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Comparative Force-at-Yield Analysis on Nigerian Market Veneered Engineered Wood (Plywood) for Sustainable Economic Development

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ABSTRACT **Original Research Article**

Force-at-yield appraisal of veneered engineered wood (Plywood) products in Nigerian market was conducted on the three most commonly used samples with the objective of providing technical guidance for material selection as a result of unavailability of the requisite technical data to obviate the usual superfluous deprivation of earnings due to failure associated with using different inappropriate veneered engineered wood (Plywood) makes for sustainable economic development. In conformity to ASTM D1037 standard and requirement with the testometric testing machine, four force-at-yield tests were conducted per sample, and digital aggregate average values reported. Stemmed from computer program utilizing the data generated were plots on the dynamics of the force-at-yield of the samples. ANOVA showed statistically significant differences in force-at-yield among samples $F(2,9) = 4.32*10^6$, $p < 0.0001$. Mean force-at-yield values were 111.43±0.13N, for Viewpoint, 210.78±0.13N, for Plywood EQ and 381.63±0.13N for Caledonian. Tukey HSD post-hoc results showed that all pairwise comparisons were significant at $p < 0.0001$, with effect sizes indicating very large practical differences as revealed by Cohen's d. Coefficient of variation was below 0.15% for all groups, reflecting high test precision. It is concluded that Caledonian plywood exhibits the highest resistance to yield, followed by Plywood EQ and then Viewpoint. These variations could be attributed to adhesives' chemical properties as the samples were prepared so as to conform with comparable conditions. Biomedical, Metallurgical, Mechatronics, Chemical, Mechanical, Civil, Production engineers and construction companies as benchmark should value this in developments of their designs and constructions. Force-at-Yield of other engineered wood products types yet to be researched should receive research attention soon.

Keywords: 0.2% Offset Yield, Mechanical Test, Plastic Deformation, Quality Assessment, Universal Testing Machine, Yield Strength.

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Introduction

Background of the Study

Processing of wood for exportation and domestic consumption played a vital role in the Nigerian economy from the late 1700s transversing 1960s usually referred to as the golden age of Nigerian forestry up till early 1970s, (Olorunnisola, 2023). Forestry products industrial goods exports were relished by Nigeria in the 1950's, 1960's and 1970's, (Ogunwusi, 2012). Global engineered wood market was expected to reach USD 282.728 billion by the end of 2025 growing at a compound annual growth rate (CAGR) estimate of as much as 5.448% during 2025 with projection to reach USD 432.191 billion by the year 2033, (Shirsath,

2025). Nigerian engineered wood market was valued at USD 8.81 billion in 2023 and is actually expected to reach USD 11.05 billion by 2030 growing at a CAGR of 3.3%, (FMRL, 2025). Engineered wood products offer improved dimensional stability, mechanical properties as well as durability that streamline improved energy performance and larger complex structural elements (Fasasi, Baba and Ogunmilua, 2024). Fiberboards and particle boards that are usually made of materials like rye and wheat straw, sugar cane residue, hemp stalks e.t.c, are widely used in the building industry as eco-friendly solutions to wood with increasing uses in equipment, ceiling boards, wall partitions and thermal insulators e.t.c, due to an excellent combination of chemical, mechanical, thermal and acoustic properties together with a competitive price, (Garcia-Garcia, Quiles-Carrilo, Montanes, Fombuena, and Balart, 2018). Engineered wood products, a derivative of wood product are typically obtained through the processes of binding fibers, particles, the strands, or boards of wood together. Wood composite, in Nigeria remains a vital engineered wood product used comprehensively across packaging industries, furniture, equipment and construction. Unfortunately, as at present despite abundant raw materials and fast-growing domestic market, Nigeria remain heavily dependent on importation of engineered wood products. A significant association exists between rate of residential development and building materials in the study of effect of building materials cost on housing development in Owerri, Imo state, eastern region of Nigeria, (Igboekulie, Monye and Joseph, 2022). The economy, especially building materials market was badly hit by the inflation with the purchasing power of the Nigerian currency, Naira seen to be decreasing from the critical study of inflation trend pattern and its impact on Nigeria's economy, (Barguma, et al, 2022). Inflation rate in Nigeria has a direct relationship with prices of building materials as inflation was the most influential factor responsible for increase in cost of building materials in a correlation analysis of the inflation rate and the prices of building materials in Benin city, (Obaedo, 2024). Mechanical properties improvements are usually remarkably observed with combination of the alkali treatment followed by silanization at the production of highly environmentally-friendly engineered fiberboards by a partially biobased epoxy resin as binder and hot-press molding using Posidonia oceanica wastes, (Garcia-Garcia, et al, 2018). Comparable engineered wood products are made from vegetable fibers using lignin-containing materials as well as chemical additives to enable the integration of polymer and wood flour to support optimal processing conditions. Remarkably, usage of wood waste materials in the production of engineered wood products has climaxed the reduction in the need to fell old-growth forests. The use of engineered wood products has some unavoidable challenges that are associated with it. A common experience in engineered wood product that are fiber-based and particle-based when exposed to moisture is humidity-induced warping which is usually not common in solid woods. Higher risk usually exists as a result of higher chemical heat content and melting properties when a comparison is made between engineered wood product and solid wood products. When cheap and commonly used resins in the engineered wood product that are usually made with urea-formaldehyde bonded products are utilized, toxic formaldehyde from the finished products, a strong apprehension with engineered wood product is formed and generally appears. Even with the substantial enhancement on the esthetic and mechanical properties despite these bottlenecks, market for engineered wood product across the globe and especially within Nigeria as projected by earlier statistics is on the increase. To support long-term economic development, it becomes indispensable to study the force-at-yield of veneered engineered wood (Plywood) products in Nigeriaas the specialized knowledge provided will effectively curtail economic impact due to use of unsuitable quality for heterogeneous applications.

