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Development of Wood-Crete Building Materials from Wood-Waste and Inorganic Binder

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Abstract

This study was to develop a new building material, wood-crete, using sawdust, waste paper and tradical lime. The paper presents the processing technologies, factors which affect the performance of the developed composites and properties of wood-crete. Properties of wood-crete were investigated based on; (1) the type of wood sawdust – hardwood (beech and oak) and softwood (pine and cedar); (2) modification of sawdust by hot water boiling, alkaline treatment and the addition of different types of waste paper. The results showed that; (1) lightweight sustainable blocks can be produced with good insulating and other relevant properties for building construction with compressive strength of up to 3.93MPa; (2) the compressive strength of wood-crete was closely related to the wood species, with the compressive strength of 3.93MPa being for hardwood wood-crete compared to 1.37MPa and 0.26MPa of wood-crete from softwood and mixed wood respectively; (3) surface modification, processing of cellulosic fibril and the extraction of lignin and hemi-cellulosic compounds with alkali had an effect on the compressive strength of wood-crete, with treating sawdust with 4% NaOH at 140mins of boiling time achieving the highest increase of 260% compressive strength. The properties were closely related to the composition of wood-crete with an addition of waste paper being a dominant influence on strength, reflecting its effect on the structure of composite and contribution of self strength of paper fibres. Of significant importance was the contribution of self strength of wood-crete due to the influence of the size of sawdust particles used. The developed wood-crete was able to withstand considerable amount of impact load and considered, like hempcrete, most suitable for wall panelling or other non- and semi-structural applications.

Keywords: Wood-Crete; tradical Lime, sawdust, compressive strength, thermal conductivity.
Corresponding Author:

Introduction

Wood-Crete is a new material made from sawdust or other wood wastes, waste paper and Tradical Lime with consideration for cheaper and locally available materials to meet desired needs, enhance self-efficiency, and lead to an overall reduction in construction cost for sustainable development.

Wood waste, a major constituent of Wood-Crete, may be sawdust from the sawing of wood or any other wood wastes. Sawdust has been used in combination with inorganic binders to produce wood-cement composites replacing sand and aggregate in concrete mix. There are a number of merits offered by wood and inorganic binders over some conventional building materials presently used. These composites combine the properties of both the wood fibre and matrix which makes them more valuable to the building industry. Inorganic wood composite, such as wood-cement composite, has been studied in a great detail. Hardwoods have been reported to have a lower compatibility with cement than softwood, partly due to the inhibitory properties of hydrolysable hemicellulose and other extractives present in hardwoods [1]. Experimentation with a group of four hardwoods and five softwoods from North America [2] revealed that hardwoods adversely affected tensile strength and exothermic behaviour of cement more than softwood.

Additionally, it has been reported that various chemical components of different wood species affects wood-cement composites. Lignin has been reported to yield high performance concrete strength, set retarder for a cement composition and improve the compressive strength of cement pastes [3]. Furthermore, it has also been stated by Pourchez et al (2006) [4] that cellulose retards cement hydration process. The effect of cellulose is attributed to the increased viscosity of the water, which imparts the movement of ions, decreasing the dissolution rate of anhydrous phases and the precipitation of hydrates [4].

The chemistry between the bonding of sawdust and binders has been argued by a number of authors [5] [6] [7]: Wood contains a number of substances, including hemicelluloses, starches, sugars, phenols and hydroxylated carboxylic acids which could dissolve and affect lime crystallization. The major problems of wood composites are associated with the hydrophilic character of the cellulose structure of fibre [8]. Researchers have suggested some propounding solutions to the above problem by stating the necessities to modify cellulose fibre surface by scientific methods to reduce the hydrophilic nature of sawdust thereby improving the sawdust–matrix bonding [8] [5].

Wood-crete is produced with a binder known as tradical lime which is known for its elasticity, durability (long lasting quality mortars), workability, vapour permeability, and healthy material (natural and solvent-free) when compared to the use of cement.

Mixture of hemp shives and cementitious binder creates a building material with different properties including mechanical, thermal and acoustic properties that differ from those of conventional concrete. Amongst these material properties, hemp concrete when used for wall application is not load-bearing. Table 1 summarises some material properties of a lime hemp concrete mixture for wall application in comparison with those of other building materials [9].

