	0	0.0003	0.0025	1.9473	1.9471	7.79

Table 5: data for annealed steel

Annealed								
Reading	Turns	End beam position	End beam deflection thouinch	End beam deflection mm	Force kN	Movement mm	Net movement = Extension	Strain %
0	0	0	0	0	0	0	0	0
1	5	0.0055	0	0.0001	0.0013	0.4233	0.4232	1.69
2	10	0.008	0	0.0002	0.0018	0.58467	0.8465	3.39
3	15	0.009	0	0.0002	0.0021	1.27	1.2698	5.08
4	20	0.0095	0	0.0002	0.0022	1.6933	1.6931	6.77
5	25	0.009	0	0.0002	0.0021	2.1167	2.1164	8.47
6	30	0.009	0	0.0002	0.0021	2.54	2.5398	10.16
7	35	0.0085	0	0.0002	0.0019	2.9633	2.9631	11.85

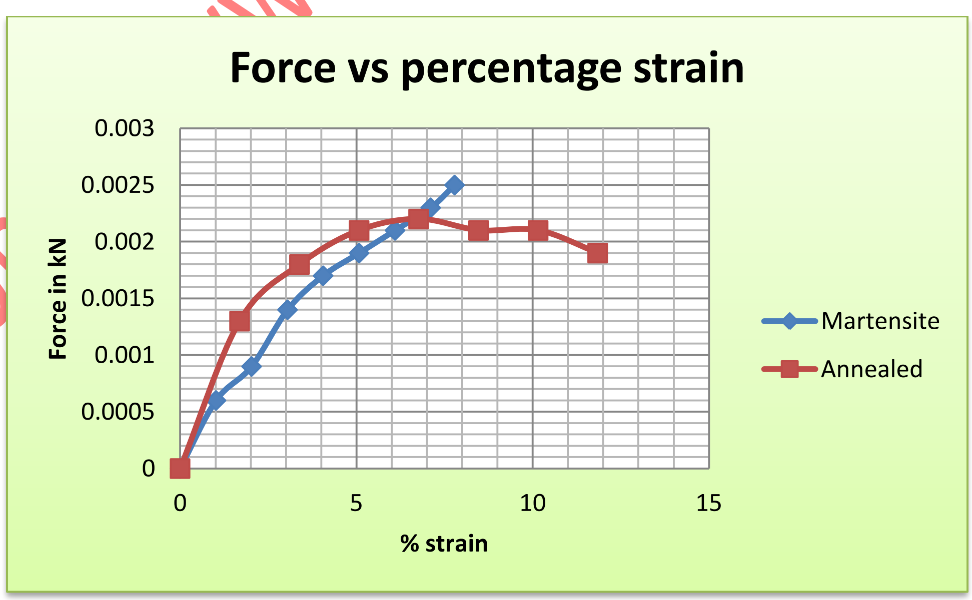

Figure 3: Graph of martensite and annealed steel

Analysis

Having collected the data and drawn the graphs shown above, it is possible to analyze the behavior of the specimens that have been treated and not treated under the influence of applied force. From figure 1and 2, Aluminum tends to yield at higher force than brass that has not been treated. Brass that has been annealed requires a larger force than normal aluminum and its percentage elongation at the yield point is lower than that of untreated brass and aluminum material. Annealed brass requires a larger force (about 0.0018kN) for yielding to take place compared to ordinary brass (0.0011 kN). Steel shows interesting properties depending on whether it is treated or not. From the graph, martensitic steel needs a large force to yield though there is no definite point of yielding. The graph almost appears roughly like a straight line. Annealed steel follows a typical force-extension pattern with the first phase exhibiting elastic deformation before plastic deformation occurs after yielding. Notably, yield point for annealed steel is higher than aluminum and brass. Brass seems to elongate more compared to steel as observed from the percentages of strain from Figure 2 and 3.

