Strength Evaluation of Aluminium Fibre Reinforced Particle Board made from Sawdust and Waste Glass

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Abstract. This research investigated the effects of aluminium shavings on particleboards produced from sawdust and waste glass using Urea formaldehyde as binder. Twelve (12) boards were produced and each had different variations of sawdust, waste glass and aluminium shavings with a constant volume of adhesive used. The boards were tested for physical properties such as density, Thickness swelling (TS) and Water absorption (WA) and mechanical properties such as modulus of rupture (MOR) and modulus of elasticity (MOE). The effects of the aluminium shavings on the boards were observed in the MOR and MOE values such that the values for board A1 were 3.30 N/mm² and 10.45 N/mm² for 20% aluminium shavings content but reduced to 3.16 N/mm² and 8.97 N/mm² respectively for board A2 with 10% aluminium shavings content. This trait was observed in other boards with the same content except in boards B1 and B2 where the MOR and MOE values increased with the values for B1 being 2.06 N/mm² and 6.98 N/mm² and 2.91 N/mm² and 10.17 N/mm² respectively. The values for density of the boards increased as the sawdust decreased and also as the glass content increased. The boards with the highest values for thickness swelling and water absorption were the first three as they possess the highest quantity of sawdust. From the results, none of the boards produced met up to the requirements for use for structural purposes, board B3 possesses the highest MOR value while board D3 possesses the highest MOE value. Therefore, the boards can serve non-structural purposes such as partitions and indoor uses.

1. Introduction

Due to the rising need for cheaper construction materials, search for solution to housing problems experienced across the world by mostly developing countries and also to provide a way of effectively recycling waste materials, researches have been taken up to explore the possibilities of utilising unconventional materials that bear close similarities with the materials normally used for structural development[1,2]. One of these construction materials is Particle board. Particle board is a construction material that has vast applications and is also eco-friendly as it usually makes use of waste materials thereby providing a way of recycling such materials [3–9]. The adhesive used in bonding the particles together could be any binding agent but there are some synthetic resins which are used frequently, these include urea formaldehyde, phenol formaldehyde etc. However, urea formaldehyde is the most commonly used due to its cheap price and easy production [10,11]. The particle board is an engineered material made from wood-based products and during the development of this board, several factors affect the properties of the board. Such factors could include the particle
size and the adhesive content. These factors could directly affect properties such as board density, modulus of rupture, modulus of elasticity etc. Different kinds of materials would have different interactions with the adhesive used, so the suitability of each material to the adhesive used would be different for several materials which would ultimately have either positive or adverse effects on the particle board produced [12].

Industrial waste management refers to the ways through which waste materials could be reused and recycled to serve a functional purpose. This shows that the mentality of regarding waste as being useless is being dismissed and more value is being attached to waste materials as more environmental awareness is created to control environmental pollution. There are various forms in which waste could present itself, some of which include; municipal solid waste such as household refuse, wastewater such as sewage, radioactive waste [13]. Sawdust is an industrial waste that is available in large quantities in sawmilling factories, paper industries and also wood processing industries and it is usually dumped in heaps to be burnt thereby causing a major concern for environmental well-being. There are several applications of sawdust as it is a raw material which could be used in the manufacture of construction materials [14,15]. Such applications include: as a material for the construction of notice boards, furniture, as a fuel source, it could also serve as an insulating material in electronic devices like refrigerators. More applications of sawdust include to produce briquettes, mixing sawdust with wood ash and calcium carbonate forms fertilizers and also sawdust could be used as a composing material for particleboard production and it can be used in the production of oil [4,16,17]. Most of the research done on the recycling of waste glass has been on the use of waste glass either as aggregate in concrete construction or as a replacement for cement in concrete construction [18–20]. A replacement of cement with waste glass powder would also mean a reduction in the production cost of concrete thereby providing a way of spending less and also promoting environmental growth by recycling waste materials. However, the use of waste glass as an aggregate in concrete production would cause a few drawbacks such as reduced bond between the aggregate and cement paste which would be stronger with a natural aggregate and the major hindrance to the progress of utilising waste glass in concrete is the Alkali-Silica Reaction. The outcome of the Alkali-Silica reaction is the alkali-silica gel which has the attribute of absorbing water with the inclination of swelling and exhibiting an increase in volume and due to this volatile behaviour, damage occurs within the structure of the concrete amid the generation of internal stresses. ASR is a problem that might not manifest for years and so, therefore, is a potential risk [21].

