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Experimental Determination of Young's Modulus of Elasticity between Construction Materials Using Some Test Metals and Woods

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ABSTRACT: *The structural strength of a material depends on its satisfactory performance when subjected to loads.Tension tests enable the determination and prediction of the deformation/deflection response of the material properties elastic modulus. This is achieved in this report through constitutive equations that relate loads to deformations using the basic concepts of stress and strain. The values of Young's Modulus for Elasticity (E) for 0.3% carbon (mild) steel, 60/40 brass, Mahogany (hardwood) and Parana Pine (softwood) have been successfully determined from laboratory experiments as 31.4, 16.2, 2.84, 1.41 in (x10^6**psi**) respectively and compared with some published results showing good correlation. Also, the stress and strain of the materials were graphically shown to have good correlations between theory and experimental values and compositions. The results further show that steel and Mahogany are more suitable for structural application than brass and Parana Pine respectively, because of their high E Modulus rating. It therefore implies that steel and Mahogany can withstand more tension hence better bearing capacity for stronger and safer built environment.*

KEYWORDS: *Young's Modulus,tensiontests, bending and compression, deformation and deflection, material integrity, temperature adaptability, material and structural optimization*

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I. INTRODUCTION

Some laboratory experiments were conducted to determine the values of Young's Modulus of Elasticity for 2 metals (mild steel and brass) and timber woods [(Mahogany (hard wood) and Parana Pine (softwood)]. Metals reach melting point at fairly well defined temperature (1450° C for steel) when it loses cohesion and becomes liquid. At room temperatures however the atoms of solid metals (e.g., mild steel and brass) are arranged as crystals in the form of regular matrix/lattice (Schoberand Rautenstrauch, 2005). The arrangement is sustained by strong bonding forces associated with free electrons. Mild steels are plain, low-carbon, general-use unalloyed steels that are easily formed but cannot be heat-treated to increase strength(The Engineering ToolBox, 2005; Borri, A et al., 2003). Timbers are much weaker materials in comparison to most metals. Unlike metals timbers are isotropic materials (Rautenstrauch, K. et al., 2004).). This implies that, the mechanical properties (strength, stiffness etc.) are different in two perpendicular directions.Beer et al. (2002),Maryland Metrics (2005),Plevris and Triantafillou (1992),ROYMECH (2009), Abdel Magid et al. (1996)and Kanamaru. (2001)explored wood beams that were strengthened with non-pre-stressed carbon sheets. But like metals, the properties of timber vary with different species. Most hardwoods are stronger and stiffer (e.g., Mahogany) than softwoods (e.g., Parana pine)(Green et al., 1999). Young's Modulus, E, is one of the most important design parameters for structural materials used to measure the stiffness and springiness of a material and can be used to estimate the deflection produced in a component by a given load joints (Hirai et al., 2006). It is important to note that Young Modulus, E is affected by rising temperature (Callister 2003), implying that material integrity is significantly affected by rise in temperature. This means that material selection process

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should consider this critical aspect of material and structural optimization, to ensure that materials deployed are capable of temperature adaptability without losing their composite and structural integrity.The value E can be obtained experimentally by imposing stress on the materials and measuring the gradient of the elastic portion of the stress-strain graph(Electro Technical Products, 2002).The objective of this study is to determineYoung's Modulus of Elasticity, E for metals and timber to enable understanding ofstiffness and what is meant by strength, difference in strength and stiffness between materials, and to show how elasto-plastic materials behave under static and variable stressing agents.

II. THEORY AND EXPERIMENTAL METHOD

(a) Metal

The machine used in this experiment was an electronic extensometer (see Fig 1) with very high resolution and accuracy which allow the determination of Young's modulus and yield point. It permits quick and easy examination of a large number of test samples and guarantees a high level of reliability. The procedure starts by measuring the cross-sectional area of the reduced section at multiple locations along specimenfor recording. Next the length of the necked region (Fig 1) is recorded. Turn on pump, clear and home machine. The test procedure follows then, thespecimen loaded into the grips of the universal testing machine to ensure it is centered on the top and bottom. Attach the axial extensometer provided. Where the gage is attached is noted and assured such that they can be collecting useful data. Ensure all channels are zero at start of test. Open Test Navigator software to understand the tensile test about to be performed. The loading rate recorded and type of control being used does not change. The default values for a metals tensile test are used. Pull the pins from the extensometers prior to starting the test. After entering the appropriate information into computer, return "Test Now". When test is complete, assured to the data is saved immediately on desktop. The sample is then removed from the test fixture and the length and cross-sectional area of necked region are recorded. The fracture plane is noted (with video camera, seeFig 1).

The measurement ranges amount to 2 mm in the positive (tensile) and 1 mm in the negative (compression) direction. The large adjustment range of the clamping force allows for the optimal adaptation to the tested material and the sample dimensions. Mechanical stoppers protect against unintended overloads, even in the case of premature breaking of the sample with the extensometer attached. Here:

$$E = \frac{F}{\Delta x} \times \frac{l}{A} \quad \text{-------------------------------------} \ (1)$$

