

Comparative Study Of Phenol Formaldehyde And Urea Formaldehyde Particleboards From Wood Waste For Sustainable Environment

Paul A.P Mamza, Emmanuel C. Ezeh, E.C. Gimba, David Ebuka Arthur.

ABSTRACT: This research work was aimed at comparing the properties of particleboards produced from sawdust with phenol formaldehyde and urea formaldehyde resins. The particleboards were produced using varied quantities of particle size 2mm. 30ml each of the resins which was prepared under same conditions, compression temperature of 180°C, pressure of 10tons, and pressing time of 15 minutes. The properties of the particleboards were tested and compared. The results showed that the particleboards produced with phenol formaldehyde had better properties compared to that of urea formaldehyde. And the property of the particleboards is a function of the percentage composition of the binder (resin) and the filler (sawdust).

Keywords: Particleboard, Urea-formaldehyde, Phenol-formaldehyde, and properties.

INTRODUCTION

Over dependency on natural solid wood for fuel, construction material and other wood works, and subsequently generation of wood wastes such as sawdust from wood processing, pose great challenges to environmental sustainability. However, production of particleboards which involves the utilization of the wood wastes and certain binder(s) now serve as an inexpensive and profitable alternative to the natural solid wood and environmental sustainability. Particleboard is a composite panel product consisting of wood particles such as sawdust, wood chips, sawmills shavings or other agricultural wastes that are bound together with a synthetic resin or other suitable binders under heat and pressure. It is an inexpensive alternative to solid wood paneling, and has emerged as a versatile substitute for wood in many applications. It can be used to create furniture, cabinets and cupboards, shelves and toys and musical instruments such as speaker-box. In building construction, particleboard find its application for decoration and acoustic purposes, AC duct covering, door panel inserts, wall panels, floor ceiling tiles, etc. In transportation sector, particleboard is used in the railways for chairs, partitioning and sliding doors, etc. Particleboard is manufactured by mixing wood particles or other agricultural wastes with a resin and forming the mix into a sheet, under heat and pressure. The primary lignocelluloses materials used in the particleboard industry are wood particles. Sawdust is recommended for its relatively low specific weight and abundance as a cheap by-product. It is a by-product of cutting lumber with a saw, composed of fine particles of wood. Agricultural wastes such as rice husk, cotton husk,

coconut husk, to mention but a few, have also been used for making particleboards. The utilization of these materials for particleboard production is significantly for reducing the demands for natural solid wood and improving environment, (Sampathrojanet al, 1992). For instance, the over dependency on natural solid wood for fuel, construction materials, and other wood works has led to uncontrolled deforestation, which has caused great loss to forestry sector, and consequentially, global warming. In addition, sawdust, the main by-product of sawmills, unless reprocessed into particleboard, burned in a sawdust burner or used to make heat for other milling operations, may collect in piles and add harmful leachates into local water systems, creating an environmental hazard. This has placed small sawyers and environmental agencies in a deadlock. It can also present a hazard in manufacturing industries, especially in terms of its flammability. Hence, the need for simple standard methods for the production of high quality and cost effective particleboards becomes imperative.

RESINS

Production of particleboards, as stated earlier, involves the use of binder (resin). A large amount of binder is being used in particleboard industry for the production of high-quality products. The binder accounts for up to 32% of manufacturing cost in the glue-wood composite industry. Various types of binders have been used in the manufacture of particleboards and they are classified as satisfying interior or exterior use requirements primarily on the basis of their response to moisture and/or temperature. At present, the principal ones are formaldehyde condensation polymers, such as Urea-formaldehyde (UF), Phenol-formaldehyde (PF), Phenol-resorcinol formaldehyde (PRF), Melamine-formaldehyde (MF) and their derivatives (i.e. modified formaldehyde condensation polymers). Others may include; isocyanate adhesive, gypsum, nitrogenous modified amylose binder, magnesia, etc. The relatively low cost and proven performance of phenol-formaldehyde and urea-formaldehyde resins has made them the most important adhesive systems for composite wood products. These two resins are formed by step-growth (condensation) polymerization reaction of formaldehyde (CH₂O) with phenol (C₆H₅OH) and urea (H₂NCONH₂) respectively. The reaction could be either acid or base-catalyzed.