2. **Materials and Methods**

The materials used for the production of the particle boards are sawdust, waste glass, aluminium shavings and Urea Formaldehyde. These materials were sourced locally in the Omu-aran community and were varied in proportions for each board following the experimental design designated for them as depicted in the table 1. The sawdust used for the project was acquired from the Omu-aran community at a moisture content of 9.46%, which was determined with the aid of an AND MX50 moisture analyser and room-dried for 7 days. The waste glass used were washed and dried to remove any impurities that may be present in it. The waste glass used for the research work was gathered and collected for the purpose of the experiment and the particle size used for the experimental procedure was sizes passing through sieve size 2mm and retained on 300 microns. The glass particles were later washed and dried to remove any impurities that may be present in it. Fabricated steel mould with internal dimensions of 350 x 350 x 30 mm were used, the mould cover was made in such a way that it extended 15 mm downwards, this provided the assurance that the board was actually compressed to the required thickness (15mm) when placed on the hydraulic press.
Table 1. Mix design for each Board Sample.

| Board Sample | Sawdust | Waste Glass | Aluminium Shavings |
|--------------|---------|-------------|--------------------|
| A            | 80%     | 0%          | 20%                |
| B            | 90%     | 0%          | 10%                |
| C            | 100%    | 0%          | 0%                 |
| D            | 64%     | 16%         | 20%                |
| E            | 72%     | 18%         | 10%                |
| F            | 80%     | 20%         | 0%                 |
| G            | 48%     | 32%         | 20%                |
| H            | 54%     | 36%         | 10%                |
| I            | 60%     | 40%         | 0%                 |
| J            | 40%     | 40%         | 20%                |
| K            | 45%     | 45%         | 10%                |
| L            | 50%     | 50%         | 0%                 |

The quantity of Urea formaldehyde was constant in all the boards. The adhesive used was 30% of the board volume.

2.1. Production of Particleboard

The quantity of material required for each board was measured out in volume into a head pan and a dry mix was done before the required quantity in volume of Urea formaldehyde (top bond) was poured into the head pan and then mixed till a completely uniform and homogenous paste was attained. The paste was then poured into cut-out polythene placed in the mould and then the paste was spread uniformly in the mould down to the edges. Another cut out polythene nylon was placed on the surface of the composite and the cover was placed on it. The mould was then transported to the hydraulic press which is used to compress the composite to the required thickness and to also attain compaction. This was done for 10 minutes after which the mould was then taken to the oven to be heated for 1 hour at 80°C. The mould was then brought out to cool for 10 minutes after which the mould cover was removed and left open for 24 hours. The board was then removed from the mould and placed in the oven to be heated at 130°C for 3 hours. The board was then allowed to slowly cool in the oven for 30 minutes before it was brought out of the oven and placed on a flat surface to finally cool for an hour after which it was then stacked.

Each board specimen was cut into the required dimensions for the tests; 50×50×12 mm for density test, water absorption and thickness swelling while 290×50×12 mm was used for the Modulus of Rupture and Modulus of Elasticity tests using the Testometric Tensile testing Machine (M500-50AT).

