Research Square

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Mechanical and Durability Assessment of Rockwool-Bamboo Reinforced Ceiling Boards

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Research Article

Keywords: Bamboo powder, Bamboo fibre, Rock wool, Urea Formaldehyde, Physical properties, Mechanical properties

Posted Date: April 17th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2762269/v1

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Abstract

It has become important to explore means of reducing deforestation in our environment by sourcing alternatives for timber in the forest. Bamboo (Bambusa vulgaris) as a type of grass grows abundantly in tropical regions around the world. It is known for its strength and flexibility, which makes it a popular material for construction, furniture, and other uses which are still being explored. This paper evaluated the use of bamboo for the design of ceiling boards based on the physical and mechanical properties of bamboo. The research explored the use of bamboo powder, bamboo fibre, and bamboo sticks which are usually wasted during construction activities. Rock wool was used as a fire-resistance agent, and urea-formaldehyde was used as a binding agent. The bamboo ceiling boards were tested for their physical (water absorption, thickness, swelling, and density) and mechanical (modulus of rupture and modulus of elasticity) properties. The results showed the resulting board has the lowest value of 41.885% and the highest value of 86.37% of water absorption and the highest value of 97.564% and the lowest value of 41.885% of water absorption when immersed in water for 2hrs and 24hrs respectively, the modulus of rupture recorded was 78.915 N/mm^2 and highest density value of 0.424kg/m^3. It was concluded that bamboo is a suitable material for the production of particle and ceiling boards.

1. Introduction

The rising demand for timber utilization is regarded as a key factor for the high rate of deforestation which has a huge impact on the environment thus resulting in global warming [1–5]. This has resulted in the unsupervised and unregulated cutting of trees and over-exploitation in plantation and natural forests leading to fresh interest in lesser-known timber species. Unfortunately, the need for wood products is higher than the timber supply, resulting in continuous deforestation without replacement [6–8]. The increasing demand for wood-based particle boards has resulted in challenges, yet the necessity to develop alternative resources to replace timber raw materials has not been explored fully [9–12]. In many developing countries including Nigeria, wood has been more and more scarce simply because producing a fully developed and matured tree can take up to 60 years and another 60 years for replacement making it a total of 120 years [13]. Meanwhile, a specie of bamboo equivalent to the height and width of a tree takes as little as 60 days to develop completely. Also, a study of active sawmills located across the country shows that a large amount of sawdust gotten from processed wood is burnt daily, leading to environmental problems such as CO_2 emission [14, 15]. Therefore, the need to figure out and introduce the use of bamboo in more construction works will help reduce deforestation and global warming. The utilization of bamboo based on its vast abilities can be used as part of the balance between demand and supply in the production of composite particle boards. The production is now common and has been adopted by various countries in the world such as India, Thailand, Vietnam, and China [16, 17]. An effective way of avoiding the wastage of bamboo is by utilizing it in various commercial forms and this is very important for a country like Nigeria because of its constant use of timber, PVC, asbestos, etc [18, 19]. It is essential to point out alternative means such as bamboo which is in excess and readily available here in Nigeria.

Bamboo ceiling boards are boards made of bamboo cranes or sticks using urea formaldehyde, cement, or any form of particle board binder. They can be used to a very high extent as a result of their positive economic and environmental qualities such as good maintenance, flexibility, good cooling effect, termite resistance, and good physical and mechanical properties [20]. According to [13], the bamboo ceiling looks more like wood than bamboo, but in its production, bamboo planks are simply attached to ceiling frames and the temperature and humidity level in the room are usually controlled to about 60^0F - 70^0F and 40%- 60% respectively. This forming process allows the framing members to expand or contract [21]. Rock wool is an inorganic flock or fibrous material made into matter fibre used mainly for insulation and soundproofing, Rock wool is a good conductor of heat on its own, but sheets and rolls of this insulation are efficient at blocking the transfer of heat which helps to prevent the occurrence of fire in buildings. It consists of a high liquefying point ranging from 1800^0F to 2000^0F, with an R-value of 3.10 to 4.0. This helps in the reduction of energy consumption in homes and businesses [22]. However, not much has been done to utilize its usefulness in ceiling boards. This research aims to produce ceiling boards from bamboo powder, bamboo fibre, and bamboo sticks as reinforcement, Rock wool was used as a fire resistance agent, and urea-formaldehyde was used as a binding agent to replace the use of other ceiling board materials and to assess its strength and durability.