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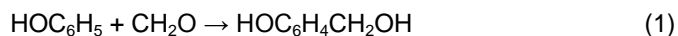
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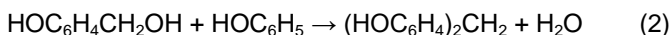
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PHENOL FORMALDEHYDE RESIN

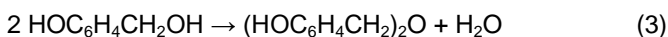
Phenolic (phenol-formaldehyde) resins, first commercially available in 1907 (Ibeh, 1999) when some of the first polymers were made, are today, among some of the most widely produced thermosetting plastics. They are produced by reacting phenol (C₆H₅OH) with formaldehyde (HCHO). According to Gardziella et al (2000), Phenol is reactive towards formaldehyde at the ortho and para sites (sites 2, 4 and 6) allowing up to 3 units of formaldehyde to attach to the ring. The initial reaction in all cases involves the formation of a hydroxymethyl phenol, as shown below;



The hydroxymethyl group is capable of reacting with either another free ortho or para site, or with another hydroxymethyl group. The first reaction gives a methylene bridge, and the second forms an ether bridge:



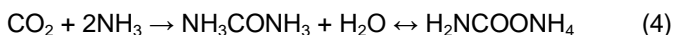
The diphenol (HOC₆H₄)₂CH₂ (sometimes called a "dimer") is called bisphenol E, which is itself an important monomer in the production of epoxy resins. Bisphenol-F can further link generating tri- and tetra- and higher phenol oligomers.



Phenolic plastics are hard, strong, inexpensive to produce, and they possess excellent electrical resistance. Phenolic resins cure (cross-link) when heat and pressure are applied during the molding process. Phenolic resin-impregnated paper or cloth can be laminated into numerous products, such as electrical circuit boards. Phenolic resins are also compression molded into electrical switches, pan and iron handles, radio and television casings, and toaster knobs and bases. ("Phenol." Microsoft® Encarta® 2009 [DVD]. Redmond, WA: Microsoft Corporation, 2008).

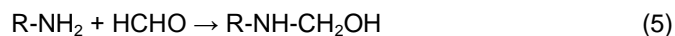
UREA FORMALDEHYDE RESIN

Urea is a colorless and odorless crystalline compound, CO(NH₂)₂, with melting point 132.7°C, also known as carbamide. It is found abundantly in the urine of humans and other mammals. In lesser quantities, it is present in the blood, liver, lymph, and serous fluids and is found in the excrement of fish and many other lower animals. Urea is produced mostly in the liver as the end product of protein metabolism. The nitrogen in urea, which constitutes most of the nitrogen in the urine, is produced mainly from food protein, but part comes from the breakdown of body cells. Urea is also present in various fungus molds as well as in the leaves and seeds of numerous legumes and cereals. The compound is soluble in both water and alcohol and is slightly soluble in ether. Urea is prepared synthetically by the Wohler synthesis, which was devised in 1828 by the German Chemist Friedrich Wohler.

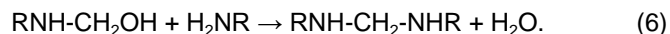


Because of its high nitrogen content, commercially prepared urea is used in the manufacture of agricultural fertilizers. Urea is also employed as a stabilizer in

nitrocellulose explosives and is a basic constituent of synthetically prepared resins. Urea-formaldehyde (UF) resins are composed of molecules that cross-link into clear, hard plastics. Properties of UF resins are similar to the properties of phenolic resins. As the names imply, these resins are formed by condensation reactions between urea (H₂NCONH₂) and formaldehyde (CH₂O). Two main steps are recognized in the reaction of formaldehyde with amino compounds to form useful resins. The first step known as methylation or hydroxymethylation involves a simple addition of formaldehyde to introduce the hydroxymethyl group. This is illustrated in the following equation:



The second step, referred to as methylene bridge formation, polymerization, resinification, or simply cure, is a condensation reaction that involves the linking together of monomer units with the liberation of water to form a dimer, a polymer chain, or a vast network. The illustration is as shown in the following equation:



The success in producing and using amino resins largely depends on the precise control of these two chemical reactions (Gordon et al., 1966) Urea-formaldehyde resins form products such as appliance knobs, knife handles and plates. UF resins are used to give drip-dry properties to wash-and-wear clothes as well as to bind wood chips and wood sheets into chip board and plywood. ("Phenol." Microsoft® Encarta® 2009 [DVD]. Redmond, WA: Microsoft Corporation, 2008).