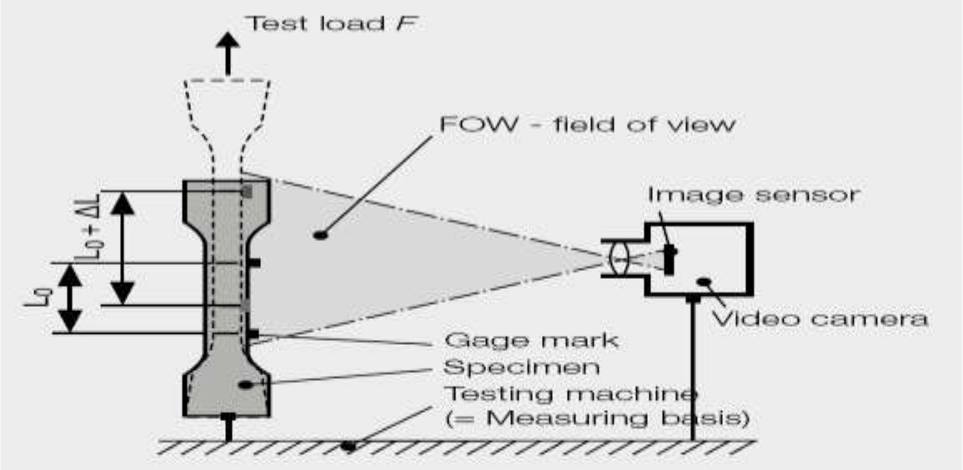

Fig 1: Measuring with extensometers with video camera. Where F = force, A = the original cross-sectional area of the specimen, found using $\pi x r^2$, x = the change in the length, l = the original length (L_0)

(b) Wood

The Hounsfield testing machine (see Fig 2) was applied by fitting a three-point bending jig. The lab procedures start with calculating the maximum load that can be applied to the specimen, assuming an approximate ultimate tensile strength (UTS) of the material. The material is identified and measurements taken, such as the diameter, Length etc. The correct beam is loaded into the Hounsfield (to suit the expected loading at UTS). Load is applied to about 75% of yield to ensure the specimen is fully seated in the jaws. The load is now released and the mercury indicator set. Paper is added to the chart roller and the test is initiated (simultaneously recording the load) until the specimen breaks. The paper is then removed and the % elongation of the specimen measured. Attempt is made to record all sources of error relevant to the measurements taken (force application and possible extension errors).

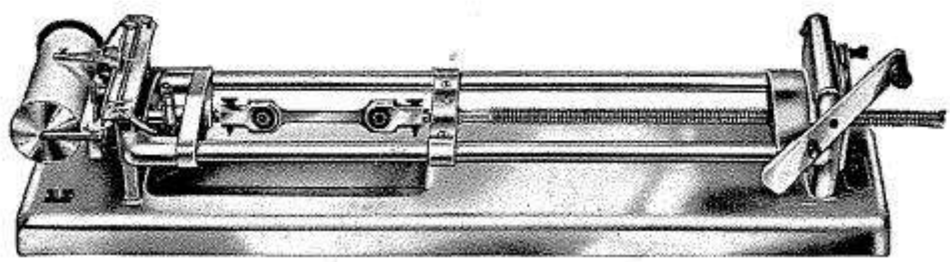

Figure 2: Hounsfield Tensometer

In practice, however, the UTS should be virtually always higher than the published values which are usually ‘guaranteed’ values rarely encountered.

It follows that:

$$E = \frac{l^3}{4bd^3} \times \frac{\Delta w}{\Delta x} \text{ -- (2)}$$

where l = beam span, w = imposed load, b = width of the beam, d = depth of the beam, x = deflection at mid-span and the term $\Delta w / \Delta x$ = gradient of a load-deflection graph.

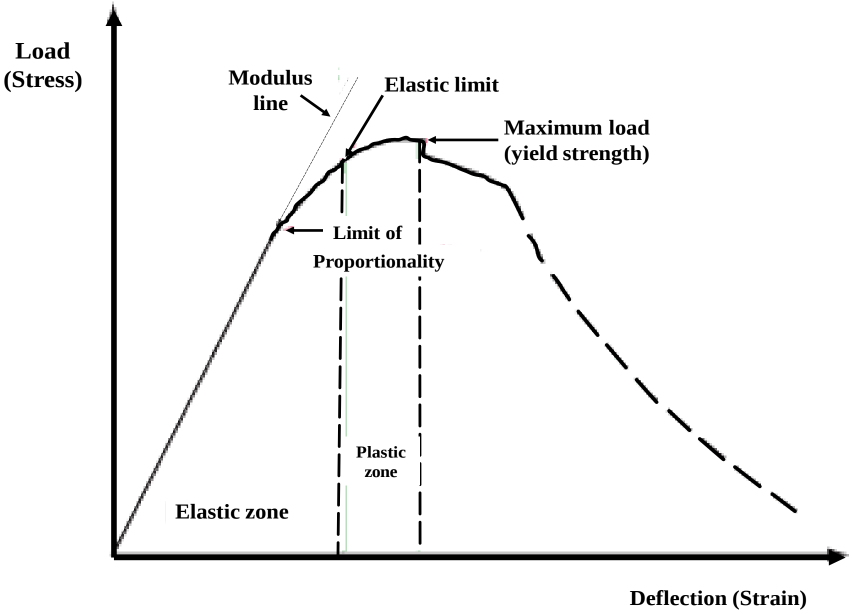

Fig 3: Static bending test showing stress-strain behaviour

III. RESULTS AND ANALYSIS

Table 1: Comparisons of Young’s Modulus of Elasticity between building materials from this study [1mm = 0.03937inch;1Psi (or Ib/inch^2) = 6.895x10^{-3}N/mm^2 = 6894.8Pa (or N/m^2) = 0.006895MPa]

Materials	Dimensions			Stress (Ib/inch^2)	Strain (-)	E (10^6 Psi)
	Length (inch)	Width (inch)	Depth (inch)			
0.3% Carbon Steel	1.9685	0.313779	-	25088.56	8.00E-04	31.4
60/40 Brass	1.9685	0.313779	-	4846.653	3.00E-04	16.2
Mahogany	4.7244	0.790943	0.290551			2.84
Parana Pine	4.7244	0.803148	0.307873			1.41

Comparisons of results with published values of E

The Modulus, E values obtained (Table 1) were compared to published values in Tables (2-3). In Table (2), the values published by The Engineering ToolBox (2005) show the E of steel varied by decreasing with increasing temperatures. Temperatures were not measured here but assuming a room temperature of 20°C, the values almost correspond with the published data. In Table (3) the E values of all four materials from several published values show similarity with the data here. However, errors could limit accuracy from measurements of the distance of the weights relative to the floor and the variations in the diameter of the wire along the length.