2. Materials And Methods

2.1 Materials

The constituents of the boards produced in this research work were bamboo sticks made into bamboo fibre (Fig. 2) and bamboo powder (Fig. 3), blended rock wool as a fire resistance agent (Fig. 4), and urea-formaldehyde as a binding agent. Samples of the materials are shown in Figs. 1–4.

Bamboo sticks were sliced into 15mm and 10mm widths to form the bamboo reinforcement mat. After which, some bamboo cranes were ground using a grinding machine and later underwent sieve analysis to obtain the bamboo fine particles and bamboo fibre, passed through 0.425mm and 0.600 mm sieves sizes. Afterwards, the rock wool was cleaned to remove impurities and then blended using a grinding machine.

The quantity of all the materials was varied to produce 15 different boards as determined by the board mix ratio (Table 1). The urea-formaldehyde was measured as a percentage of the number of bamboo materials used. The sliced bamboo reinforcement mat was put into the mould and positioned centre and surface for boards respectively. The dry materials were mixed and then the urea-formaldehyde was added to the dry mix and mixed evenly together.

Table 1
Experimental Design

Board Name	Composition	Bamboo Reinforcement width (mm)	Bamboo Reinforcement Spacing (mm)	Bamboo Reinforcement Position	Bamboo Powder (%)	Bamboo Fibre (%)	Rock Wool (%)	Bamboo Powder Volume (mm^3)	Bamboo Fibre Volume (mm^3)
A	$BP_{40}BF_{40}R_{20}BR_{10/10}$	10	10	Centre	40	40	20	980	980
B	$BP_{60}BF_{20}R_{20}BR_{10/10}$	10	10	Centre	60	20	20	1470	490
C	$BP_{50}BF_{50}R_{0}BR_{10/10}$	10	10	Surface	50	50	-	1225	1225
D	$BP_{40}BF_{40}R_{20}BR_{10/0}$	10	0	Centre	40	40	20	980	980
E	$BP_{60}BF_{20}R_{20}BR_{10/0}$	10	0	Centre	60	20	20	1470	490
F	$BP_{50}BF_{50}R_{0}BR_{10/0}$	10	0	Surface	50	50	-	1225	1225
G	$BP_{40}BF_{40}R_{20}BR_{15/10}$	15	10	Centre	40	40	20	980	980
H	$BP_{60}BF_{20}R_{20}BR_{15/10}$	15	10	Centre	60	20	20	1470	490
I	$BP_{50}BF_{50}R_{0}BR_{15/10}$	15	10	Surface	50	50	-	1225	1225
J	$BP_{40}BF_{40}R_{20}BR_{15/0}$	15	0	Centre	40	40	20	980	980
K	$BP_{60}BF_{20}R_{20}BR_{15/0}$	15	0	Centre	60	20	20	1470	490
L	$BP_{50}BF_{50}R_{0}BR_{15/0}$	15	0	Surface	50	50	-	1225	1225
M	$BP_{40}BF_{40}R_{20}BR_{0/0}$	-	-	-	40	40	20	980	980
N	$BP_{60}BF_{20}R_{20}BR_{0/0}$	-	-	-	60	20	20	1470	490
O	$BP_{20}BF_{60}R_{20}BR_{0/0}$	-	-	-	20	60	20	490	1470

(BP = Bamboo Particles, BF = Bamboo Fibre, R = Rockwool, BR = Bamboo Reinforcement)