METHODOLOGY

This section is grouped into three main stages. Viz:

PRELIMINARY STAGE

The sawdust, collected from a Sawmill, was first dried and screened to obtain uniformed particle size sawdust (2mm). The urea formaldehyde (UF) resins preparation involved condensation reaction of formaldehyde with urea in the ratio of 1.7:1. 38-40% aqueous solution of formaldehyde in a quick-fit round-bottomed flask, neutralized with freshly prepared 1 mole of NaOH solution, was first heated on a heating mantle for about 15 minutes, after which the urea was added, and homogeneous mixture of the two formed by thorough stirring. The mixture was then refluxed for about 15 – 30 minutes, and cooled at room temperature. The preparation of the resins was carried out at 60°C and pH of 9 – 10.

RESINIFICATION & FORMULATION STAGE

In the formulation of the particleboards, Sawdust was first blended with molten paraffin wax (water repellent agent) in a mixer, after which the resin was added and thoroughly blended, wrapped in aluminum foil and cold-pressed into mat-form, known as furnish. The furnish was molded into board (panel) form by compression molding in an electrically heated hydraulic press at the temperature of about 150°C, pressure of 12.5MPa, and time of 4min, using a metal mould with the dimensions (160mm length, 150mm width, and 3mm thickness). The

particleboard samples formed were cooled at room temperature, and their physical properties determined.



Plate.1: Photograph of the particleboard samples.

CHARACTERIZATION STAGE (TESTING OF SAMPLES)

WATER ABSORPTION

The particleboard specimens were tested for their water absorption property at different temperatures (Room temperature and 65°C). The test was carried out by weighing the specimens (26mm length, 16mm width, and 3mm thickness) before and after soaking in water for 24hrs. Two sets of specimens were prepared, one was soaked in water contained in a beaker and was kept in an oven at 65°C, while the other set was also soaked in water contained in a beaker but was kept at room temperature. They were allowed to stay in their respective conditions for 24hrs, after which they were removed from water and reweighed. The ratio of the difference in weight to the original weight of sample expressed as a percentage is the percentage Water Absorption of the specimens.

THICKNESS SWELL

As in the case of water absorption test, two sets of sample specimens were prepared. The thickness swell test was carried out by measuring the thickness of the specimens before and after 24 hours in water; one set at room temperature and the other at 65°C. The ratio of the difference in thickness to the original thickness of the specimens expressed as a percentage is the percentage thickness swell of the sample.

DENSITY

The density of each of the specimens was obtained by dividing the weight of the specimen with its corresponding calculated volume. Their weights were obtained using analytical-weighing balance, while the volume was obtained by multiplying their respective measured Length, width, and Thickness.

The density of the specimens was calculated as follows; $\rho = m/v$.

where ρ = density.

m = mass of the specimens in grams.

v = volume in cm^3 .

TENSILE STRENGTH

Using Hounsfield Tensometer (S/N = **W3179**); A tensile testing machine, designed to elongate the specimen at a

constant rate and continuously and simultaneously measure the instantaneous applied force and resulting elongations, the tensile strength of the samples were obtained. The tensile specimens were configured in dumbbell (i.e. dogbone) shape. During the testing, the specimen was clamped at one end and pulled at constant rate of elongation at the other clamped end. The dogbone shape of the tensile specimen encouraged its failure at the center, where the stress was the highest, and not at the grip sites, where stress concentration may otherwise result to premature failure. The tensile response was plotted as stress, σ , versus strain, ϵ .

$$\text{Where } \sigma = \frac{\text{Force (F)}}{\text{Cross-sectional Area (A)}}$$

$$\epsilon = \frac{\text{Change in length } (\Delta L)}{\text{Original length } (L_0)}$$

RESULTS

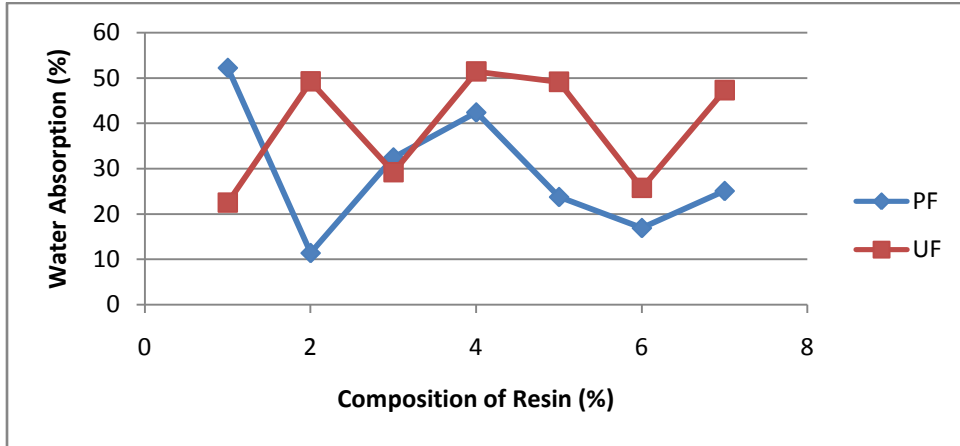


Fig. 1.(a) Water Absorption at room temperature Vs Composition of resin.