Force-at-Yield

Force-at-Yield is the amount of force required to cause a material to begin deforming plastically. This usually marks the transition point where a material stops behaving elastically and starts to permanently change shape. In engineering design, force at yield is utilised to determine safe loads. In other words, it is the force at which a material transitions from elastic to plastic deformation. Below the force, the material returns to its original shape when unloaded. Above it, permanent deformation occurs. Designing below this force ensures that there is no permanent deformation of materials. The significance of it is that it defines the maximum load a component can sustain without permanent deformation, making it critical for design, material selection and quality control. In materials selection, materials with high force-at-yield are chosen for structures that bear heavy loads without changing shape. They ensure reasonable dimensional stability. A universal testing machine (UTM) is designed to measure force at yield. Force-at-yield is a critical mechanical property that defines the safe working limit for a material under load. Exceeding it implies permanent deformation, which can compromise safety and function.

Review of Literature

Ojo and Idieunmah, (2021) in an attempt to find the relationship between age and properties of timber, established linear relationship between age and strength properties of timber, increasing both the compression and shear strengths and even to a reasonable extent the bending strength. In Nigerian economy marine board engineered wood load strain evaluation, (Ilo, Emenike, and Oshim, 2025) established that Super-Plex ability to elongate at break is 61.37% and 117.96% higher than that of Marine Plex and Nplex respectively while Marine Plex elongation at break potential over Nplex is 35.07%. Again, in load strain evaluation of veneered engineered wood (plywood) in Nigerian market, (Ilo, Alumona, and Nwanjoku, 2025) from statistical analysis,

