International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 11, November 2018, pp. 732–740, Article ID: IJMET_09_11_074
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=11
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

EXPERIMENTAL DETERMINATION OF MODULUS OF ELASTICITY OF OVEN DRIED COCOA-BEANS VARIETIES

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ABSTRACT

In the present study, the modulus of elasticity of three dried cocoa-beans varieties (N38, F3 and WA) were determined through the compressive and tensile properties tests. The tests were carried out with a universal material tester. The average maximum compressive force and deflection were 21.46 ± 8.013 *N and 6.37* ± 2.331 *mm; 54.41* ± 3.819 *N and 8.82* ± 3.787 *mm; and 44.11*± 12.617 *N and 4.0* ± 0.557 *mm respectively for N38, F and WA. The average maximum tensile force and the corresponding elongation for the three investigated varieties (N38, F and WA) were 1.037*± 0.356*, 2.680*± 1.178 *and 2.250*± 0.368 *N; and 5.326*± 0.883*, 4.941*± 0.783 *and 6.45*± 2.1357 *mm respectively. The average value of modulus of elasticity for N38, F3 and WA were 0.4338*$\pm$ 0.056*, 1.055*± 0.214 *and 1.121*$\pm$ 0.207 *MPa respectively. The result of this work will be useful in the design of dried cocoa beans processing machines.*

Keywords: Cocoa-beans, varieties, compression, tensile, Young's modulus

Cite this Article Clement A. Komolafe, M. Adekojo Waheed, and Taye S. Olabamiji, Experimental Determination of Modulus of Elasticity of Oven Dried Cocoa-Beans Varieties, International Journal of Mechanical Engineering and Technology, 9(11), 2018, pp. 732–740.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=11

1. INTRODUCTION

The policy thrust of the recently launched programme tagged cocoa re-birth in Nigeria aimed at promoting the production of cocoa beans to meet the needs of industrial sector and export market (Alamu, 2013). Cocoa beans are seeds of Theobroma cacao L. and major raw material in the production of cocoa butter, cake, drugs, powder, cocoa liquor, chocolate etc. which need to undergo drying process to a safe moisture content considered suitable for long term storage. The recommended safe moisture content and highest drying temperature for cocoa beans are 7.5% (w.b.) and 60 ºC (Hii *et al.,* 2007; and Hii *et al.,* 2009). Processing of dried cocoa beans into semi-finished products requires the design and fabrication of processing machines for unit operations such as shelling, grinding, crushing, cracking, milling, threshing etc.

Drying generally entails complex processes of heat and mass transfer in which extraction of moisture occur through the application of thermal energy in order to reduce chemical, biological and microbiological deterioration of the product. However, change in internal structure usually occur as a result of internal stresses coupled with some shrinkage (Barte-Plange, 2012). Information and data on the physical and mechanical properties of cocoa beans are required in the development of optimization parameters for efficient and effective processing equipment (Burubai et al., 2007).

The knowledge of mechanical properties plays an important role in evaluating fundamental properties of materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. It also provides the basis for avoiding failure in engineering applications (Bart-Plange et al., 2007).

Several studied have been reported on the physical and mechanical properties of different materials including dried corn, dried deffated spongy bone, dried apples, cement-based material, porous graphene oxide, ceramic, rice, faba bean grains (Abasi and Minaei, 2014; Lindahl, 1976; Marzec, 2009; Li et al; 2015; Chen et al., 2015; Banaszak, 2013; Correa et al., 2007; Altuntas and Yidiz, 2007). Few literature are available on mechanical properties of cocoa beans (Garcia-Alamilla et al. 2012; Bart-Plange and Baryeh, 2003; Bart-Plange et al., 2012). However, to the best knowledge of the authors, no work has been reported on the experimental determination of modulus of elasticity of different varieties of oven-dried cocoa beans.

2. MATERIALS AND METHODS

2.1. Sample preparation and equipment

Samples of ripe, undamaged, and free from infection pods each from three varieties namely: Amelonado (N38), F3 Amazon (F) and WACRI series (WA) used in the investigations were obtained from the Cocoa Research Institute of Nigeria (CRIN), Ibadan. The beans from each variety were fermented for five days (Hii, 2007; Hii *et al.,* 2012 and Dina *et al.,* 2015). The fermented cocoa beans of known weight were dried on separate day using laboratory air oven (UF. 75 Memmert, Schwabach, Germany serial No:. 0109.0088) at 60 ºC and air velocity 2.7 m/s until the moisture content reached 7.5% w.b. Compressive and tensile tests were performed on samples of the varieties using a Universal Material Tester (Testometric M500 – 50AT Serial No: 500-10113) as shown in Figure 1.