Table 1. *Material Properties of Lime-Hemp Concrete with Other Building Materials*

Material	**Young Modulus (MPa)**	**Compressive Strength (MPa)**	**Density (kg/m^3)**	**Thermal Conductivity ($W/M.^0C$)**
Steel	210000	350-1000	7500-8500	52.00
Concrete	20000	12-80	20000	1.50
Cellular Concrete	1000-2500	5	420-1250	0.14-0.23
Brick	10000-25000	25 – 60	1300-1700	0.27-0.96
Wood	230–20000	4 – 34	350-900	0.12-0.3
Lime Hempcrete	24	0.4	445	0.17

The ratio of mix of hemp concrete determines the compressive strength of the material. Compressive strength values for Hemp-Crete vary from 0.02 to 1.22MPa [3, 10], depending on the composition of the mixture.

This study aims at developing a novel sustainable building material (Wood-Crete) which is lightweight, has good insulating properties and is able to withstand considerable amount of impact load.

Materials and Methods

Binders (Tradical lime HB) was sourced from Lime Technology Ltd. UK and commercial Ordinary Portland cement (OPC) was mixed with sawdust sourced from the Wood Workshop at Brunel University, London. The sawdust particles were refined to 1mm mesh size. Waste paper (newspaper) also a constituent in this experiment was de-fibred firstly by soaking in water. The average microscopic measurement taken for 50 fibres was 1211.79µm in length and 25.97µm in breadth. The de-fibred waste paper was then mixed with sawdust and Tradical lime to improve the insulating properties and reduce the density of block samples.

Preceding block formation, the wood particles were dried in the oven at 100^0C for 24 hours to reduce the amount of water and then mixed with Tradical lime and cement at the designed ratios.

Softwood chosen for this study is pine and cedar. Pine sawdust was chosen due to its resistance to shrinkage and swelling [10] with a density of about 510kg/m^3. Sawdust from cedar wood was chosen due to high shock resistance [10], good dimensional stability and pleasant scent of the wood which acts as a natural insect repellent which can add natural properties to wood-crete blocks [10]. Cedar wood has a density of 480 – 580kg/m^3.
Hardwood chosen for this study includes oak and beech. Oak wood was chosen for this study due to its common use for making furniture which leads to high availability of sawdust from sawmills. As well, oak wood is known for great strength and hardness, and is very resistant to insect and fungal attack because of its high tannin content and has a density of about 750kg/m^3. Beech wood sawdust was chosen as a result of good strength properties, abrasion resistance and high in resistance to shock associated with beech wood [10] with a density of 730kg/m^3. In general, oak wood and beech wood are the most used type of wood in production of furniture in European markets [11] which makes them well known and popular in sawmills. Other parameters of wood species used in this study can be summarised in Table 2.

Table 2. *Composition of Different Wood Species*

	Beech	**Oak**	**Pine**	**Cedar**
Density (kg/m3)	730	750	510	530
Cellulose (%)	44.0	42.0	44.0	45.0
Hemicellulose (%)	24.5	29.0	28.5	13.2
Lignin (%)	22.4	25.0	28.1	29.3
Extractives (%)	2.0	4.4	3.8	10.2
Ash (%)	0.3	0.3	0.4	0.2

Wood-crete investigated through modification of sawdust by hot water boiling, alkaline treatment was treated by boiling sawdust in water for 100, 120, 140 and 160min with addition of NaOH at various percentages of 0, 1, 2, 3, 4, 5 and 6 and at boiling times of 40, 60, 100, 120 and 140 with addition of NaOH at 0, 2, 4, 6 and 8%. This group of treated materials was used for the experiments of wood-crete with the addition of waste paper (de-fibred and paper strip at 50% and 75%). The second type of waste papers (paper strip) used is measured 279.4mm in length and 10.0mm in breath. The de-fibred and paper strip waste papers were then mixed with sawdust and Tradical lime to improve the insulating properties and reduce the density of block but most importantly contributing to self-strength of wood-crete [12]. More details of experimental designs are included in Tables 5 and 6. The treated sawdust solution was washed with distilled water to remove the adsorbed alkali and soluble like sugar which tends to inhibit hydration as noticed in wood-cement composites [8]. The treated sawdust was then dried in an oven at 100±3°C for 24hours and sealed in an airtight container before use.

Wood-crete blocks were made by mixing waste paper in water before the required amount of sawdust and lime were added in the mixer. This method is advised so that the waste paper can be thoroughly wetted. The mixtures were placed in a forming mould for 24 hours before de-moulding while maintaining a relative humidity between 46% - 49% for all samples.