Table 2: Published results of Young's Modulus of Elasticity between different construction materials with effects of temperature [The Engineering ToolBox (2005)]. **[1Psi (or Ib/inch^2) = 6.895x10^{-3}N/mm^2 = 6894.8Pa (or N/m^2)].**

Young Modulus of Elasticity, E (10^6 psi)														
Metal	**Temperature (°C)**													
	-200	-129	-73	21	93	149	204	260	316	371	427	482	538	593	649
	Temperature (°F)													
	-325	-200	-100	70	200	300	400	500	600	700	800	900	1000	1100	1200
Steel														
Carbon steel C <= 0.3%	31.4	30.8	30.2	29.5	28.8	28.3	27.7	27.3	26.7	25.5	24.2	22.4	20.4	18.0	
Carbon steel C => 0.3%	31.2	30.6	30.0	29.3	28.6	28.1	27.5	27.1	26.5	25.3	24.0	22.2	20.2	17.9	15.4

Table 3: Published results of Young's Modulus of Elasticity between different construction materials

Material	E (x10^6lb/inch^2)		
	Green et al (1999)	Tatulli (2000)	ROYMECH (2009)
Mahogany, African (Khaya spp.)	1.15 (Green) 1.4 (12% moisture content)	-	-
Mahogany, true (Swietenia macrophylla)	1.34 (Green) 1.5 (12% moisture content)	1.50	1.07
Parana-pine (Araucaria augustifolia)	1.35 (Green) 1.61 (12% moisture content)	1.46	[Pine (Scots)]1.06
	Electro Technical Products (2002)	Maryland Metrics (2005)	PHYWEE [N · m^{-2}]
Steel	30.0	29.0	$2.111 \cdot 10^{11}$
Brass	16.0	14.1	$9.222 \cdot 10^{10}$

Component stiffness (strength) and material stiffness

The two components or requirements when designing a building lie on whether the materials are strong or stiff enough. Whether the bearing capacity of the materials can sustain the expected load, that is, will they crack, break, and collapse easily or bend readily. The Young's Modulus, E rating is therefore an important requirement that relates all materials capabilities to enable meeting reliable and sustainable construction goals. Component stiffness along with E rating also relates to shape factor and material distribution. For instance, Fig (3) may be useful comparison to the results of the experiments graphically expressed in Figs (4,6; 8,10; 12,14; and 16,18) for Mahogany, Parana Pine, brass and steel respectively. Comparing the pairs of Figs [(4,6; and 8,10), and (12,14; and 16,18)] we can relate that the higher E allows the material to span greater distance and compensate for low E values by using stronger construction forms. The correlations of theory and experiment in both woods and metals are shown in Figs [(6,10, and 14,18)] respectively. It can be seen that at extreme values of Δx due to stress, the material tend to cease from satisfying Hooke's Law, and E as a linear function fails. In Figs (10 and 18) the computed results and experiment correlated well. The theoretical estimates of σ were derived from the equations in Figs (5,9, and 13,17) which were fitted to correlate with experimental results. The residual stress-strain relationships are shown in Figs (7,11,15, and 19).

Most suitable metal for applications

The results presented here show that steel is a more suitable material for structural application than brass. This is because it has better E Modulus rating. This implies that steel has higher bearing capacity and can withstand more tension when in use as a component. In addition it shows that structures with steel would be stronger and safer compared to brass.