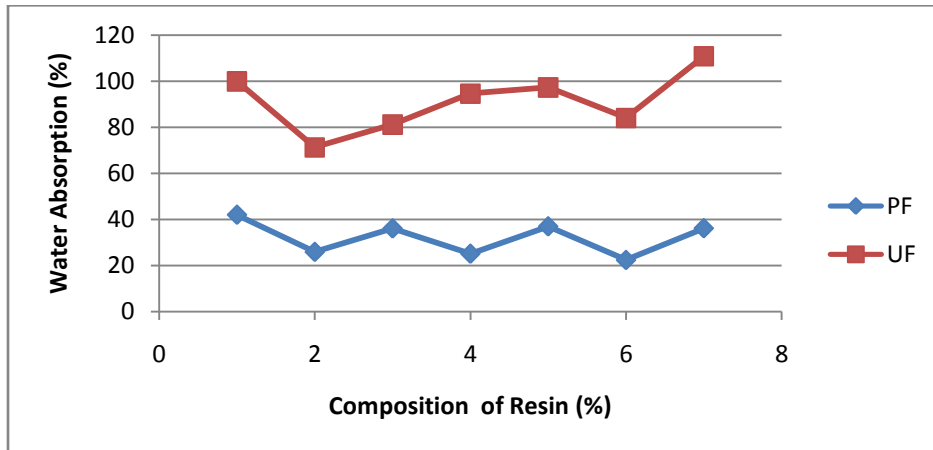


Fig. 1.(b) Water Absorption at 65°C Vs Composition of Resin

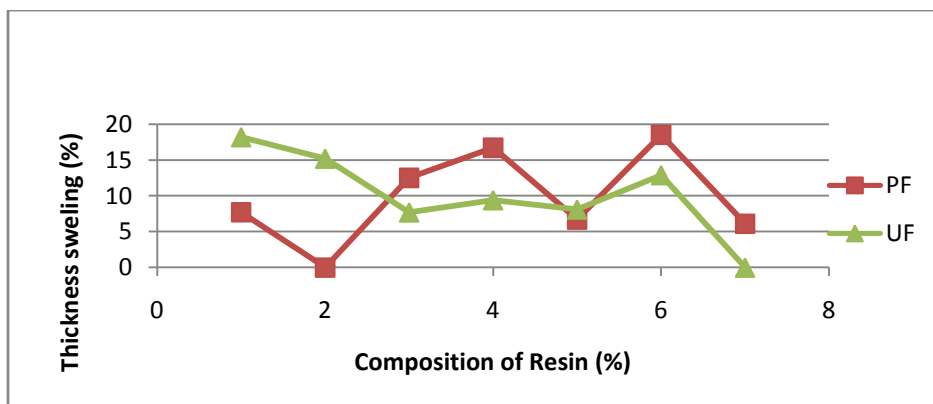


Fig.2.(a) Thickness Swelling at room temperature Vs Composition of Resin.

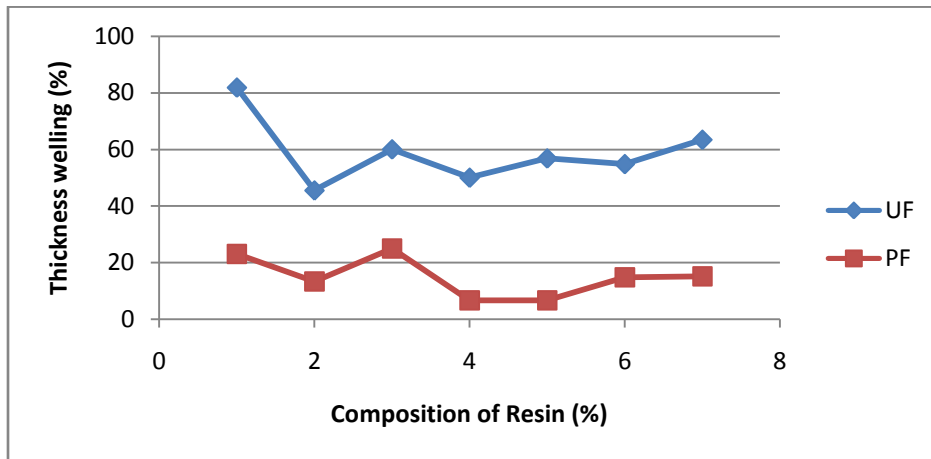


Fig.2.(b) Thickness Swelling at 65°C Vs composition of Resin.