showed that Viewpoint ability to elongate at break is 119.51% and 289.49% better than that of Caledonian and Plywood EQ respectively while Caledonian elongation at break potential over Plywood EQ is 78.32%. Recently, (Ilo, Ajibo, and Dim 2025a) in Nigerian economy marine board assessment analysis, found that Marine Plex marine board plywood had ultimate bending strength of 17.96 N/mm^2, Nplex marine board plywood recorded 21.502 N/mm^2 while Super Plex marine board plywood had the best flexural strength at peak of 65.84 N/mm^2. Ilo, Ezirim and Onwe, (2026), investigated the energy to break capabilities of Medium Density Fibre Board (MDF) products in the Nigerian market economy and found that there is a significant differences among brands ($F(2,9) = 362,970$, $p < 0.0001$) with mean energy-to-break values were 0.5975 Nm for SGK Nordic, 0.5795 Nm for Richard Russel, and 0.1705 Nm for MDF Hokusan while Tukey HSD confirmed that all pairwise differences were statistically significant. Effect sizes were large, with Cohen's d values exceeding 13 for all comparisons, indicating both statistical and practical significance. All groups exhibited low variability, with CV values below 1%. Flexural strength values in glulam beams were found significantly higher than the control (custom wood) especially in edgewise direction in the assessment of glued laminated beams made from local wood species bonded with phenol resorcinol formaldehyde, urea-formaldehyde adhesives and polyurethane, (Ekundayo, Arum, and Owoyemi, 2022). Okoye, Ilo, and Chikelu, (2025) appraised the veneered engineered wood (Plywood) product in Nigerian economy bending modulus and found that statistically, the bending modulus for Caledonian is 132.79% and to the extent of 2155.50% more superior than that of Plywood EQ and Viewpoint respectively while bending modulus for Plywood EQ is 868.89% more suitable than that of Viewpoint. Ilo, Ajibo, and Dim (2025b) found in experimental investigation of flexural strength of veneered engineered wood (Plywood) in Nigerian commercial sector that Viewpoint plywood recorded 4.956 N/mm^2, Plywood EQ recorded 9.467 N/mm^2 while Caledonian recorded 16.973 N/mm^2 as the maximum stress, modulus of rupture (MOR) each of them can withstand while being bent before failing or rupturing. Agina, Ilo and Ezirim, (2026) investigated the energy to break of three widely used High Density Fibre Board (HDF) engineered wood products in the Nigerian market and found that Sinoply attained the highest energy to break of 10.88725N.m, as the toughest implying high impact resistant and most durable, Dabar is in-between with 0.67175N.m to balance toughness and brittleness while Joubert has least energy to break of 0.588N.m as the best suited for applications where toughness is not much of a concern. Flexural strength and elongation at break increased as coconut shell proportion got increased in the study of the effects of carbonized coconut shell (CS) volume fraction on mechanical properties of unsaturated polyester resin (UPR) composite and the mechanical properties by (Iloabachie, Obiorah, and Anene, 2018). Ilo, Uro, and Edeh, (2025) found that Plywood EQ attained aggregate average hardness of 459.25 HLD, View Point attained aggregate average hardness of 456.5 HLD while Caledonian attained aggregate average hardness of 407.5 Leeb Hardness Test (HLD) in a hardness test analysis of veneered engineered wood (Plywood) in Nigerian market. In the statistical analysis of wood load strain of high-density fibre engineered wood product in Nigeria, (Ilo, Nwachi, and Chukwunyere, 2025) asserted that Sinoply ability to elongate at break is 544.89% and 507.44.89% more than that of Dabar and Joubert respectively thereby placing Sinoply at an advantage position while Joubert elongation ability at break potential over Dabar is just 6.16% higher. Maximum flexural and ultimate tensile strength were attained at 20wt% for the 425 microns when the effect of particle size on the ultimate tensile strength, flexural strength, density and water absorption characteristics of uncarbonized coconut shell/unsaturated polyester composites of particle size 425 microns sample and 170 microns sample were investigated, (Iloabachie, et al, (2017). Coconut fibre reinforced HDPE had 28.6 mega pascal as optimum value for flexural strength in an analysis of the performance characteristics and reinforcement combinations of coconut fibre reinforced high density polyethylene (HDPE) polymer matrixes at optimum condition of volume fractions and particle sizes of coconut fibre-filler, (Ihueze, Achike, and Okafor 2016). In an investigation by (Okoye, Ilo and Ozono, 2026) on the bending modulus of three widely used high Density Fibre Board (HDF) engineered wood products in the Nigerian market with the objective of providing technical guidance for material selection to support sustainable economic development, the research show that Dabar has the highest bending modulus of approximately 14282MPa, indicating the stiffest and best for applications needing strength and stiffness especially in structural uses, Joubert has lowest bending modulus of approximately 9862MPa as the most flexible is suited for applications requiring flexibility such as in curved designs while Sinoply is in between with approximately 10674MPa balancing strength and flexibility. Ilo, Ezirim and Ozono, (2026), investigated the energy to break capabilities of marine board engineered wood in Nigeria and found that super-plex exhibited the highest energy to break ($M = 3.32$, $SD = 0.005$ N.m), followed by marine-plex ($M = 1.48$, $SD = 0.004$ N.m) and Nplex ($M = 1.24$, $SD = 0.029$ N.m). In assessment of Medium Density Fibreboard (MDF) engineered wood load strain in Nigeria, (Ilo, Okoye, and Ugama 2025) found that statistically, MDF Hokusan ability to elongate at break is 35.9526% and 57.8750% higher than that of Richard Russel and SKG Nordic respectively, placing MDF Hokusan favoured while Richard Russel elongation potential over SKG Nordic is just 16.1250%. Akinyemi, Afolayan, and Oluwatobi 2016) found that panels with 50% CC had the most preferred performances for both physical and mechanical properties in a study of the properties of developed composite corn cob (CC) and sawdust (SD) particle boards using 0%, 25%, 50%, 75% and 100% variations for both agricultural wastes using formaldehyde as binder at constant volume. Eze, Ilo, and Dim