2.2. Board Formation

The wooden moulds had a uniform dimension of 350 mm × 350 mm × 20 mm and a cover of 15 mm. The cover was fabricated to fit properly into the moulds to ensure a final thickness of 5mm for the boards produced. The boards produced were wrapped with a nylon bag to aid easy removal after formation (Fig. 6). A 100kg load was placed on the cover for 3 hours after the formation. After which, the boards were removed from the mould and placed inside the oven to dry at 100^0C for 3hrs. After oven drying, the boards were air-dried at room temperature for 14 days before subjection to physical (water absorption, thickness swelling, and density) and mechanical (modulus of rupture and modulus of elasticity) tests.

2.3. Board Testing

The boards were subjected to physical and mechanical tests which were gotten by obtaining samples from the boards produced to carry out the tests. Samples were obtained from the 15 boards produced and properties like thickness, weights and density were measured and recorded as initial values before the samples were immersed in water for 2hrs and 24hrs respectively. The same properties were measured and recorded as final values after the hours of soaking to determine the Water Absorption (WA), Thickness Swelling (TS) and Density of the board samples. The Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) for each sample of the 15 boards were tested and calculated.

3. Results And Discussion

The results for water absorption (2hrs & 24hrs), thickness swelling (2hrs, & 24hrs,) and density are shown in, Fig. 7, 8, and 9 respectively. The MOR and MOE are shown in Figs. 10 and 11 respectively.

3.1 Water Absorption

Based on the mean values obtained from each board type, after 2 hours of immersion, board J which was made up of 40% of bamboo powder, 40% of bamboo fibre, 20% of rock wool, and 15mm bamboo reinforcement width placed at the centre with 0mm spacing had the least value (41.885%) for water absorption while board B which contained 60% of bamboo powder, 20% of bamboo fibre, 20% of rock wool, 10mm of bamboo reinforcement width and 10mm of bamboo reinforcement spacing had the highest value (86.370%) for 2 hours and board M for 24 hours had the highest value (97.564%), followed by board B, A, O, N, F, I, H, G, D, K, L, C and E (Fig. 7). Board type J either for 2 hours or 24 hours immersion had the best water resistance characteristics or capability when compared to other boards produced.

The effect of bamboo reinforcement width and position in the boards was quite significant as boards G (centre), H (centre), I (surface), J (centre), K (centre) and L (surface) with 15mm reinforcement width positioned at both centre and surface had the least water absorption values for both immersion for 2 hours and 24 hours compared to boards A (centre), B (centre), C (surface), D (centre), E (centre) and F (surface) with 10mm reinforcement width positioned at both centre and surface which had the highest water absorption value for both 2 hours and 24 hours. Therefore boards G to L with a reinforcement width of 15mm have more water resistance characteristics than boards A to F with a 10mm reinforcement width. Also, boards without bamboo reinforcement (M, N and O) have very low water resistance compared to boards with reinforcement (A to L).

3.2 Thickness Swelling

From the observation of thickness swelling at 2hrs, it was discovered that board G has the lowest value (1.720%) followed by boards H, K, N, M, E, D, B, C, O, J, F, A and H respectively while board I also had the highest value of thickness swelling at 2 hours (7.105%). After 24 hours of soaking in water, board D has the least value of thickness swelling followed by boards K, N, H, B, M, C, E, G, F, J, I, O, A and L respectively and board L had the highest value of thickness swelling of (13.399%) (Fig. 8). Therefore, board K after soaking for 2 hours and 24 hours has more stability characteristics as the lowest values were obtained there and the boards are said to be more suitable for structural purposes than other boards.