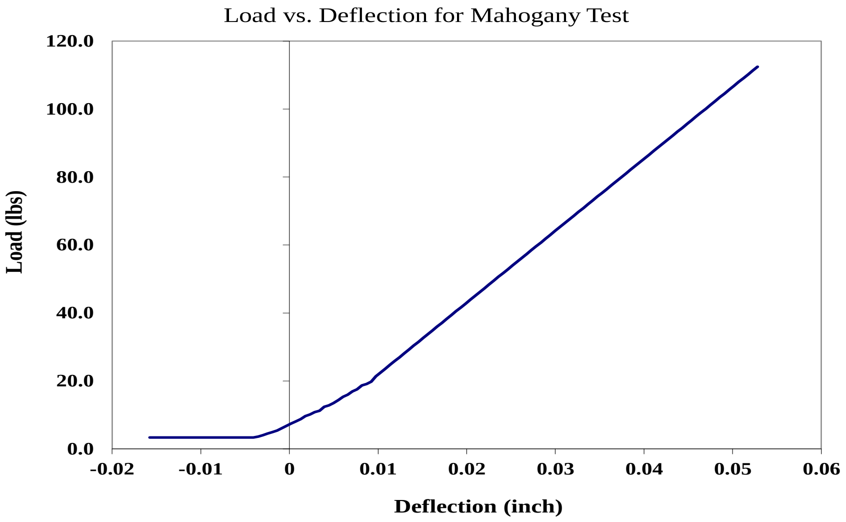

Fig 4: Load – deflection relationship in wood (mahogany) test

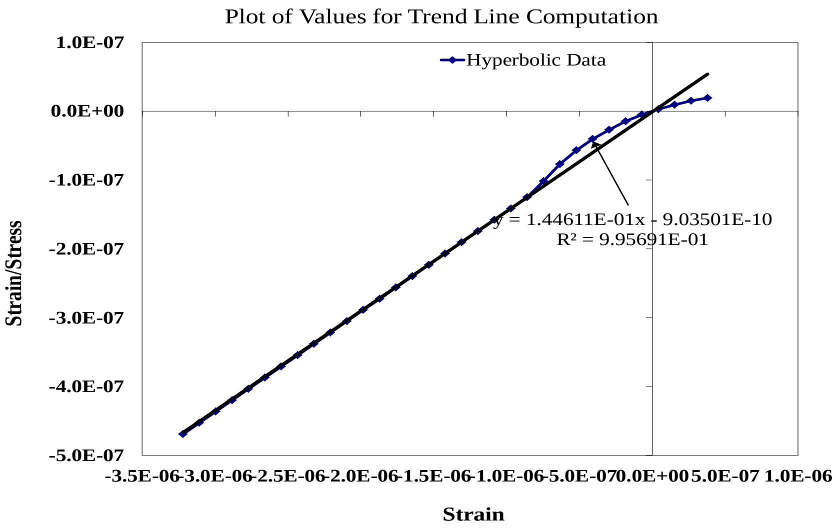

Fig 5: Linear least-squares trend line relationship between strain-stress ratios vs. strain. The A = intercept, and B = gradient of the equation.

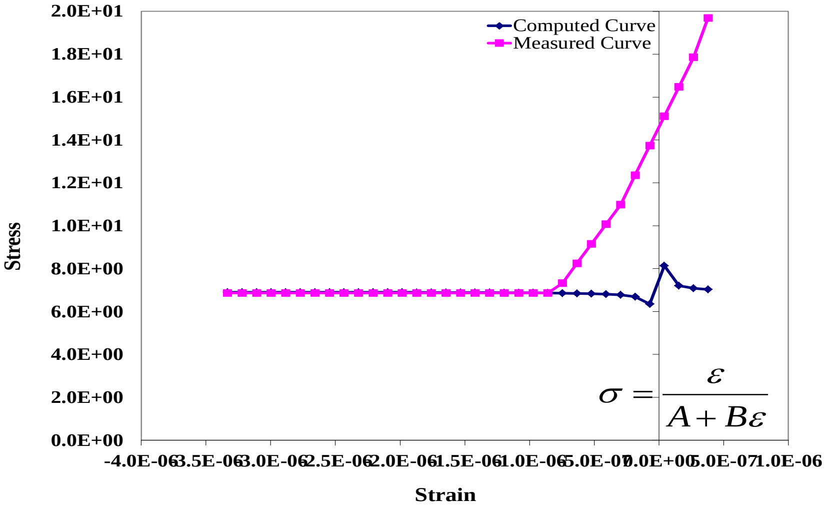

Fig 6: Curves showing stress vs. strain with equation inset representing the computed curve related to the measured outcome, where σ = stress and ε = strain. The A = intercept, and B = gradient was fitted in the equation [Fig (3)] to obtain the computed curve.

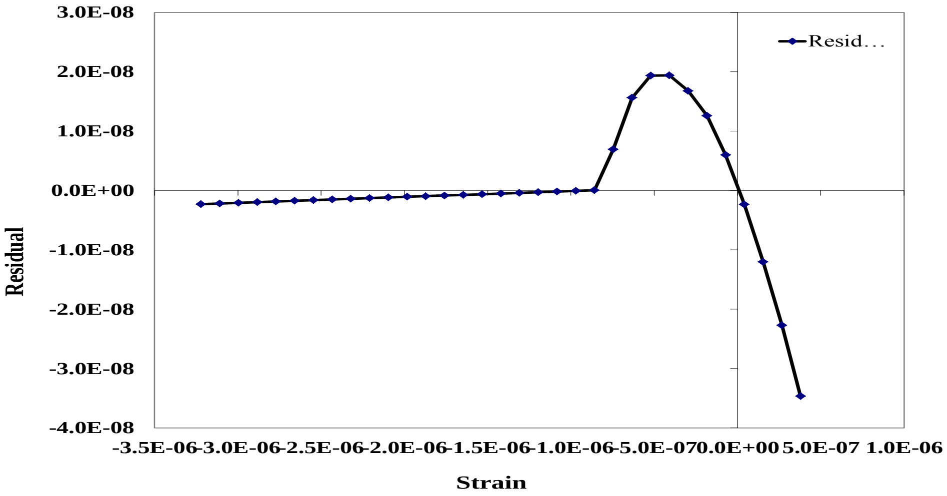

Fig 7: Development of residual plot of the relationship

Determination of E for timber (Parana Pine)