(2025a), unearthed that Dabar reached aggregate average hardness of 526.50 Leeb Hardness Test (HLD), Sinoply reached aggregate average hardness of 547.50 HLD while Joubert reached aggregate average hardness of 548.50 HLD in the hardness examination on high density fibreboards in Nigerian economic sector. In a study of the flexural strength of high density fibreboard (HDF) engineered wood in Nigerian economy, (Ilo, Nneji, and Igede, 2025) discovered that Joubert (HDF) recorded 15.604 N/mm^2, Dabar (HDF) recorded 32.604 N/mm^2 while Sinoply (HDF) recorded 39.248 N/mm^2 of their flexural strength at peak. Using descriptive statistics on data obtained from energy-to-break tests conducted on veneered engineered wood (plywood) products in the Nigerian commercial sector, results showed significant differences among the groups with (ANOVA: $F = 7938.6$, $p < 0.001$; Kruskal-Wallis: $H = 10.26$, $p = 0.0059$), while mean energy to break was highest for Caledonian (2.836 ± 0.042 N.m, CV = 1.49%), followed by View Point (2.234 ± 0.003 N.m, CV = 0.12%), and lowest for Plywood EQ (0.484 ± 0.006 N.m, CV = 1.29%) even as post-hoc analysis indicated that Plywood EQ differed significantly from both Caledonian and View Point, (Ozono, Ilo and Onyejaka, 2026). A modification of surface quality was noticed after 80 reuses with marine plywood formworks while such changes were observed after 50 reuses with oriented strand board (OSB) panels formworks in the study of the evolution of surface properties of concrete through measured lightness and absorption by (Courard, et al, 2012). Ilo, Nwanjoku and Olayeye (2025) studied flexural strength of medium density fibreboard (MDF) wood composite in Nigerian market and found that SGK Nordic had the best ultimate flexural strength of 13.568 N/mm^2, MDF Hokusan (MDF) recorded 1.24 N/mm^2, while Richard Russel had ultimate flexural strength of 12.986 N/mm^2. Okoye, Ilo, and Obuka, (2026) compares the bending modulus of MDF Hokusan, SGK Nordic and Richard Russel, the top most used medium density fibre board in Nigeria, with ANOVA showing highly significant differences ($p<0.0001$) between all the three as well as Turkey's post-hoc showing differences with $p<0.001$ for all pairs. Richard Russel exhibited the highest aggregate average bending modulus of 8697 MPa, indicating superior stiffness and strength. MDF Hokusan had the lowest with 1296 MPa, suggesting greater flexibility. SGK Nordic fell in-between with 7398 MPa. Aziz, et al, (2015) while studying the influence of activated carbon filler on the mechanical properties of wood composites, noted that MDF composites samples show higher strength value than plywood composites samples because of the increasing thickness of the activated carbon filler. In hardness test analysis of medium density fibreboards MDF in Nigerian economy, (Eze, Ilo, and Dim, 2025b) found that Richard Russel attained aggregate average hardness of 545.75 HLD, Hokusan attained aggregate average hardness of 535.75 Leeb Hardness Test (HLD), while SGK Nordiac attained aggregate average hardness of 558.50 HLD. Marine Plex attained aggregate average hardness of 364.5 Leeb Hardness Test (HLD), Nplex attained aggregate average hardness of 392.25 HLD while Super-Plex attained aggregate average hardness of 370.75 HLD in a hardness test evaluation of marine board in Nigerian economy according to (Ilo, Nweke and Nebo, 2025). Okoye, Ilo, and Kanu (2025) asserted that statistically, the bending modulus for Marine Plex is just 19.60% and as much as 163.66% better suited than that of Super-Plex and Nplex respectively while for Super-Plex, it is as much as 120.45% favourable than that of Nplex in appraisal of marine board engineered wood products in Nigerian market. Consequently, the force-at-yield of veneered engineered wood (Plywood) products remains understudied. The evident necessity of providing technical insight on veneered engineered wood (Plywood) products in Nigerian economy with regards to their force-at-yield becomes critical to be sought, hence this paper as research gap being closed.