2.2. Experimental procedure

Three dried samples of measured dimensions (length, width and thickness) from each of the varieties inside air tight polythene bags were used for the tests. Each bean was placed laterally on the stable up platform between testometer and compressed with a motion probe at a constant speed of 1.5 mm/min until the cocoa beans fracture. The same approach was reported by Bart-Plange *et al.* (2012) and Adejumo (2006) for cocoa beans and okra seeds respectively. The applied force at bioyield and their corresponding deflections for each sample were read directly from the force-deflection curve. The compressive strength of the dried cocoa beans is expressed in terms of the force required to deform the sample to initial rupture and its specific deformation. The rupture force was taken as displayed on the digital screen when the sample under compression makes a clicking sound. Similarly, tensile tests were carried out on the same varieties and the computer recording system was used to draw a force-elongation curve.

Figure 1: Mechanical test on dried cocoa beans using Universal testometric

2.3. Modulus of elasticity

The moduli of elasticity of dry cocoa beans were calculated from the data on compressive and tensile strength of dry cocoa bean under compression and tensile load obtained using Universal Material Testometer. Projected area of the randomly selected cocoa-beans was measured with overhead projector. Samples of cocoa bean were projected on a screen and then pencil-traced on graph paper and the area of each sample was measured by counting the squares with the traced marks. The initial diameter of the beans were measured with a digital vernier caliper, reading to 0.01 cm and the corresponding force to deflection of samples was taken as the slope of force (N) versus deflection (mm) curve under the elastic limit of the sample. The modulus of elasticity was calculated as:

$$E = \frac{\textbf{Stress}}{\textbf{Strain}} \quad (1)$$

$$= \frac{Force\ (N)/projected\ area\ (mm^2)}{Deflection(mm)/initial\ diameter\ (mm)} \quad (2)$$

3. RESULTS AND DISCUSSION

Figures 2-4 depict mechanical behaviour of N38, F3 and WA series varieties of cocoa bean dried at 60 °C under compression loading. The figures reveal that the compression loading generally increased with the increase in deflection. The average maximum compressive force and deflection were 21.46 $\pm$8.013 N and 6.37 $\pm$2.331 mm; 54.41 $\pm$3.819 N and 8.82 $\pm$3.787 mm; and 44.11$\pm$12.617 N and 4.0 $\pm$0.557 mm respectively for N38, F3 and WA. Similar compression force – deflection curve was reported by Shitanda et al. (2000) for thick varieties of rice compressed in their natural state. The compression-deflection curves for the three cocoa beans varieties does not look like that usually obtained for metals. This agreed with Shitanda et al. (2000) submission that the compression behaviour of agricultural materials does not obey Hooke's law like metals.

Figures 5-7 describe the mechanical behaviour of N38, F3 and WA series varieties of cocoa bean dried at 60 °C and subjected to tensile force. From the figures, it can be seen that the tensile force increased at initial stage with the increase in the elongation and later at a stage began to decrease. The average maximum tensile force and the corresponding elongation for the three investigated varieties (N38, F and WA) were 1.037±0.356, 2.680±1.178 and 2.250±0.368 N; and 5.326±0.883, 4.941±0.783 and 6.45±2.1357 mm respectively. Generally, it was observed that N38 variety has the lowest tensile force which is an indication of hardness; F3 highest tensile force and lowest elongation interprets toughness while WA with highest elongation is more elastic than other varieties.

Table 1 shows the values of the modulus of elasticity for three dried varieties of cocoa beans dried at 60 °C. From the table, the average value of modulus of elasticity for N38, F3 and WA were 0.4338± 0.056, 1.055±0.214 and 1.121± 0.207 N/mm^2 respectively. Among the three varieties, WA has the highest modulus of elasticity; while N38 has the lowest. The values of Modulus of elasticity obtained were lower than the reported range of 130 to 205 MPa by Bart-Plange *et al.* (2012). This most likely might be connected to varieties, fermentation and drying methods, drying air velocity etc. However, the low values of the Modulus of elasticity under compression loading demonstrate the ductile behaviour of a material (Abasi and Minaei, 2014). The lowest value obtained for N38 variety therefore, made it to exhibit more ductile behaviour than the other two. This is in congruent with the fact that ductile materials exhibit low strength under compression compared to brittle materials (Abasi and Minaei, 20014).