The boards' A (centre), B (centre), C (surface), D (centre), E (centre) and F (surface) with 10mm reinforcement width positioned at both centre and surface had the least thickness swelling value for both 2 hours and 24 hours, while boards G (centre), H (centre), I (surface), J (centre), K (centre) and L (surface) with 15mm reinforcement width positioned at both centre and surface had the highest thickness swelling values for soaking for 2 hours and 24 hours. Therefore boards A to F with a reinforcement width of 10mm have more stability characteristics than boards G to L with a 15mm reinforcement width. Also, comparing boards without reinforcement (boards M, N and O) with boards that have reinforcement (boards A to l), stability characteristics are more efficient in boards without reinforcement than boards with reinforcement. The effect of bamboo reinforcement spacing on the thickness swelling of boards was quite significant as boards D, E, F, J, K and L with 0mm spacing have higher thickness swelling values than boards A, B, C, G, H and I with 10mm spacing.

3.3 Density

Board O has the lowest mean density value (0.256Kg/m^3) followed by A, D, G, I, B, F, M, K, N, J, E, H and L while board C has the highest density value (0.424 Kg/m^3) (Fig. 9). The urea-formaldehyde-bonded bamboo boards of composition C and L has the highest values of density and they correspond with the boards made from bamboo reinforcement width of 10mm and 15mm respectively and differ also in spacing as board C has 10mm spacing while board L has 0mm spacing. They are similar in the mix proportion and composition of 50% of bamboo powder, 50% of bamboo fibre, and 0% of rock wool but differ in reinforcement width and spacing with C containing 10mm bamboo reinforcement width at the surface and 10mm spacing while board L has 15mm bamboo reinforcement width at the surface and 0mm spacing.

3.4 Modulus of Rupture (MOR)

It can be observed that the mean values of MOR for the boards produced varied from 0.933–78.915 N/mm^2 (Fig. 10). Board O has the lowest value for MOR which was 0.933 N/mm^2, then followed by boards E, I, M, N, D, C, A, B, H, G, J, K, and F respectively while board L has the highest value of MOR which was 78.915 N/mm^2. It was also discovered that there is a relationship between board densities and the MOR, as board L with the highest density recorded a high value of MOR and board O has the lowest values of density and modulus of rupture. Also, it was discovered that boards G to L with 15mm bamboo reinforcement width has higher values of MOR than boards A to F with 10mm width, while the boards M, N and O without bamboo reinforcement have the least values of MOR compared to boards with bamboo reinforcements (Fig. 10).

3.5 Modulus of Elasticity

MOE of the boards varied from 15.3724–1052.28 N/mm^2. Board I has the lowest value of MOE which was 15.3724 N/mm^2 followed by boards E, O, N, D, G, H, C, A, B, M, J, L and K respectively while board F has the highest value for MOE. It was also observed that boards A to F with a bamboo reinforcement width of 10mm have the highest values for MOE than boards G to L with a bamboo reinforcement width of 15mm. It

was also observed that the boards with an equal proportion of bamboo powder and fibre with 0% rock wool, 10mm or 15mm reinforcement width and 0 mm spacing have the highest values for MOE.

4. Conclusion

At the end of the research, it was discovered that;

1. 95% of the boards produced showed favourable physical properties thereby recommending them to be used for indoor and outdoor purposes in buildings.

2. 70% of the boards produced showed poor performance in terms of mechanical properties except for boards A, B, and C whose MOR values were relatively good, and boards F and K whose MOE values were also good.

Declarations

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

Conflict of interest

This research work is part of a BSc Thesis of Aina Salome Oluwademilade and there is no specific grant from funding agencies in the public, commercial, or non-profiting sectors.

Acknowledgement

We wish to acknowledge Engr. Segun Aladegboye from the Department of Civil Engineering, Landmark University, Omu-Aran, Kwara state, Nigeria, for making appropriate input in the laboratory works in this research.