Research Methodology

Material

Three most used veneered engineered wood (Plywood) products in Nigerian economywere selected to value their force-at-yield capacity. The samples were selected for test and subsequent analysis and they were Viewpoint, Caledonian, and Plywood EQ as represented accordingly in table 1.

Table 1: Veneered Engineered Wood (Plywood) Products Samples Tested for Force-at-Yield

SAMPLE	A	B	C
MAKE	Viewpoint	Caledonian	Plywood EQ

Equipment

Adhering to ASTM D1037 standard and requirement with the testometric testing machine the test specimens were prepared. Quasi-static tests were carried out using three-point loading (centre-point flexure) configuration at loading (crosshead) rate of approximately ≈ 5mm/min (±50%). The tests were done at relative humidity of 65% ± 5%, 27 ± 1^{0}C, and controlled lab with minimal vibrations. The samples were confirmed to have comparable density and moisture content. Oven-dry method per ASTM D4442 a direct moisture content measurement of wood was used to measure the moisture content. The specimens were conditioned to approximately 12 ±0.3 % MC per ASTM D1037. Figure 1, testometric testing machine was used in the test. According to the resistive tendencies of each sample as the jaw moves down Force-at-Yield data of the sample tested were generated. According to the requirement by the testometric machine shown in figure 1, the samples were all tested on the machine one after the other after being prepared meticulously. Force-at-Yield aggregate average statistics of four replicates conducted on each of the samples were generated. With computer program the dynamics of the Force-at-Yield chats for the test are also generated from digital data obtained. The

plot being a function of the samples compositions resulting from their nature is obviously a clear indication or measure of potentials of the material's amount of force needed to exceed before it deforms plastically. To check if samples differ significantly, analysis of Variance (ANOVA) was run on the data. A follow-up Post-Hoc test (Tukey's) compared the pairs of samples. The statistical analysis and the chats generated are analysed under results and analysis below.

Figure 1: Testometric machine

Results and Analysis

For each of the samplesViewpoint, Caledonian, and Plywood EQ, the chats for Force-at-Yield are shown as charts in figures 2, 3 and 4 respectively while figure 5 X rays the Force-at-Yield aggregate average results for Viewpoint, Caledonian, and Plywood EQ. Tables 2, 3 and 4 x rays One-Way ANOVA for Force-at-Yield, Post Hoc Turkey HSD Test Result and Effect Size-Cohen's D respectively.

Plots

The figure 2 below is a chart for results for four tests conducted on Viewpoint**.** The data generated were within a close range which is an indication of homogeneity of the sample, Viewpoint.