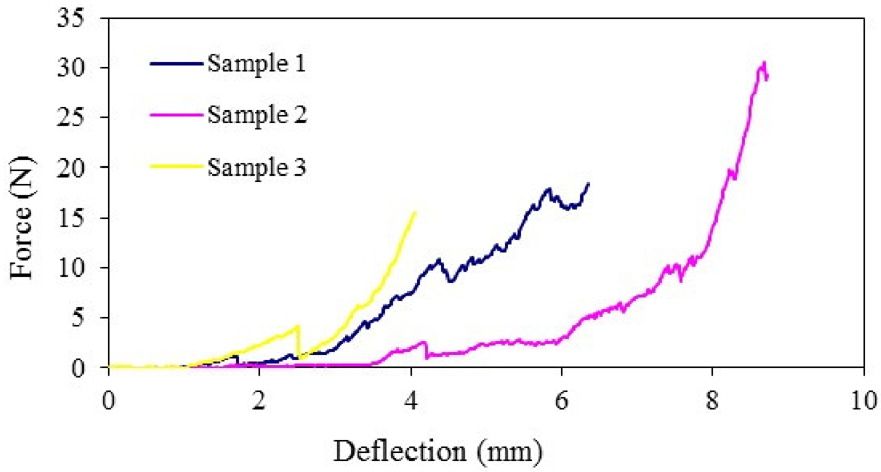

Figure.2: Variation of compressive force with deflection of dried N38 variety at 60 °C

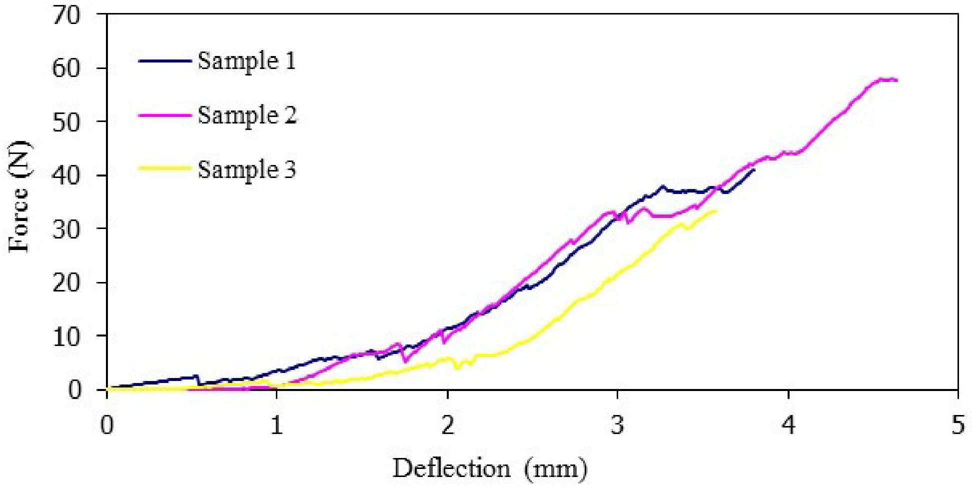

Figure 3: Variation of compressive force with deflection of dried F3 variety at 60 °C

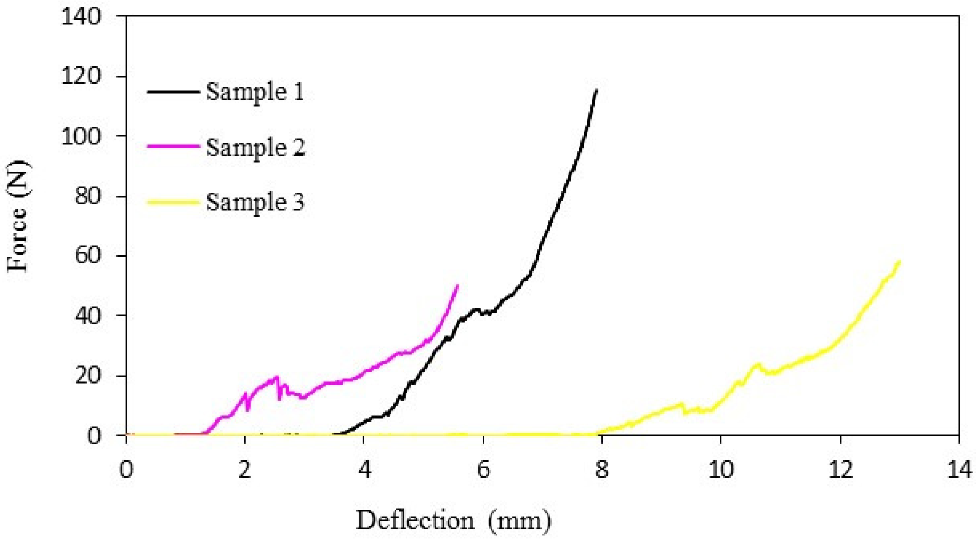

Figure 4: Variation of compressive force with deflection of dried WA variety at 60 °C