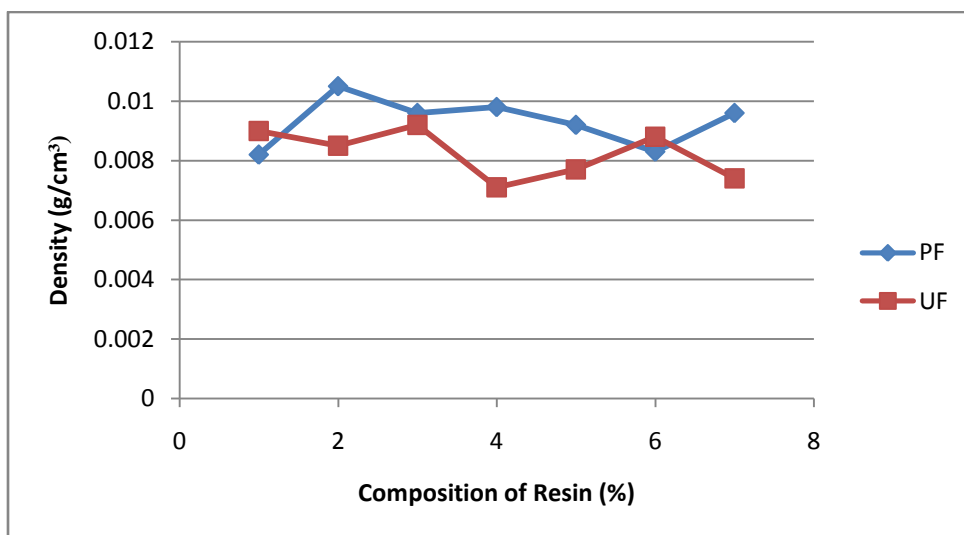


Fig.3: Density Vs composition of Resin.