Discussion

Based on the analysis above, it is evident that heat treatment has a significant effect on the way materials perform under different conditions. Annealed brass implies that its microscopic and crystalline structure has been altered to improve some characteristics including tensile strength, yielding capacity but poor in elongation. The same case applies to martensite steel. Childs, P. R. N. (2004) established that when the state of ordinary steel is changed from solid to liquid by raising the temperatures above eutectoid point and cool rapidly in cold water or fluid, the final product is martensite. The crystalline structure is change with crystals becoming more dislocated accompanied by numerous dislocations. The final microstructure has ***cementite*** properties which include hardness and brittleness.

As shown from the experiment results, the martensite material did have a lower percentage strain rate compared to other materials and the force required to reach the fracture point is quite large. At the same time, annealed steel undergoes a hardening process, for example, case hardening which improves the strength of the material including its yield strength (In Doroftei et al,. (2014). Mechanical devices such as gears need annealing to ensure the teeth do not wear easily when meshing. According to Callister, (2007) the materials extend significantly as shown by the percentage strain rate because of temperature conditions which enhance expansion and contraction. However, tools or machine elements should be designed carefully to avoid abrupt failures as depicted by martensite products. A sudden change of the working environment where components experience a sudden fall of temperature may cause unexpected failures hence damage or accidents (Abdul & Salit, 2013). The same case applies to brass which is used in components such as rollers that may bend easily under action force. Annealing improves yield strength and toughness allowing the materials to withstand higher loads compared to when they are not treated ((Neghaban, 2000).

Conclusion

The objective of the experiment was achieved and the whole exercise was successful. It was an informative exercise understanding the importance of improving mechanical properties of materials through processes such as case hardening. With such knowledge in mind, it is possible to avoid breakdowns of equipment due to failure and suitable application in industrial practices. The exercise was a bit challenging especially organizing data in excels sheet and generating graphs shown above.

Test 2: Verification of the Theory of Pure (Elastic) Bending

Purpose

The objective of this exercise is to show the use the Sagital ‘Radius of Curvature’ method with a beam and prove the theory of Pure Bending and determine the Young’s Modulus for the beam

Experiment apparatus

- Two load cells
- Three digital indicators
- Two hangers
- A set of weights
- A 6 mm thick beam

Introduction/Background

Structures such a bars that are subjected to pure bending manifest two kinds of lines; circumferential and radial lines. When a beam is placed on two supports which provide upward forces it is referred to as a simply supported beam (Gupta, 2013). Considering two downward forces that are positioned equidistant from the two supports, the system is known as Four Point Bending as illustrated below. F implies a downward force which is equidistant from supports R_1 and R_2.