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Figures



Figure 1

Sliced Bamboo



Figure 2

Bamboo fibres



Figure 3

Bamboo fine particles



Figure 4

Blended Rock wool



Figure 5

Fig. 6: Board Formation (a) Bamboo-Rockwool Composition first layer (b) Bamboo Reinforcement Mat (c) Bamboo-Rockwool Composition Second layer

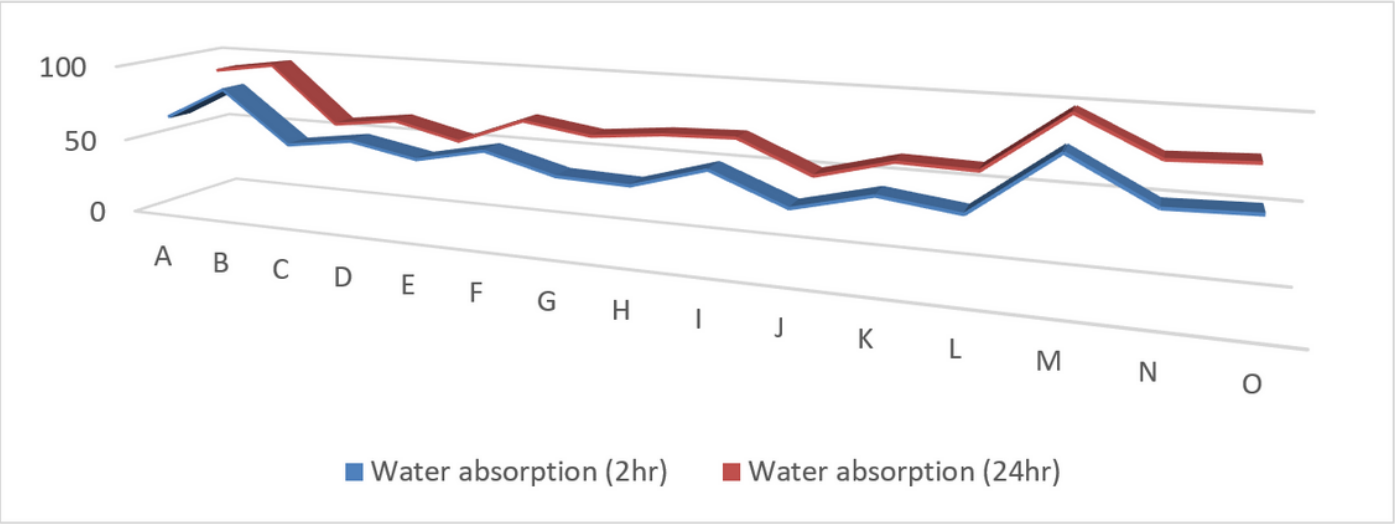


Figure 6

Fig. 7: Average Water Absorption Values