3. Results and Discussion

3.1. Physical Properties

3.1.1. Density Test: This is the ratio of the mass of a material to its volume. Density is a physical property for particle boards this property is dependent on the particle size of the material in use. For commercial purposes, the standard density for particle board is 37-50 lb/cubic ft. (593-801 kg/m³). It is taken as:

\[ \text{Density (kg/m}^3) = \frac{W_a}{V_a} \]  

(1)
Where; \( W_a \) - air dried weight, \( V_a \) – air dried volume

The density for three samples of each board produced is determined and recorded as shown in Table 2. For this research work, the mean densities obtained ranged from 568.89 kg/m\(^3\) to 2004.45 kg/m\(^3\) and these are as shown in table below.

| Board Sample | Mean Density (Kg/m\(^3\)) |
|--------------|---------------------------|
| A            | 808.89                    |
| B            | 568.89                    |
| C            | 577.78                    |
| D            | 1004.44                   |
| E            | 1044.44                   |
| F            | 1048.89                   |
| G            | 1662.22                   |
| H            | 1524.44                   |
| I            | 1671.11                   |
| J            | 1862.22                   |
| K            | 1817.78                   |
| L            | 2004.45                   |

It can be observed from the table that board L had the highest density, this might be as a result of the trend in the table which is an increase in the density as there is a decrease in the sawdust content and increase in the glass content. Boards A, B and C have the highest composition of sawdust and contain no waste glass but possess the lowest values for density while boards J, K and L have the lowest composition of sawdust and contain the highest content of waste glass but possess the highest values for density. This gives a better density compared to boards made from sawdust and plastic waste as reported by [6]. According to ANSI 208 [22] standard, board B and C can be classified as low density particle boards with densities less than 640 \( kg/m^3 \), while all other boards are classified as high densities particle board with densities above 800 \( kg/m^3 \) [22].

3.1.2. Thickness Swelling: This is done through a test which determines the alteration of the thickness of the particle board after immersion in water for a specified period of time. This property depends on the moisture and absorption nature of the board specimen. It should not be more than 2-3% and its value decreases after the specimen dries.

\[
\text{Thickness swelling (\%)} = \left( \frac{T_f - T_i}{T_i} \right) \times 100
\]

Where; \( T_i \) - initial thickness, \( T_f \) - final thickness

For one of the physical properties for particle boards, the thickness swelling for each board is determined and each board has three samples. The mean thickness swelling percentage value is then obtained and recorded. The test involves submerging the test samples in water at room temperature.
and recording the variations in the thickness after 2 hours and 24 hours. The mean values for the percentage thickness swelling are as shown in the table 3.

**Table 3. Mean values for thickness swelling**

| Board Sample | % TS after 2 hours | %TS after 24 hours |
|--------------|--------------------|--------------------|
| A            | 3.38               | 21.41              |
| B            | 4.44               | 33.41              |
| C            | 5.5                | 32.52              |
| D            | 2.95               | 3.46               |
| E            | 1.56               | 1.89               |
| F            | 1.39               | 2.41               |
| G            | 1.25               | 7.95               |
| H            | 0.77               | 8.9                |
| I            | 2.46               | 9.82               |
| J            | 0.44               | 1.09               |
| K            | 0.58               | 0.95               |
| L            | 0.61               | 0.94               |

It can be observed that boards A, B and C have the highest values for thickness swelling, this is a result of the high sawdust content in them. The trend, therefore, observed in the table is that decrease in the sawdust content leads to decrease in the thickness swelling. It is also observed that due to the high sawdust content, the difference between the thickness swelling after 2 hours and that of 24 hours in the first three boards is quite large. Board J has the lowest thickness swelling value after 2 hours but not the lowest after 24 hours, board L has the lowest thickness swelling value after 24 hours but not the lowest after 2 hours. The American National Standards Institute [22] stipulated that the maximum thickness swelling is 8%. Thus, boards A, B, C and I does not fulfill the thickness swelling requirement.

3.1.3. Water Absorption: Water absorption is the test done to determine the ability of the particle board to absorb water at room temperature until constant weight is attained. This procedure puts the other properties to test as it causes a reduction in the strength of the particle board.