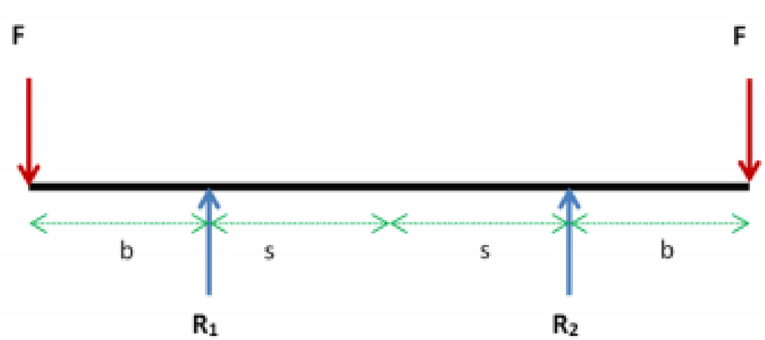

Figure 1 shows a four point bending system

R_1 and R_2 are reaction forces that act upwards

For this particular experiment the set-up is shown below analogous to Figure 1

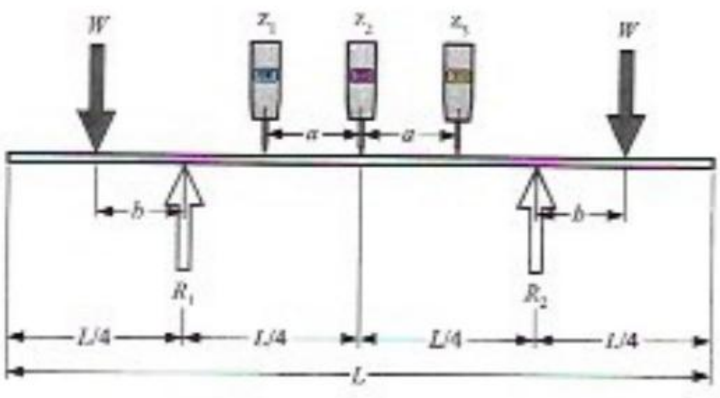

Figure 2 shows a force diagram for verification of pure bending experiment

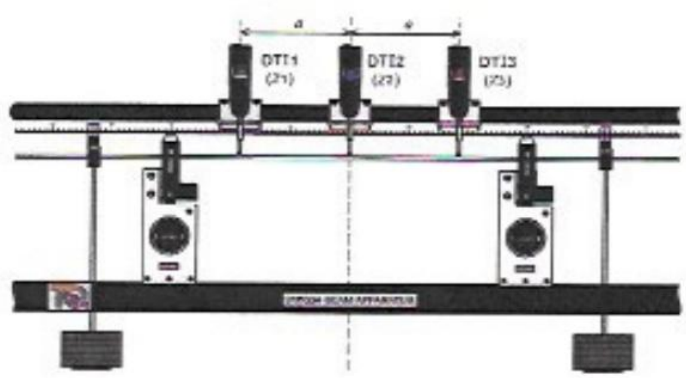

Figure 3 shows a set-up for verification of pure bending experiment

<u>Curvature of the Beam</u>

As the beam bends with the two loads and supports, it does so symmetrically forming something like an arc of a large circle as shown by Figure 4. With this, the Sagital method can be used to prove the pure bending theory (Sinha, 2010). The exercise relates deflection ***h*** to deflections at distances ***a*** from the ***h*** deflections as shown below.

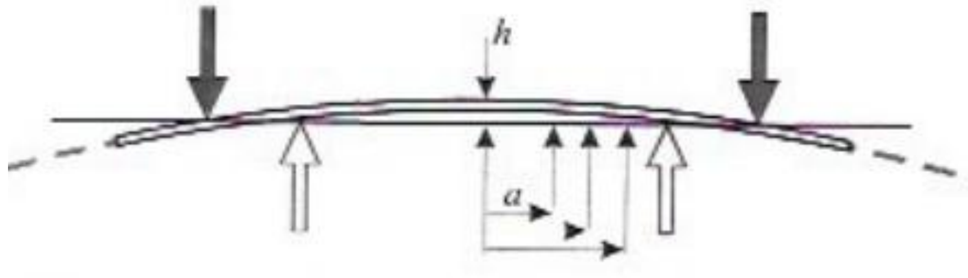

Figure 4 shows curvature of the beam

<u>Procedure</u>

- Blank results table were created similar to Table 2.
- The overall beam length (***L***) was measured and a pencil was used to mark the mid-span and equal distances (l/2) from the mid point. The thickness and width of the beam was measured, for example 350mm.
- A suitable reading adjacent to the middle of the upper scale of the apparatus was chosen to match to the center of the beam.
- Set up the beam as illustrated by Figure 3. The Load cells were positioned at the pencil marks (equidistant from the beam center). The beam's mid-span was positioned directly under the scale reading chosen in the above step c.
- The Load Cells had their locking pins properly fit and the beam had two overhanging ends
- Two weight hangers were put to the beam at equal distances (b) from the supports , for instance, 200 mm away.
- A digital indicator was fixed on the upper cross member to contact the mid-point of the beam. Two more digital indicators were fitted at equal distances (a) from the center (e.g. 100 mm). The stems of the indicators had to be ensured that they are positioned vertically and they were reading zero.