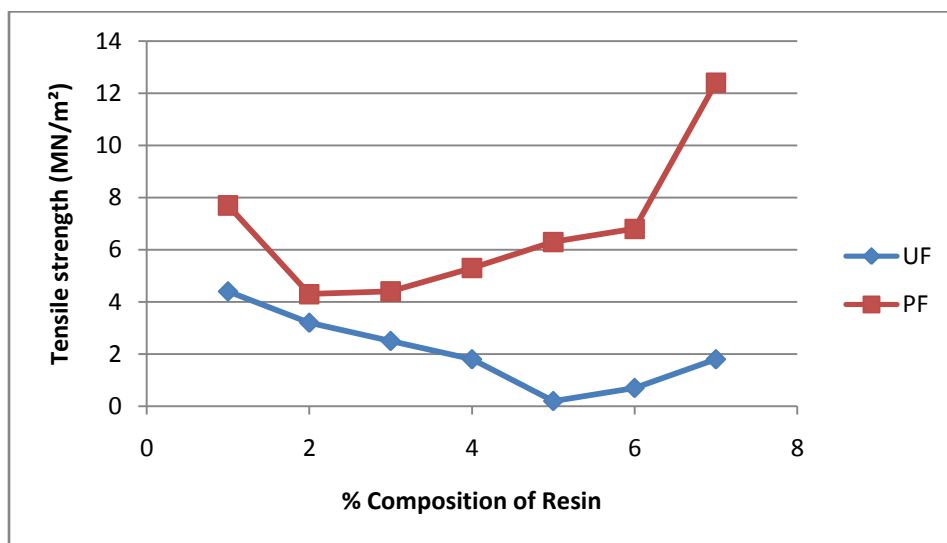


Fig.4: Tensile Strength Vs Composition

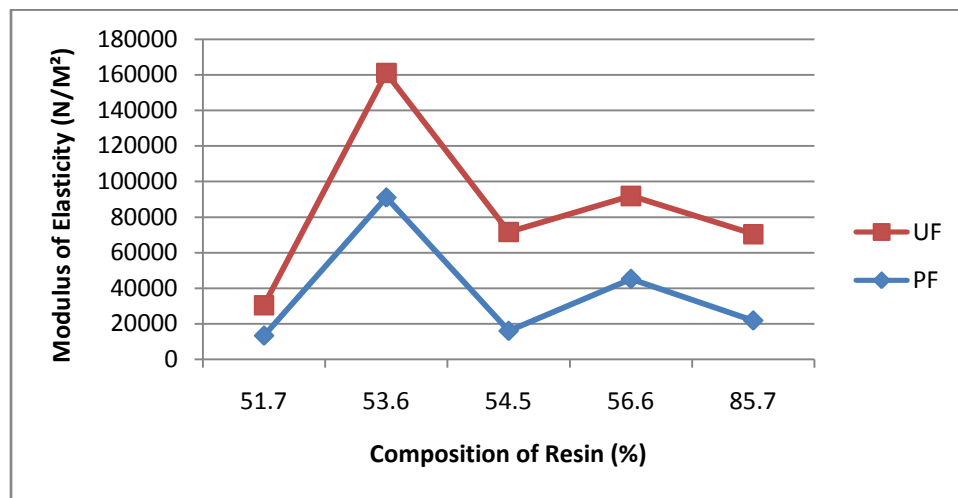


Fig.5: Modulus of Elasticity Vs Composition of resin.

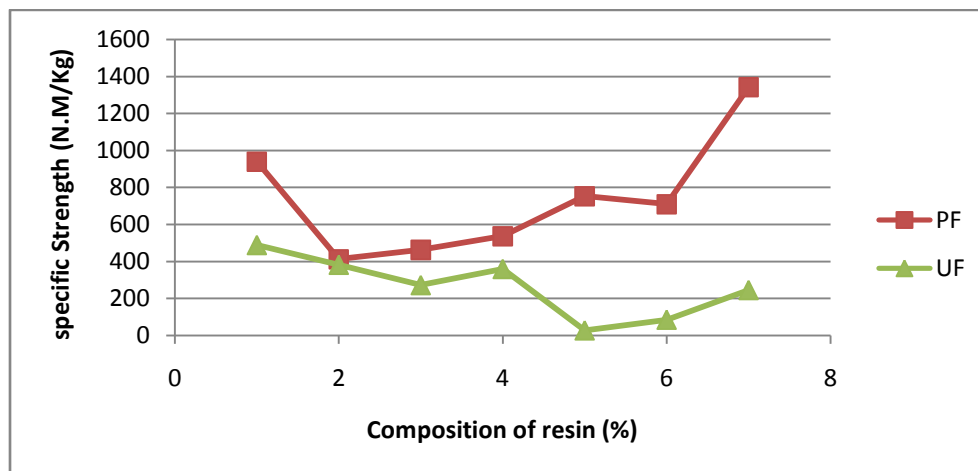


Fig. 6: Specific Strength Vs composition of resin.

DISCUSSION

WATER ABSORPTION

The response of a particleboard to humidity is a function of the degree of its water absorptibility or ability to resist moisture. It is a sample rather than material property, and as such, it depends on the composition and processing history of the sample. From the results of the percentage water absorption shown in fig:1.(a), the PF particleboards of resin composition; 54.5%, 55.5%, 56.6%, and 85.7% exhibited better resistance to water than the UF counterpart. The corresponding UF particleboards had percentage water absorption; 34.8%, 9.02%, 25.38%, 8.81%, and 22.2% respectively higher than the PF particleboards. However, 51.7% and 53.6% resin composition UF particleboards showed better resistance to water, with the PF particleboards having 29.67% and 3.26% respectively higher than the UF counterparts. The overall disparity in their response to water was more pronounced at elevated temperature as shown in fig:1.(b). This is not unexpected because, principally condensation polymers are susceptible to degradation due to effect of water, and

multiple exposures such as moisture and heat can result in accelerated deterioration (Joel, 2003). It was observed that the UF particleboards absorbed much more water than the PF particleboards at 65°C, with 57.9%, 45.36%, 45.09%, 69.4%, 60.27%, 61.56% and 74.56% respectively higher. This is an indication that the cohesive and binding forces of the PF resin are stronger and more sustainable, even at elevated temperature.

THICKNESS SWELL

Fig:2.(a) and (b); the graphical illustration of the results of the thickness swelling of the particleboards showed that the degree of thickness swelling; a measure of the dimensional stability of particleboards in humid environment is a function of the composition and the prevailing temperature. At room temperature, the particleboards exhibited highest thickness swell of 18.2% and 18.5% with the UF and PF resin composition of 51.7% and 56.6% respectively. Also, with resin composition of 52.6% and 56.6%, UF and PF particleboards respectively showed thickness swell of 12.7% and 12.5%. But, with 52.6% and 85.7% of UF and PF resin composition respectively, there

was no significant change in their original thickness as shown in fig:2.(a), implying that the particleboards had high dimensional stability at the room temperature and the resin composition. However, at elevated temperature (65°C), UF particleboards exhibited overall higher thickness swelling. It can be deduced therefore, that the PF particleboards generally, had better dimensional stability than that of UF, even at elevated temperature. This could be attributed to its strong and relatively stable cohesive and adhesive forces.