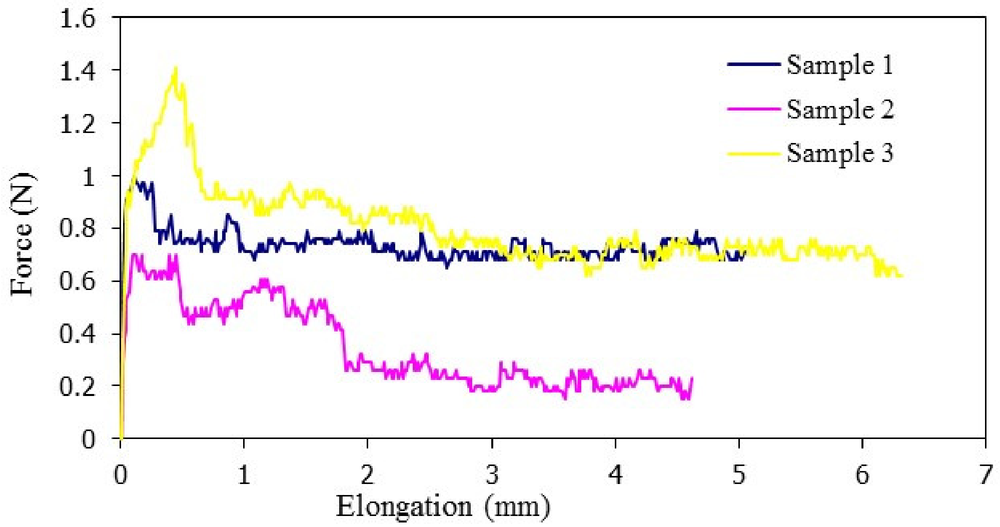

Figure 5: Changes in tensile force with elongation of dried N38 variety of cocoa at 60 ºC

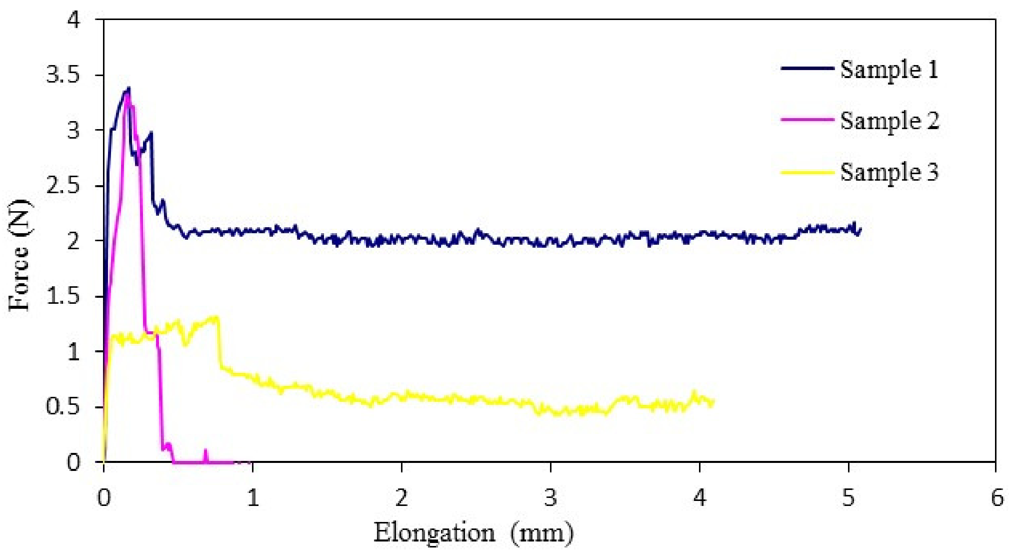

Figure 6: Variation of tensile force with elongation of dried F3 cocoa variety dried 60 ºC