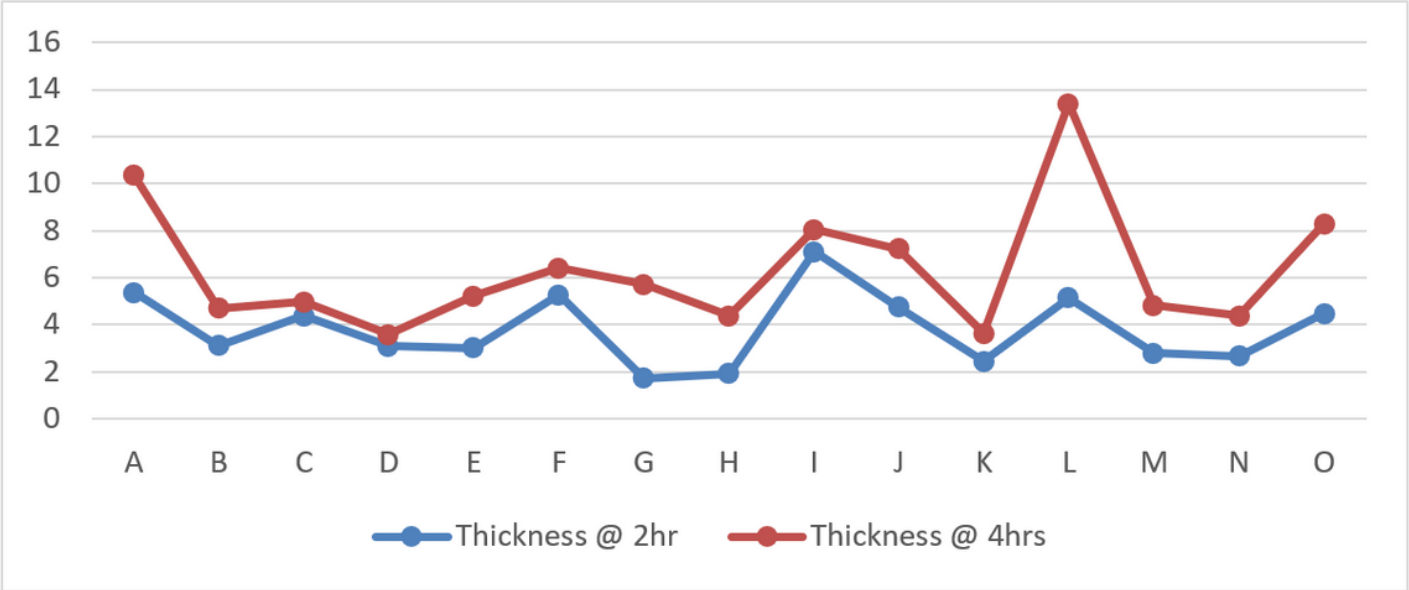


Figure 7

Fig. 8: Average Thickness Swelling Values

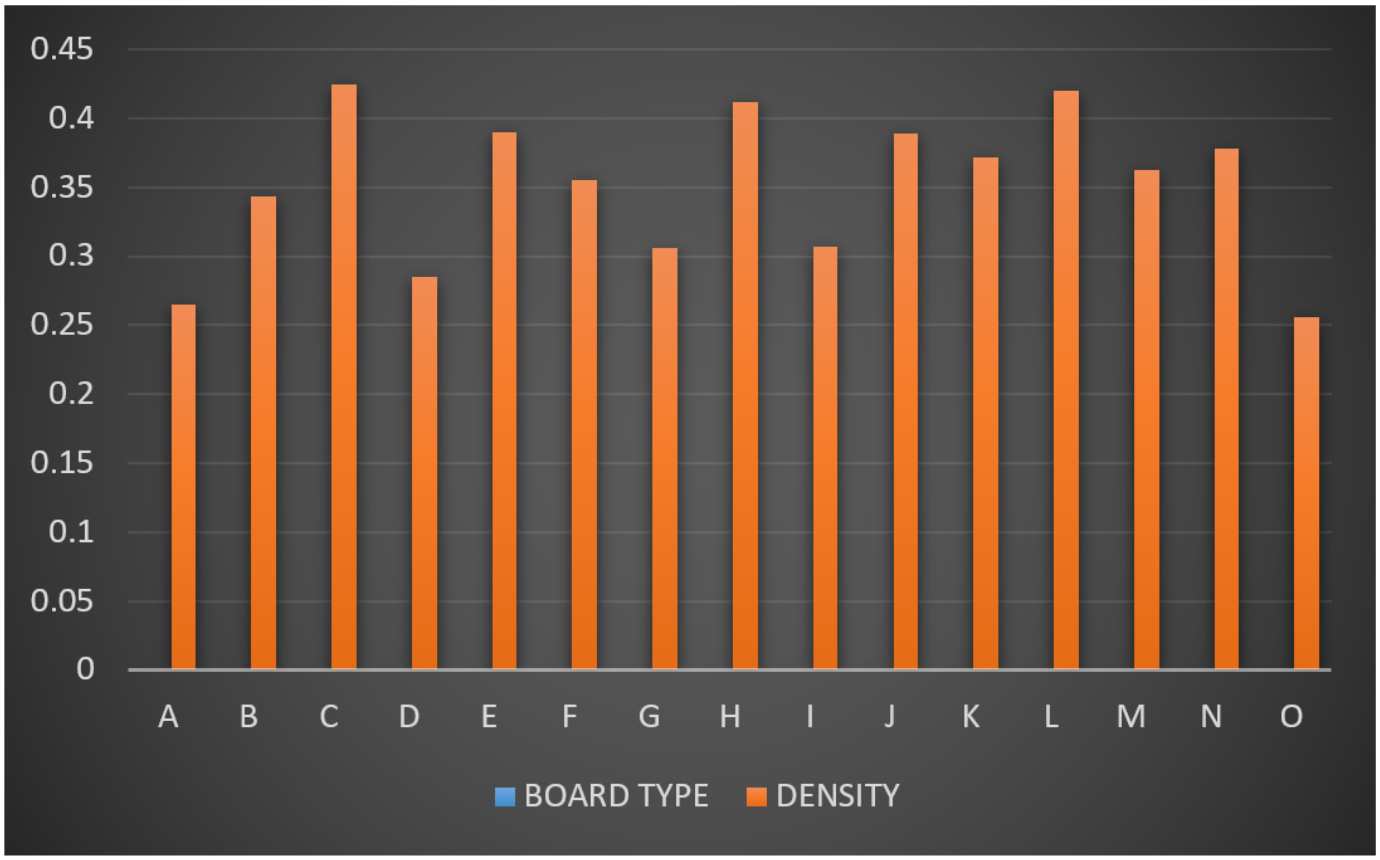


Figure 8

Fig. 9: Average Density of Urea-formaldehyde-bonded Bamboo Boards