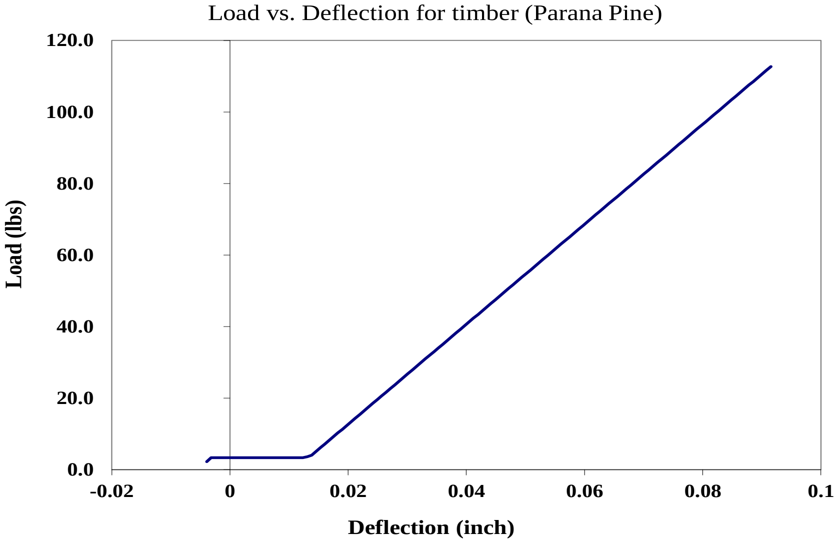

Fig 8: Load – deflection relationship in wood (Parana Pine) test

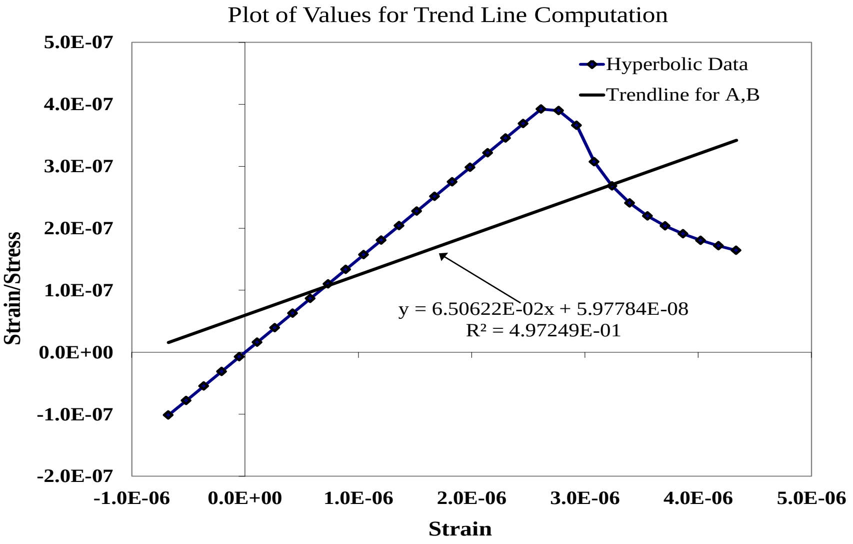

Fig 9: Linear least-squares trend line relationship between strain-stress ratios vs. strain. The A = intercept, and B = gradient of the equation.

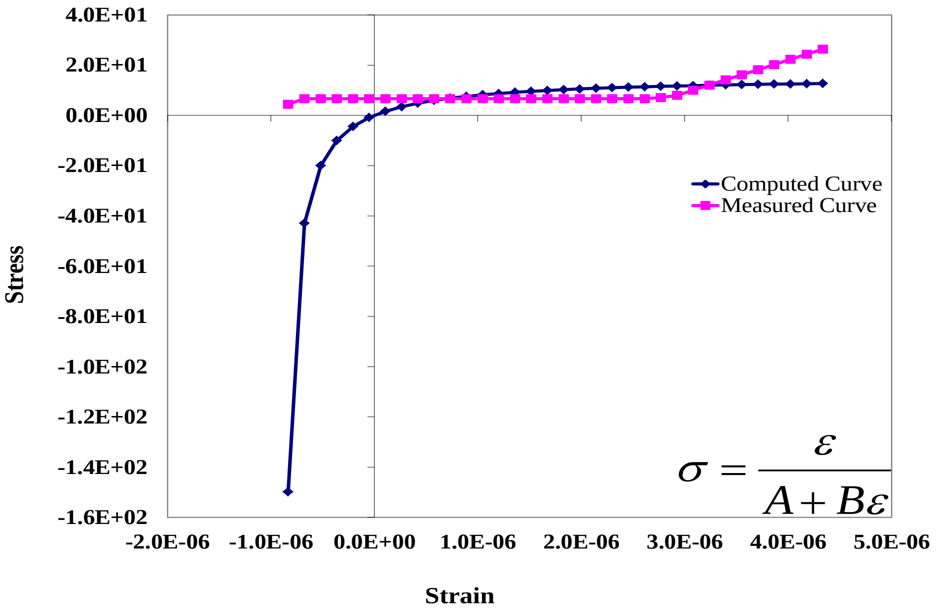

Fig 10: Curves showing stress vs. strain with equation inset representing the computed curve related to the measured outcome, where σ = stress and ε = strain. The A = intercept, and B = gradient in the equation [Fig (9)] to obtain the computed curve.