DENSITY

The density of material connotes its mechanical properties. This may give reasons for the decrease in tensile strength of UF particleboards experienced by the particleboards of 51.7% to 55.5% UF resin concentration as shown in fig: 4. Fig:3. shows that the density of the UF particleboard decreased from the particleboard samples of 51.7% to 55.5%; same trend followed by the tensile strength of the particleboard samples of the above UF resin composition. However, at the 53.6% UF resin composition, there was significant increase in density. PF particleboards were found to be denser than that of UF perhaps, due to stronger compaction force that exists in the PF particleboards than that in UF particleboards. However, at 51.7% and 56.6% UF resin composition, the UF particleboards are slightly denser.

TENSILE STRENGTH

From the results of the tensile strength test, as shown in fig: 4., it was observed that the mechanical behavior of the particleboard samples is actually in line with the earlier stated presumption; that the ultimate stress, resulting from large and irreversible deformation, is a sample rather than material properties and strongly influenced by sample defect and processing history. The PF particleboards generally, exhibited better tensile strength than the UF particleboards, which can be attributed to the strong binding force and compaction strength of PF resin at the resin – sawdust interface. Fig: 4. shows that as the percentage composition of the resin increased from 52.6% through 53.6%, 54.5%, 55.5%, to 85.7%, there was corresponding increase in the tensile strength from 4.3MN/m², through 4.4 MN/m², 5.3MN/m², 6.3MN/m², to 12.4MN/m² respectively. This suggests that the binding strength of the resin at the resin – sawdust interface, plays major role in the ability of the particleboards to resist deformation. The strong binding force and compaction strength exhibited by the PF resin may be due to high tendency of the resin penetration into the pores and crevices of the sawdust besides the three-dimensional bonding effect, resulting to better mechanical interlocking (Mark, et al). The enhanced adhesion between the resin-sawdust interfaces resulted in more efficient transfer of stress along the interface. The effects of the resin on the mechanical behavior of the PF particleboards are similar to those reported in literature (Mamza and Shadrach, 2008); where it was stated that the tensile strength, Modulus of Elasticity, and percentage Elongation of the particleboard increased with increase in resin concentration. However, sample of 51.7% PF resin composition deviated from the above stated trend perhaps, due to processing factor. On the other hand, UF particleboard of 51.7% resin composition exhibited highest tensile strength than all the other samples of UF

particleboards tested. The tensile strength decreased with increase in the resin concentration from 51.7% to 55.5%. However, an increase in tensile strength was experienced at 56.6% and 85.7% resin composition. It was observed as shown in fig: 4., that the UF particleboards with 55.5% resin composition had least tensile strength. Perhaps, the viscous nature of the resin could not allow easy penetration into the pores and crevices of the sawdust, hence, allowing the filler-influence to dictate the mechanical behavior of the particleboards (i.e. UF particleboards) until above 55.5% resin composition, when the resin assumed to be enough to exert its adhesion and mechanical interlocking influence, resulting to the experienced increased tensile strength shown in fig: 4. The tensile strengths of both PF and UF particleboard samples were found to be similar to those reported by Mamza et al (2010), and showed higher value than the BIS specification of 0.8N/mm² (Marjidet al), except the samples of 55.5% and 56.6% UF resin composition.

MODULUS OF ELASTICITY

On an atomic scale, macroscopic elastic strain is manifested as small changes in the interatomic spacing and the stretching of interatomic bonds. As a consequence, the magnitude of the modulus of elasticity is a measure of the resistance to separation of adjacent atoms, that is, the interatomic bonding forces. Furthermore, this modulus is proportional to the slope of the interatomic force-separation curve at the equilibrium spacing (Ralls et al, 1976). On particulate scale, the interstitial spaces allow the stretching of the inter-particle bonds formed by the resins. The results of the modulus of elasticity of the PF and UF particleboards as illustrated in fig: 5, showed that particleboards of 53.6% resin composition exhibited higher modulus in both (i.e. PF & UF particleboards), while that of 51.7% resin composition showed the least modulus. The modulus of both followed similar trend. However, UF particleboards exhibited higher modulus of elasticity, thus, stiffer than the PF particleboards. This is as a result of the greater tendency of stretching of the inter-particle bonds formed by the resins, and perhaps, slippage or plastic flow along the crystal planes in the UF resin than that of PF resin. This also indicates that less energy would be required to deform the UF particleboards to the point of failure than that PF because, in stress-strain plot for polymer, lower modulus implies that higher energy would be required to deform the sample to the point of failure (Joel, 2003).