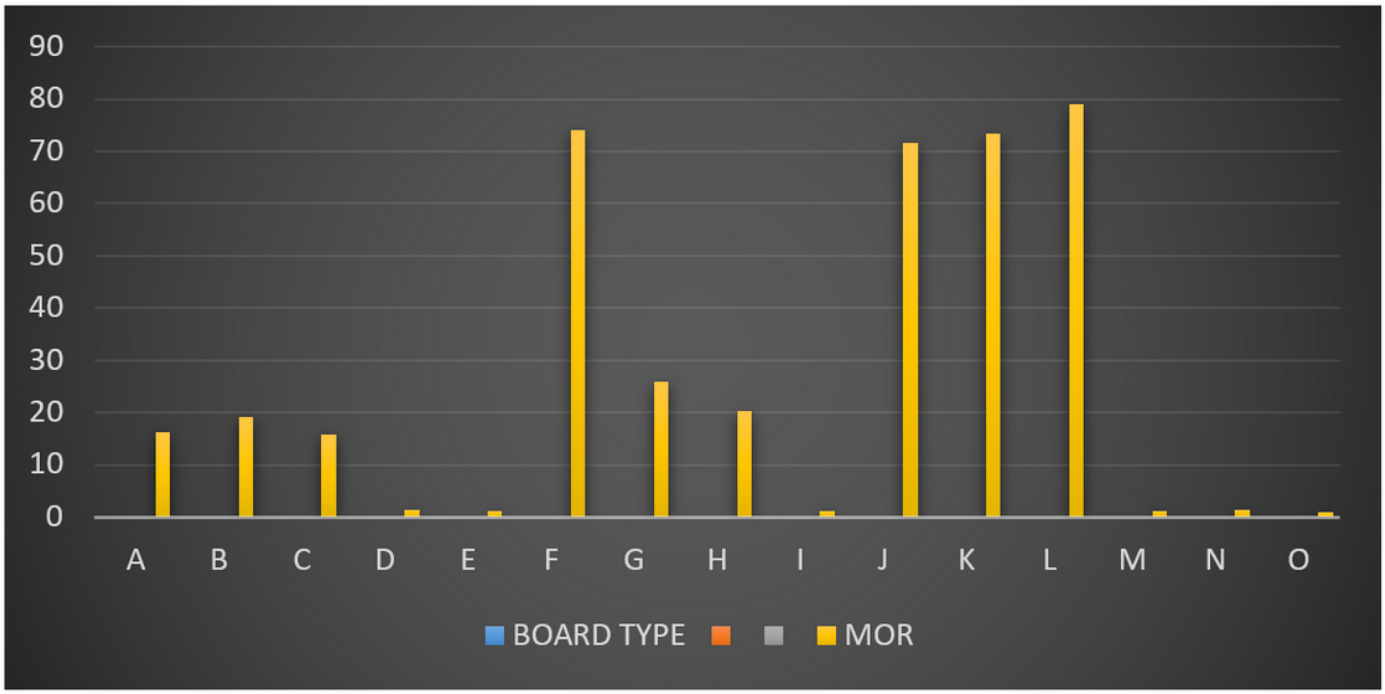


Figure 9

Fig. 10: Average Modulus of Rupture for different Boards

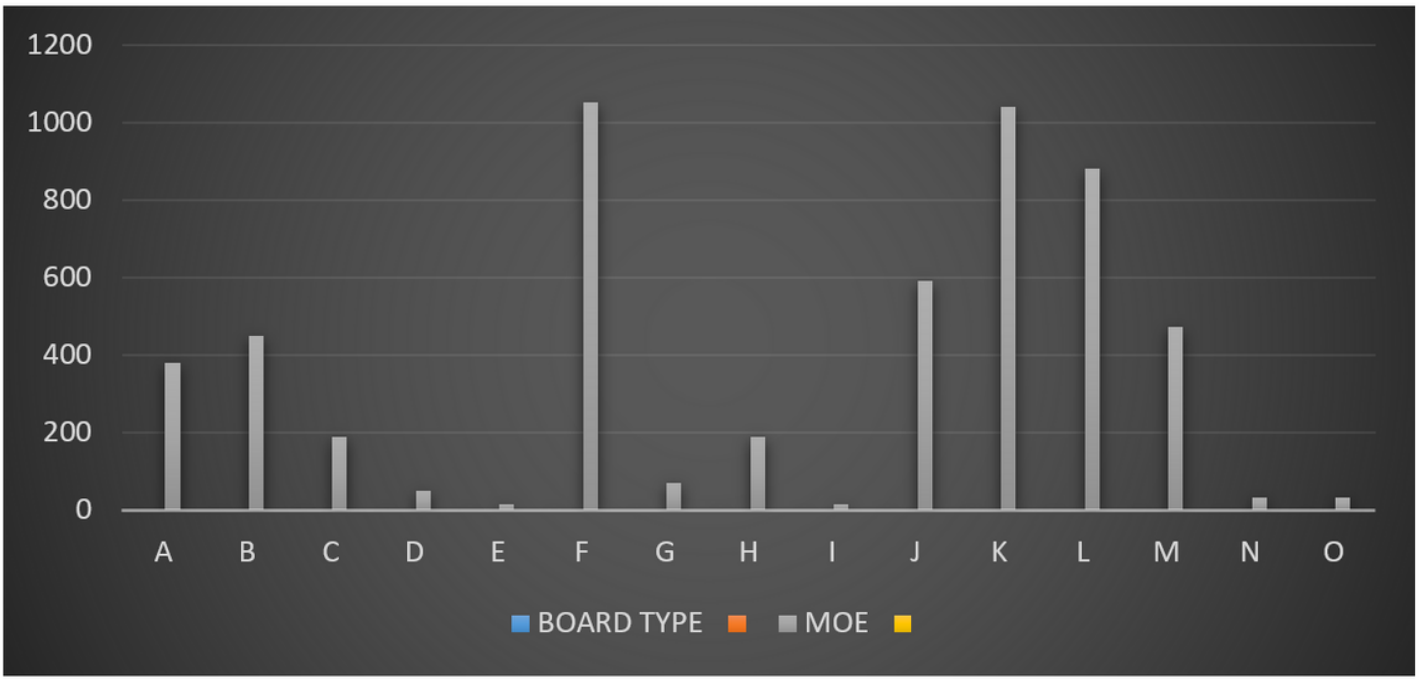


Figure 10

Fig. 11: Average Modulus of Elasticity for different boards