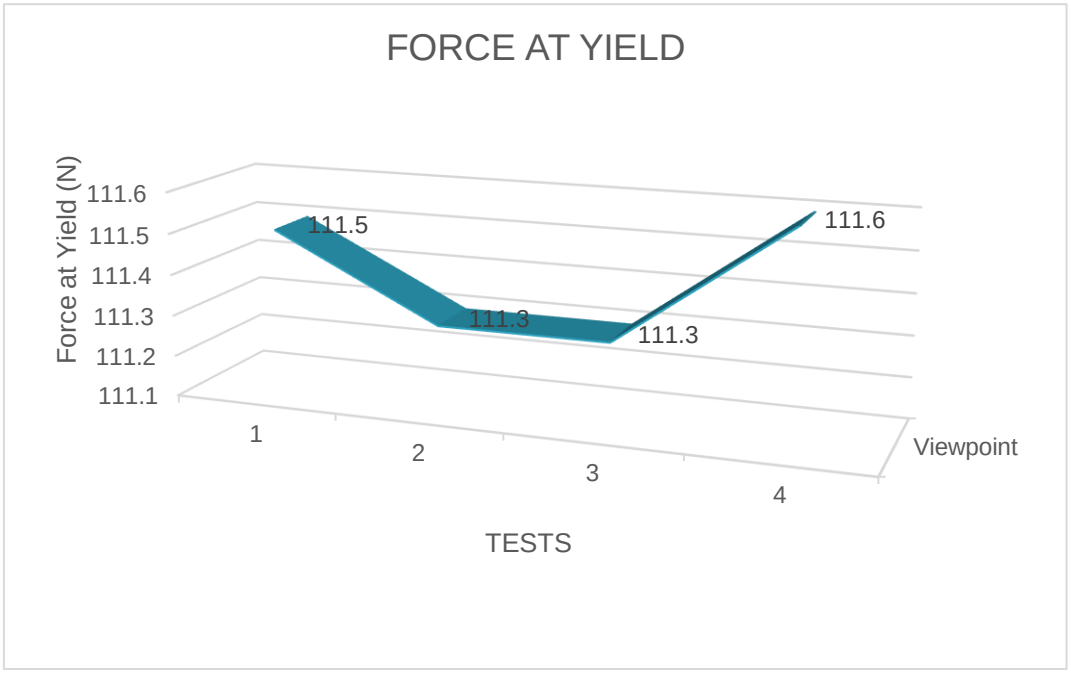

Figure 2: Force-at-Yield results for Viewpoint

The figure 3 below is a chart for results for four tests conducted on Caledonian. The data generated did not widely spread out showing clear trend of the Force-at-Yield of the sample, Caledonian.

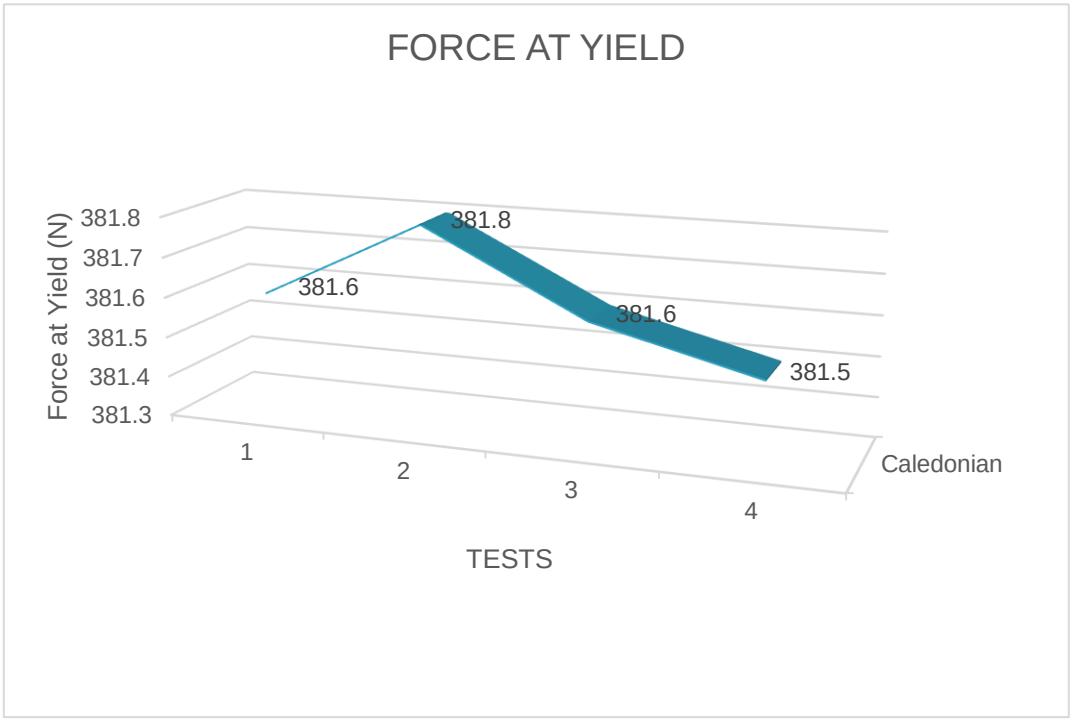

Figure 3: Force-at-Yield results for Caledonian

The figure 4 below is a chart for results for four tests conducted on Plywood EQ. The data generated was within the average range showing uniformity and clear trend of Force-at-Yield of the sample, Plywood EQ.