- Equal loads were applied to the hangers in increments as shown in Table 2 and avery time a load was added, the apparatus was tapped gently.
- The readings, z_1, z_2, and z_3, of the three deflections were taken.
- The loads were then removed and the distance (a) between indicators was increased by 50mm and the steps repeated until the final time.

Results and Analysis

$\mathbf{z_1}$, $\mathbf{z_2}$, and $\mathbf{z_3}$ have been recorded in Table 1 below which helped in determining an accurate value of ***h***. Also, an average of the two outside deflections was determined and recorded on the second last column of the table. The average deflections were subtracted from $\mathbf{z_2}$ to get deflection ***h***.

Table 1 showing values of **a, b, z** and **h**

	W (N)	b (mm)	a (mm)	a^2 (mm^2)	z_1 (mm)	z_2 (mm)	z_3 (mm)	1/2 (z_1+z_3) (mm)	h = z_2 - 1/2 (z_1+z_3) (mm)
Test 1	5	250	100	10000	1.73	1.9	1.72	1.725	0.175
	10	250	100	10000	8.5	3.84	3.48	3.49	0.35
	15	250	100	10000	8.25	5.75	5.22	5.235	0.515
	20	250	100	10000	6.99	7.66	6.95	6.97	0.69
	25	250	100	10000	8.68	9.52	8.65	8.665	0.855
Test 2	5	250	150	22500	1.54	1.93	1.54	1.54	0.39
	10	250	150	22500	3.08	3.86	3.09	3.085	0.775
	15	250	150	22500	4.67	5.84	4.67	4.67	1.17
	20	250	150	22500	6.21	7.78	6.2	6.205	1.575
	25	250	150	22500	7.77	9.73	7.76	7.765	1.965
Test 3	5	250	200	40000	1.23	1.92	1.23	1.23	0.69
	10	250	200	40000	2.48	3.88	2.5	2.49	1.39
	15	250	200	40000	3.7	5.8	3.73	3.715	2.085
	20	250	200	40000	4.93	7.74	4.97	4.95	2.79
	25	250	200	40000	6.17	9.67	6.21	6.19	3.48

The graph below shows ***h*** values against load;

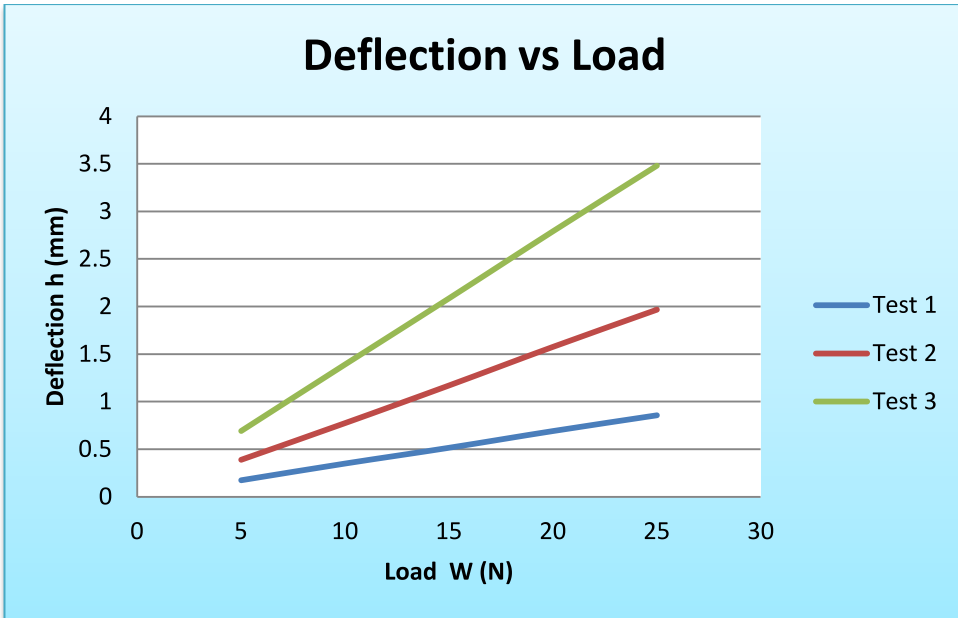

Figure 5; a graph of ***h*** versus load

Test gradients;