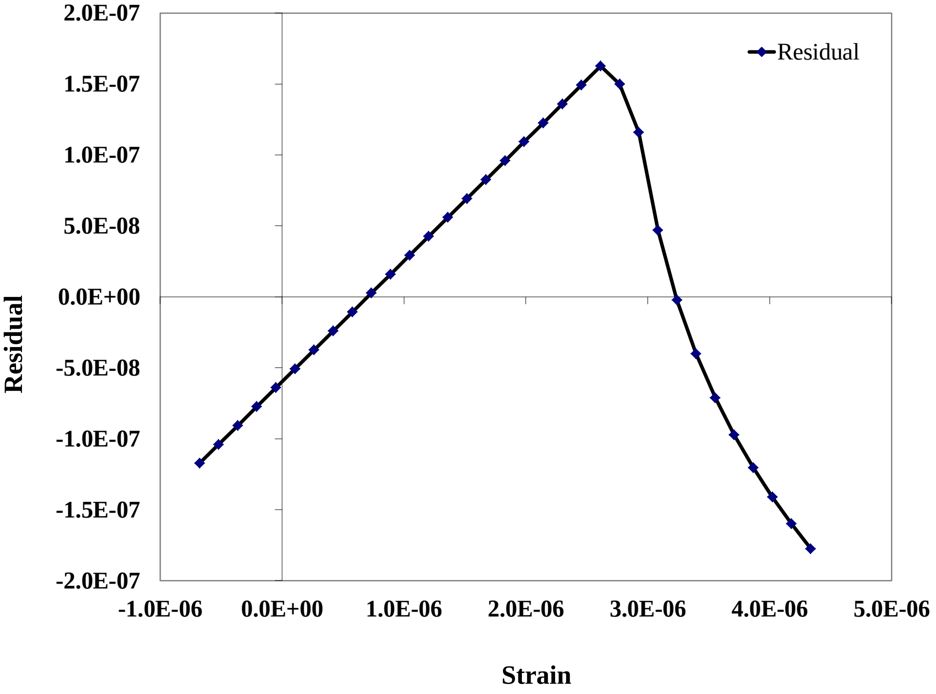

Fig 11: Development of residual plot of the relationship

Determination of E for 60/40 Brass

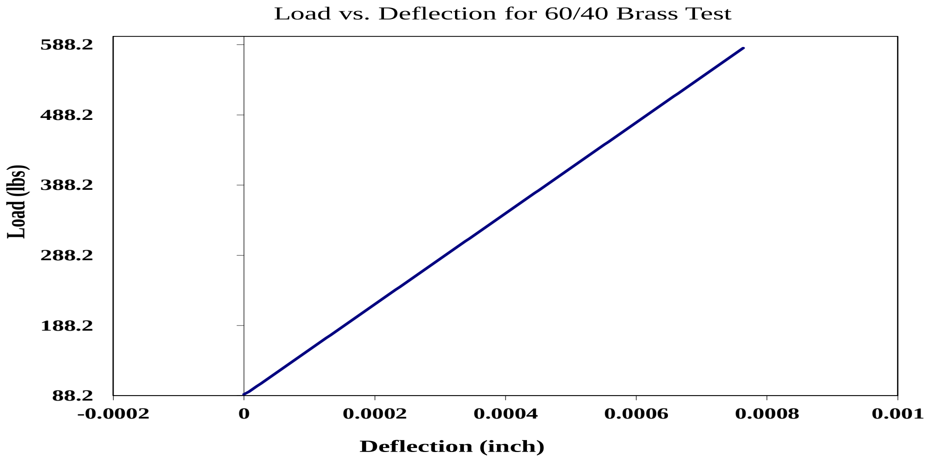

Fig 12: Load – deflection relationship in 60/40 Brass test

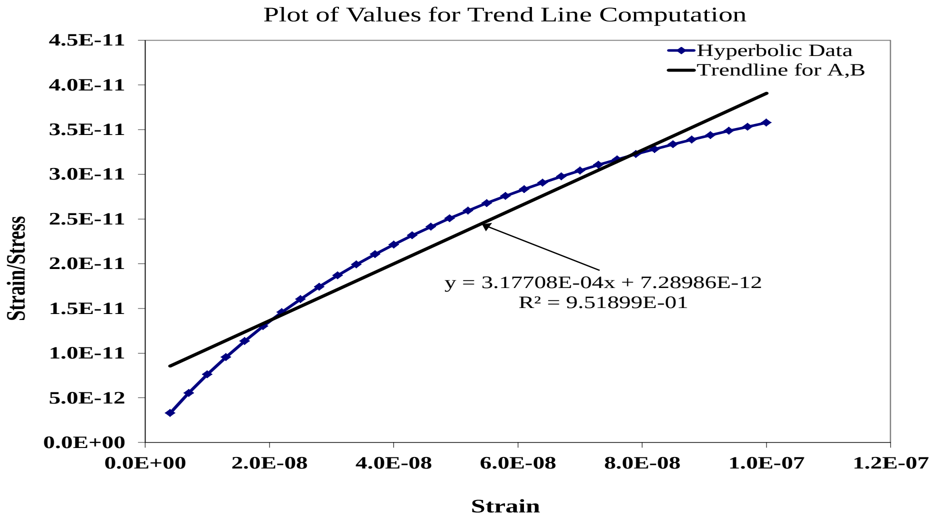

Fig 13: Linear least-squares trend line relationship between strain-stress ratios vs. strain. The A = intercept, and B = gradient of the equation.

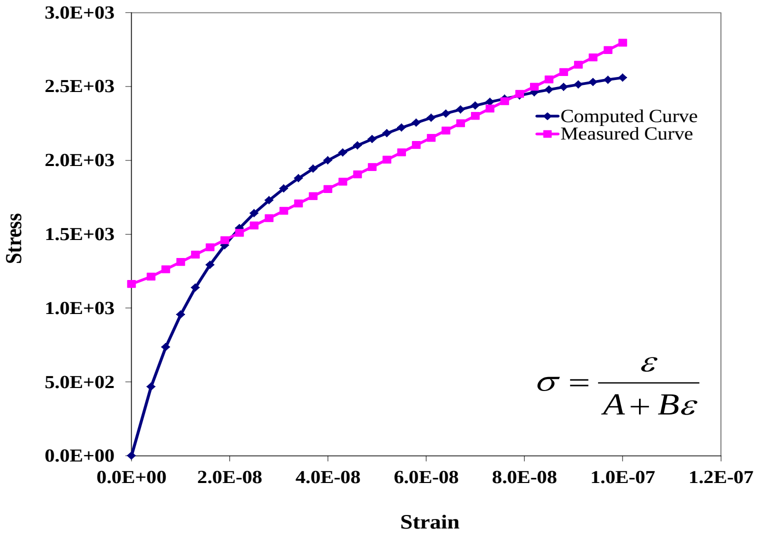

Fig 14: Curves showing stress vs. strain with equation inset representing the computed curve related to the measured outcome, where σ = stress and ε = strain. The A = intercept, and B = gradient in the equation [Fig (13)] to obtain the computed curve.