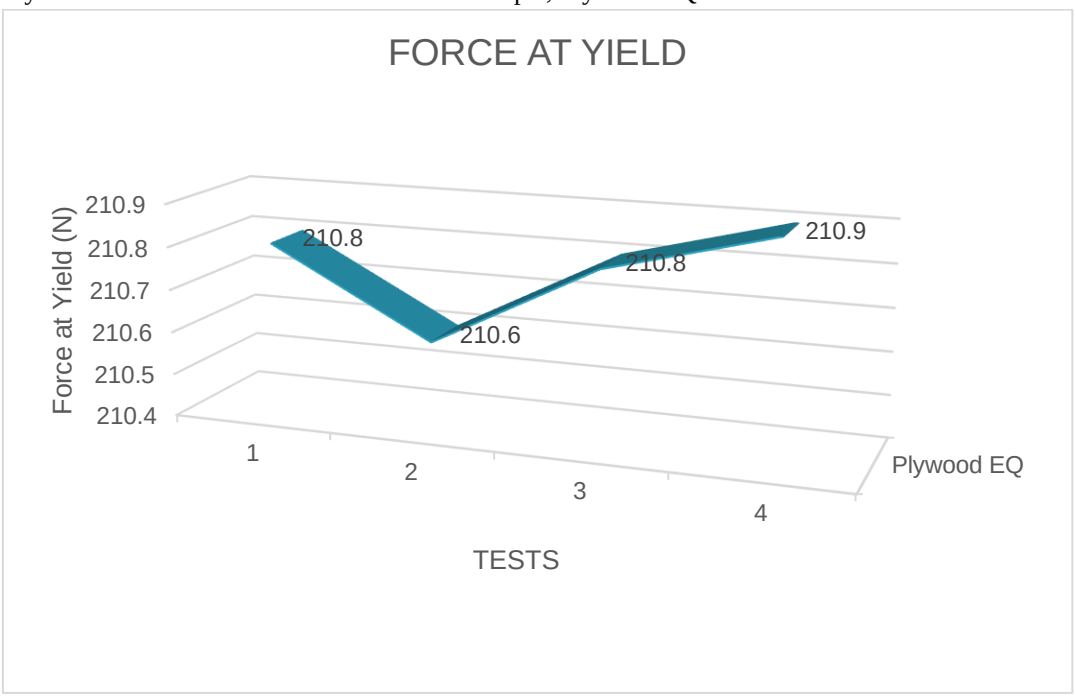

Figure 4: Force-at-Yield results for Plywood EQ

The figure 5 below shows aggregate average for the four tests on Viewpoint, Caledonian, and Plywood EQ.

The results show how much Force they take before plastically deforming. Caledonian has the highest force-at-yield by a large margin. It's approximately 3.4 times Viewpoint and approximately 1.8 times Plywood EQ. Precision is excellent across all samples. CV<0.15% means the test was repeatable and sample preparation consistent. With regards to force-at-yield, Caledonian has a higher load bearing capacity without getting permanent sag or dent.