Water absorption (%) = \( \left( \frac{W_f - W_i}{W_i} \right) \times 100 \)  

(3)

Where; \( W_f \) – final weight and \( W_i \) – initial weight

Water absorption is a test performed to determine the ability of the particle board to absorb water until a constant weight is attained. Board samples of dimensions 50x50x15 mm were submerged in water at room temperature and the weight was measured and recorded after 2 hours and 24 hours. The values for the water absorption percentage are as shown in table 4.
Table 4. Mean values for Water absorption percentage.

| Board Sample | % WA after 2 hours | %WA after 24 hours |
|--------------|--------------------|--------------------|
| A            | 63.88              | 77.47              |
| B            | 74.95              | 93.79              |
| C            | 98.52              | 121.53             |
| D            | 40.13              | 49.2               |
| E            | 41.64              | 50.91              |
| F            | 40.33              | 49.08              |
| G            | 31.82              | 35.68              |
| H            | 30.05              | 37.05              |
| I            | 26.38              | 33.7               |
| J            | 31.85              | 37.75              |
| K            | 35.45              | 39.25              |
| L            | 31.97              | 34.58              |

It can be observed that boards A, B and C have the highest values for water absorption due to their high sawdust content as sawdust absorbs water easily. It can also be observed that board I has the lowest value for water absorption while board C has the highest value for water absorption owing to the fact that it comprises of only sawdust. It can be seen the addition of aluminium shavings to the particle board aids in the resistance of the board to water absorption as aluminium shavings does not absorb water.

3.2. Mechanical Properties

3.2.1. Static Bending: The mechanical properties of the particle boards produced were tested and the various values for the Modulus of elasticity and the Modulus of rupture were determined. Modulus of elasticity is the ability of a material that describes the resistance offered by the material to deformation upon the application of stress. It is the property of a material that describes the resistance offered by the material to deformation upon the application of stress. This is a mechanical property for particle board.

\[ \text{MOE} = \frac{P_{bp}L^2}{4bh^3Y_p} \]  

Where; \( P_{bp} \) – load at the proportionality limit, \( L \) – Span length in mm, \( b \) – Width of the specimen in mm, \( h \) – Thickness of the specimen in mm, \( Y_p \) – deflection corresponding to \( P_{bp} \) (mm)

3.2.2. Modulus of Rupture: Modulus of rupture is the property of a material that measures the stress applied in the material and its structural components. Just like MOE, this is a mechanical property of a particle board which measures the stress applied in a material and its structural components. This material property is dependent on the density of the specimen material.

\[ \text{MOR} = \frac{3P_bL}{2bh^2} \]  

Where; \( P_b \) – Maximum load, \( L \) – Span length in mm, \( b \) – Width of the specimen in mm, \( h \) – Thickness of the specimen in mm

The mean values of three samples each for the Modulus of rupture and Modulus of elasticity are as shown below.
Figure 1. Mean values for MOR and MOE.

It can be observed that board L has the highest value for Modulus of elasticity while board F has the highest value for Modulus of rupture. The board with the lowest MOR and MOE is C. The BS EN 13353 [23] states that panels intended for structural use should have densities of minimum 420 Kg/m$^3$ and also have minimum values of MOR and MOE to be 5 N/mm$^2$ and 600 N/mm$^2$ respectively. This means that none of the boards produced can serve the purpose of structural use. It was observed that, apart from the case of boards D, E & F, there was a higher MOE and MOR value when the composition of aluminium shavings increased in the boards. Board A has higher MOE and MOR compared to B, board G has higher MOE and MOR values when compared to H and J has higher values than K.

4. Conclusion
The results of this research work show that the particle boards produced cannot be used for structural or load bearing purposes. It was also observed that the only noticeable effect aluminium shavings had on the panels was in the Modulus of elasticity and Modulus of rupture values and the impact it had was minimal. The properties the panels exhibited make it possible for them to be used as partition walls. The addition of glass to the boards brought about an increase in the densities of the boards. Therefore the boards produced can serve non-structural purposes such as partitions etc.

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