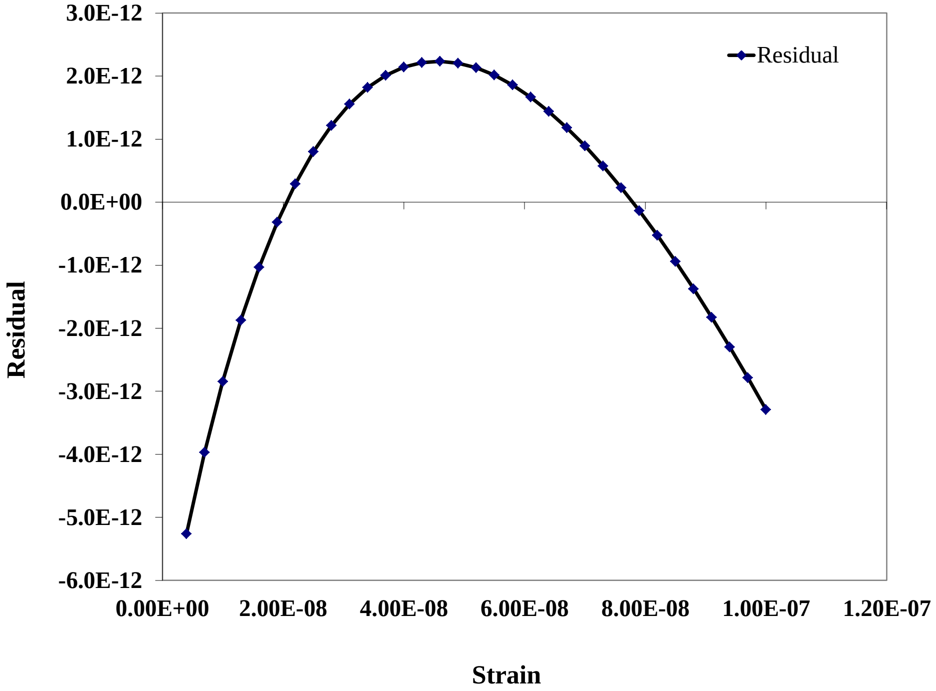

Fig 15: Development of residual plot of the relationship

Determination of E for 0.3% Carbon Steel

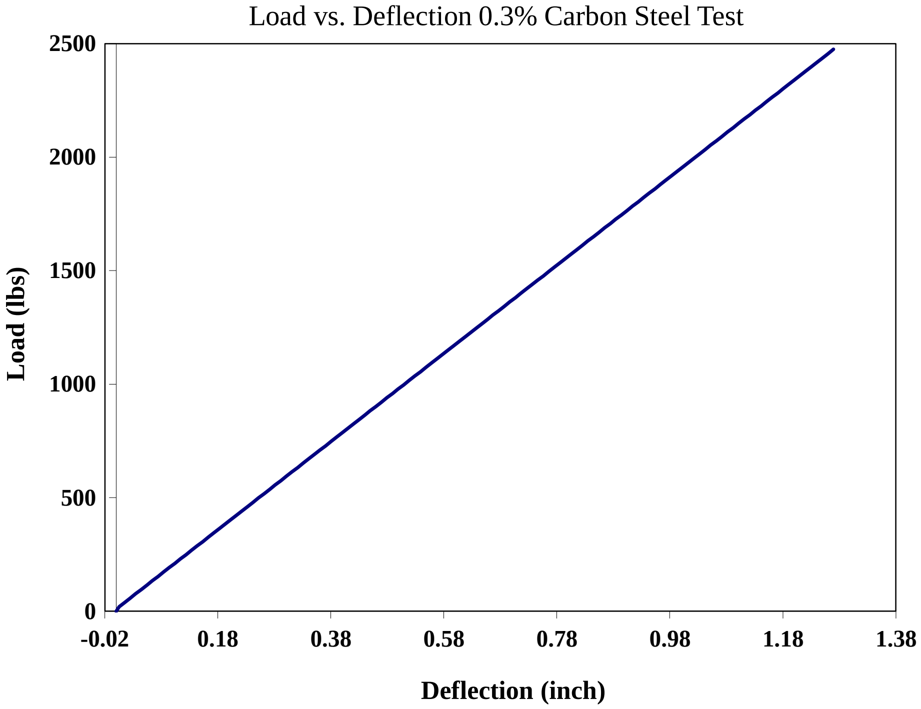

Fig 16: Load – deflection relationship in 0.3% Carbon Steel test

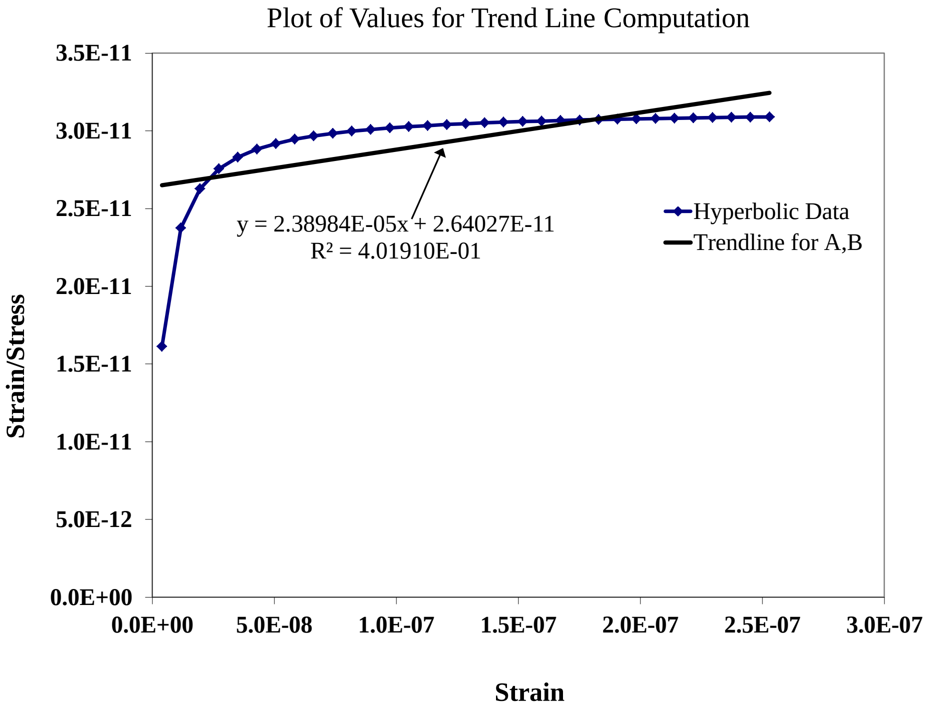

Fig 17: Linear least-squares trend line relationship between strain-stress ratios vs. strain. The A = intercept, and B = gradient of the equation.