$$G_1 = (0.69\text{-}0.175)/(20\text{-}10) = \mathbf{0.034}$$

$$G_2 = (1.575\text{-}0.775)/(20\text{-}10) = \mathbf{0.08}$$

$$G_3 = (2.79\text{-}1.39)/(20\text{-}10) = \mathbf{0.14}$$

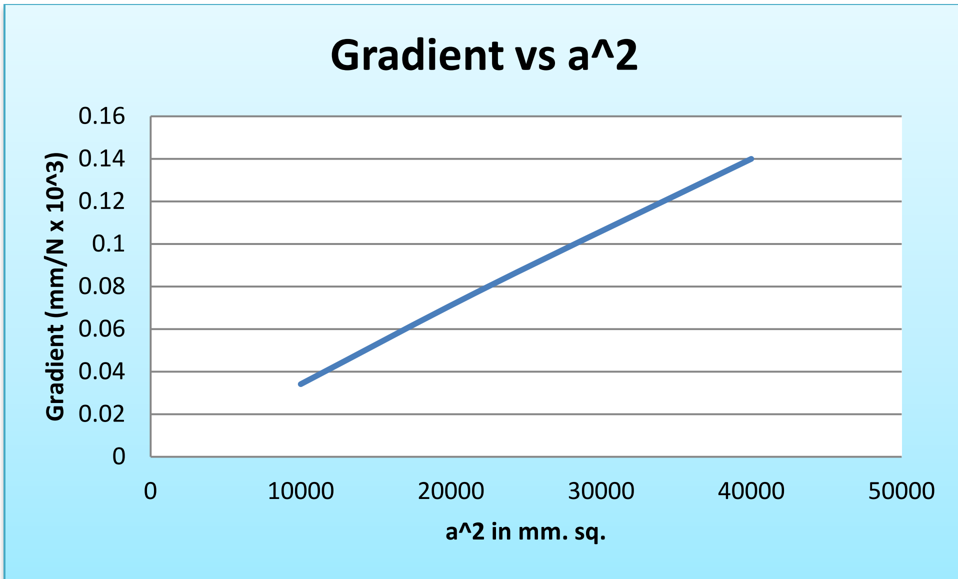

Figure 5; Gradient versus a^2

The gradient of the graph above (Figure 5);

$$\text{Gradient} = \frac{a^2 b}{2EI}$$

When b = 250mm (0.25m),

$$\text{Gradient} = \frac{0.125a^2}{EI}$$

$EI = \frac{0.125}{slope}$ where slope is the gradient of figure 5,

Slope = (0.14-0.034)/ (40000-10000) = **3.5333 x 10^{-6}**

Second moment of area (I) of the beam,

Given b = h = 350 mm

$I = b^4/12 = 0.35^4/12 = 0.001251\ m^4$

$$E = \frac{0.125}{slope\ x\ I} = \frac{0.125}{3.5333x10^{-6}\ x\ 0.001251} = \mathbf{28.28\ GPa}$$

<u>Conclusion</u>

The exercise was successful and the value of Young's Modulus obtained was almost similar to the theoretical value of 28 GPa for composites polymer. However, there is a possibility of some errors in conversion and taking readings. Sagital 'Radius of Curvature' method is a useful method in determining Young's Modulus for specimens subjected to pure bending as it happens sometime in our daily lives.

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