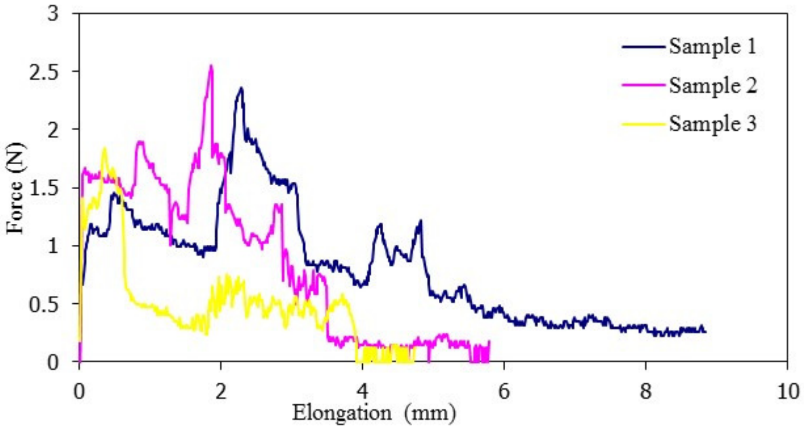

Figure 7: Variation of tensile force with elongation for dried WA variety of cocoa dried at 60 ºC

Table 1: Modulus of elasticity of three varieties of cocoa beans

Variety/Te st No	Force @ Peak (N)	Def. @ Break (mm)	Initial width (mm)	Length mm	Width (mm)	Thicknes s (mm)	Projected Area (mm^2)	Stress	Strain	Modulus of Elasticit y MPa
N38										
1	18.33	6.344	9.62	22.52	6.54	6.24	75	0.2444	0.65945 9	0.37060 7
2	30.57	8.723	9.34	22.76	5.46	5.96	68.5	0.44627 7	0.93394	0.47784 4
3	15.49	4.061	8.55	21.88	5.52	5.85	72	0.21513 9	0.47497 1	0.45295 2
Av.	21.46 3	6.376	9.17	22.3866 7	5.84	6.016667	71.83333 3	0.30193 9	0.68945 7	0.43380 1
STD	8.013	2.331	0.554	0.454	0.606	0.201	3.253	0.125	0.230	0.0561
F3										
1	55	7.9	9.03	18.26	7.26	5.42	63.5	0.86614 2	1.08815 4	0.79597 3
2	50.33	5.579	8.75	17.94	6.3	5.56	59	0.85305 1	0.88555 6	0.96329 5
3	57.9	12.98 3	8.92	18.62	6.74	5.74	56	1.03392 9	1.92626 1	0.53675 4
Av.	54.41	8.821	8.9	18.2733 3	6.7666 7	5.573333	59.5	0.91770 7	1.29999	0.76534 1
STD	3.819	3.787	0.141	0.340	0.481	0.160	3.774	0.101	0.552	0.215
WA										
1	41.07	3.797	9.78	22.15	7.34	5.42	72.5	0.56648 3	0.51730 2	1.09507 1
2	57.97	4.632	9.64	22.1	7.06	5.56	66	0.87833 3	0.65609 1	1.33873 8
3	33.29	3.577	9.25	21.65	6.68	5.74	67	0.49686 6	0.53547 9	0.92789
Av.	44.11	4.002	9.5566 7	21.9666 7	7.0266 7	5.573333	68.5	0.64722 7	0.56962 4	1.12056 6
STD	12.61 8	0.557	0.275	0.275	0.331	0.160	3.5	0.20314 8	0.07543 2	0.20660 7

4. CONCLUSION

Experimental determination of modulus of elasticity of three oven dried cocoa-beans varieties were carried out and the following conclusion were drawn:

1. The compression loading generally increases with the increase in the deflection.
2. The average maximum compressive force and deflection were 21.46 ± 8.013 N and 6.37 ± 2.331 mm; 54.41 ± 3.819 N and 8.82 ± 3.787 mm; and 44.11± 12.617 N and 4.0 ± 0.557 mm respectively for N38, F and WA.
3. The tensile force increased at initial stage with the increase in the elongation and later at a stage began to decrease.
4. The average maximum tensile force and the corresponding elongation for the three investigated varieties (N38, F and WA) were 1.037 ± 0.356, 2.680 ± 1.178 and 2.250 ± 0.368 N; and 5.326 ± 0.883, 4.941 ± 0.783 and 6.45 ± 2.1357 mm respectively.
5. The average value of modulus of elasticity for N38, F3 and WA were 0.4338 ± 0.056, 1.055 ± 0.214 and 1.121 ± 0.207 MPa respectively.

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