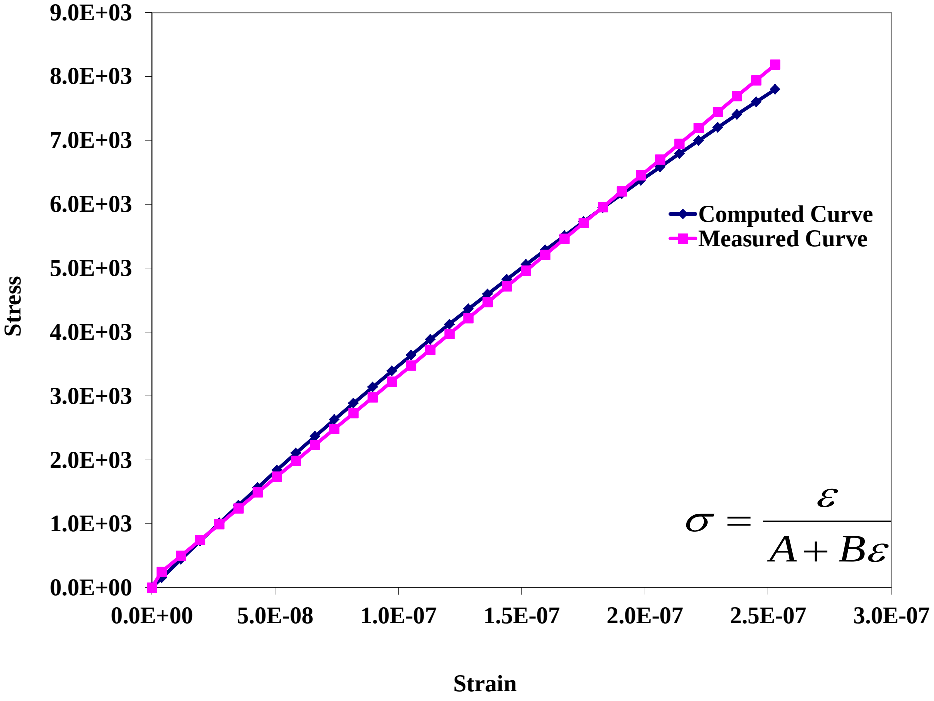

Fig 18: Curves showing stress vs. strain with equation inset representing the computed curve related to the measured outcome, where σ = stress and ε = strain. The A = intercept, and B = gradient in the equation [Fig (2)] to obtain the computed curve.

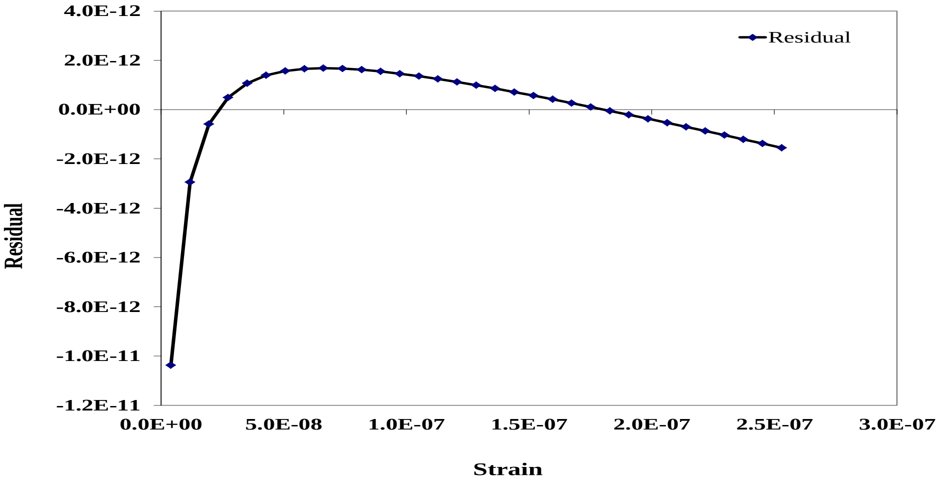

Fig 19: Development of residual plot of the relationship

IV. CONCLUSION

The value of E has been obtained experimentally by imposing stress on the materials and measuring the gradient of the elastic portion of the stress graph.The values of Young's Modulus for elasticity (E) for 0.3% carbon (mild) steel, 60/40 brass, Mahogany (hardwood) and Parana Pine (softwood) have been successfully determined as 31.4, 16.2, 2.84, 1.41 in ($x10^6$ Psi) respectively and compared with some published results showing good correlation. Also, the stress and strain of the materials were graphically shown to have good correlations between theory and experiment. The results show that steel and Mahogany are more suitable for structural application than brass and Parana Pine respectively, because of their high E Modulus rating. It therefore implies that steel and Mahogany can withstand more tension hence better bearing capacity for stronger and safer built environment. Also that steel is a more suitable material for structural application than brass. This is because it has better E Modulus rating. This implies that steel has higher bearing capacity and can withstand more tension when in use as a component. In addition it shows that structures with steel would be stronger and safer compared to brass.

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