SPECIFIC STRENGTH

The specific strength followed similar trend as tensile strength. Fig: 6, shows that there was corresponding increase in the specific strength of PF particleboards from 412.38N-m/kg to 1344.07N-m/kg as the PF resin composition increased from 52.6% to 85.7% respectively, with the particleboard of 85.7% PF resin composition exhibiting highest specific strength. On the other hand, UF particleboards exhibited decreasing specific strength as the resin composition increased from 51.7% to 55.5%, and then increased at 56.6% and 85.7%. It can be deduced from the overall results of specific strength of the particleboards, that PF particleboards would be more applicable than that of UF, where weight savings are worth the higher cost. Interestingly, at resin composition of 52.6%, the

corresponding PF and UF particleboards exhibited similar specific strength.

SUMMARY AND CONCLUSION

SUMMARY

Indeed, the manufacture of particleboards provides profitable and inexpensive alternatives towards the availability of solid wood products and ensuring environmental sustainability. Firstly: Sawdust, the main by-product of sawmills and the most recommended primary lignocelluloses materials for the manufacture of particleboards may collect in piles and add harmful leachates into local water systems, creating an environmental hazard if not utilized. It can also present a hazard in manufacturing industries, especially in terms of its flammability. Besides, the availability of this inexpensive wood product (particleboard) reduces the dependency of wood users on natural solid wood. This in turn, reduces reckless deforestation and illegal logging; the major problems in the forestry sector, which contributes immensely to global warming. Global warming occurs due to increase in greenhouse gases. These gases admit the Sun's light but tend to reflect back downward the heat that is radiated from the ground below, trapping heat in the Earth's atmosphere. Plants utilize the most significant greenhouse gas (Carbon (iv) Oxide, CO₂) during photosynthesis. Illegal logging reduces the number of plants which utilize this gas, hence, encouraging its abundance in the atmosphere. Secondly, the synthesis and application of Urea-formaldehyde resin for the manufacture of particleboards is excellent inexpensive alternative for environmental sustainability and the manufacture of particleboards of acceptable standard quality. Urea, the main component of Urea-formaldehyde resin is readily and cheaply available. It is abundant even in human urine. Hence, urine, a despised liquid with offensive odour, generally considered as useless liquid pollutant, can now be used as primary raw material for production of Urea, which may be reacted with appropriate proportion of formaldehyde to form Urea-formaldehyde resin. This may also serve as a measure for environmental sanitation and control. Moreover, the utilization of Carbon (iv) Oxide; the most significant greenhouse gas in the chemical synthesis of urea by Wohler process, is an excellent measure towards controlling the amount of the greenhouse gas, and consequently, preventing or reducing global warming. Finally, in addition to providing relatively cheap and good resin, the production of Urea-formaldehyde resin and the application of same for the manufacture of particleboard reduce over-dependency on petroleum-based raw materials for the production certain resins. Thus, increasing the quantity of other economically viable petroleum products, and consequently, improving the country's economy.

CONCLUSION

Based on the result obtained from this research work as stated in chapter four, the following conclusions were drawn:

- ✓ The property of the particleboard is a function of the percentage composition of the components. This implies that the properties of the particleboard depend

on the resin-filler ratio. Consequently, variation in the percentage composition alters the properties of the particleboard.

- ✓ Phenol-formaldehyde particleboards have more ability to resist water penetration than the Urea formaldehyde particleboards. Hence, PF particleboards have more dimensional stability than the UF particleboards. As a result, PF particleboards have better application in moist or humid environment than UF particleboard. However, UF particleboard of resin composition of 51.7% and 53.6% exhibited better water repellent property than the PF counterpart.
- ✓ PF resin imparted better mechanical properties to the particleboards. As a result, the PF particleboard is said to exhibit better resistance to deformation than the UF particleboards. Therefore, the PF particleboards would be more durable, tough and have more ability to resist abrasion.
- ✓ UF particleboards are less expensive to produce as one of the major components (Urea) is readily and cheaply available, as compared to PF Particleboards.

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