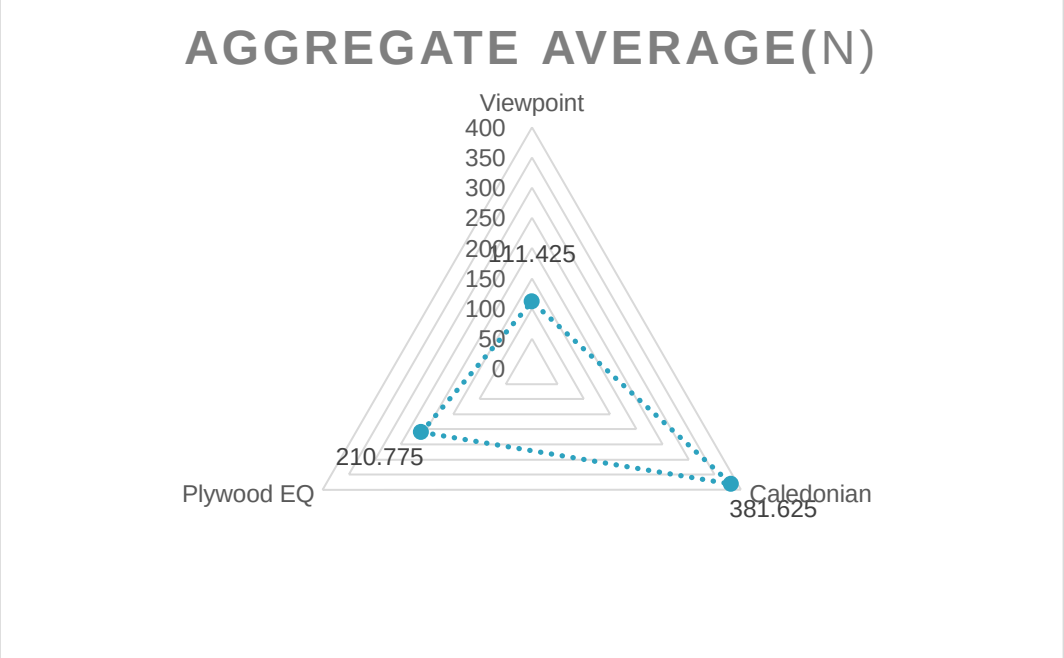

Figure 5: Force-at-Yield aggregate average results for Viewpoint, Caledonian, and Plywood EQ

Table 2: One-Way ANOVA for Force-at-Yield of Veneered Engineered Wood (Plywood) Samples

Source of Variation	Sum of Squares	Df	Mean Square	F	p-value
Between Groups	**138674.92**	**2**	**69337.46**	**4318000.0**	**<0.0001**
Within Groups	**0.145**	**9**	**0.0161**		
Total	**138675.07**	**11**			

A close look at table 2 shows that at α=0.05 significance level the result indicates a statistically significant difference in mean force-at-yield among the three samples Statistical analysis reveals ANOVA with $F(2,9) = 4.32*10^6$, while $p<0.0001$. This means that a statistically significant difference exists between mean force-at-yield among the three samples. Hence the probability that these differences are due to chances is essentially zero.

Table 3: Post Hoc Tukey HSD Test Result

SAMPLES COMPARED		Mean Difference (N)	95%Cl	p-adj	Significance
Caledonian Viewpoint,	**vs**	**270.20**	**269.96, 270.44**	**<0.0001**	**Significant**
Plywood EQ Viewpoint	**vs**	**99.35**	**99.11, 99.59**	**<0.0001**	**Significant**
Caledonian Plywood EQ	**vs**	**170.85**	**170.61, 171.09**	**<0.0001**	**Significant**

Table 3 reveals that the differences are not just statistically significant. They are practically massive. All pairwise comparisons were statistically significant at <0.0001. Ranked by force-at-yield, Caledonian is greater than Plywood EQ and far greater than Viewpoint.

Table 4: Effect Size-Cohen's D

SAMPLES COMPARED	Cohen's D	Interpretation
Caledonian vs Viewpoint,	**2110**	**Huge**
Plywood EQ vs Viewpoint	**770**	**Huge**
Caledonian vs Plywood EQ	**1350**	**Huge**

From table 4, the huge effect size-Cohen's D >2 for all pairs shows that the differences are large enough that one doesn't need more samples to be confident. This confirms that the groups are practically different and not just statistically.

Conclusion and Recommendation

The force-at-yield test shows clear differences in mechanical performance among the threeveneered engineered wood (Plywood) samples tested. The analysis confirms that the threeVeneered Engineered Wood (Plywood) samples differ significantly in force-at-yield. The results are statistically robust and practically meaningful. Performance ranking is clear. Caledonian had the highest force-at-yield: 381.63±0.13N, Plywood EQ is 210.78±0.13N while Viewpoint is 111.43±0.13N. Caledonian is approximately 3.4 times stronger than Viewpoint and 1.8 times stronger than Plywood EQ.

These findings provide empirical evidence for quality grading of veneered engineered wood (Plywood) in Nigeria aimed at technical guidance for material selection. The identified insights play key role in the choice of veneered engineered wood (Plywood) samples in Nigerian commercial sector with particular reference to their force-at-yieldso as to maintain sustainable economic development through prevention of loss associated with use of inappropriate veneered engineered wood (Plywood) in Nigeria market. Concerning one's need for veneered engineered wood (Plywood) in Nigeria, the avant-garde stands out as a baseline for technical insight needed in decision making regarding appropriate choice by engineers, contractors, policy makers and stake holders for sustainable development. Future research interest should centre on force-at-yieldof other types of engineered wood products commonly used in Nigerian commercial sector not yet researched.

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