Testing

Actual volume of the blocks was taken from the measurement of samples after drying. Samples were sandpapered for evenness and flatness in all sides while sample mass was determined using a weighing scale. The density of the blocks was calculated from mass and volume. Three replicates were taken for each type of the wood-crete blocks and the mean value taken.

The de-moulded wood-crete blocks were further cured for 32 days and tested for compressive strength at 20°C/65% relative humidity by applying a gradually increasing load under an universal Instron. The test pieces were placed between a supporting base and a flat steel plate. The machine applied a uniform load at a rate of 6mm/min until the maximum failure load was reached. The maximum load (in Newton) was automatically recorded and the compressive strength was calculated as maximum failure stress per unit area.

Density of Wood-Crete

It is observed that the density of Wood-crete blocks was closely related to the composition of sawdust, waste paper, Tradical lime and cement (Table 3). Increase in waste paper, sees a reduction in density of Wood-crete which is about 1/3 reduction in density for X-series. This trend is also observed in the Y series of Wood-crete composites made, with a reduction from 640 to 411 kg/m3 when waste paper was increased from 0 to 50% weight of sawdust. The reason for the lower density of pure sawdust and tradical lime composites compared with those of composites with 10 and 15% waste paper in the X-series experiment is still unknown. The only suspicion is the experimental deviation for some of the specimen made in this group as the cov is also abnormally high (Table 3).

Table 3. *Mean Density and Compressive Strength of Wood-Crete*

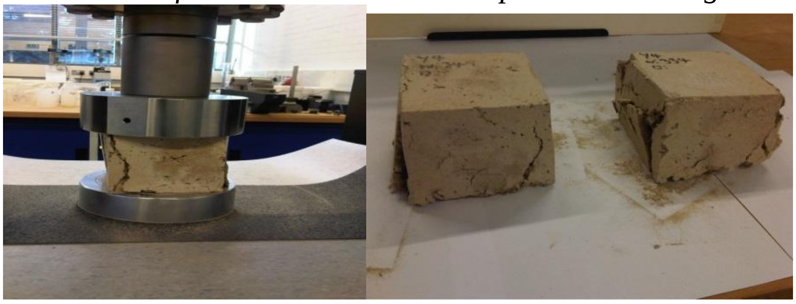
Samples	Waste paper (%)	Density (kg/m^3)	Compressive strength (N/mm^2)*	Overall Mean
S:TL=1:2				9.02
X1	75	473	0.80 (2.0)	
X2	50	526	0.61 (15.1)	
X3	30	604	0.48 (6.4)	
X4	15	702	0.41 (5.5)	
X5	10	713	0.35 (5.7)	
X	0	616	0.26 (19.4)	
S:TL=1:1				5.88
Y1	50	411	0.49 (2.9)	
Y2	25	485	0.41 (10.3)	
Y3	10	530	0.31 (11.6)	
Y4	5	549	0.22 (4.6)	
Y5	0	640	0.21 (0.0)	
S:C=1:1				37.33
Z	0	424	0.06 (37.3)	
S:C=1:2				10.00
Z1	0	543	0.10 (10.0)	
S:TL:C=2:1:1				18.33
W1	20	397	0.27 (15.7)	
W2	15	404	0.22 (19.3)	
W3	10	416	0.18 (20.0)	
S:TL=1:1 (2mmSieve size)				18.45
XX1	25	409	0.29 (14.6)	
XX2	10	376	0.19 (22.3)	
S:TL=1:1 (3mm Sieve size)				13.15
XXX1	25	364	0.20 (18.0)	
XXX2	10	356	0.12 (8.3)	
Hempcrete		445	0.4	
Concrete		20000	12 - 18	

Compression Strength of Wood-Crete

Compressive strength of Wood-Crete blocks are summarised in Table 3. It is very interesting that there was an increase in compression strength of blocks with the decrease of the density of the Wood-crete. This may be due to the presence of waste paper in mix which acts as fibrous substance to network the materials and improve the bonding between sawdust and Tradical lime and among them whilst reducing density of blocks.

Another important property of Wood-crete noticed during testing was the large deformation that can undergo after reaching the ultimate load. An example of the failure is given in Figure 1. Main failure mode of sawdust-Crete blocks was ductile followed by shear cracks in the core of blocks. This reveals that Sawdust-Crete has a quasi-ductile behaviour unlike the sudden brittle failure associated with concrete.

Figure 1. *Behaviour of Wood-Crete under Compressive Loading*

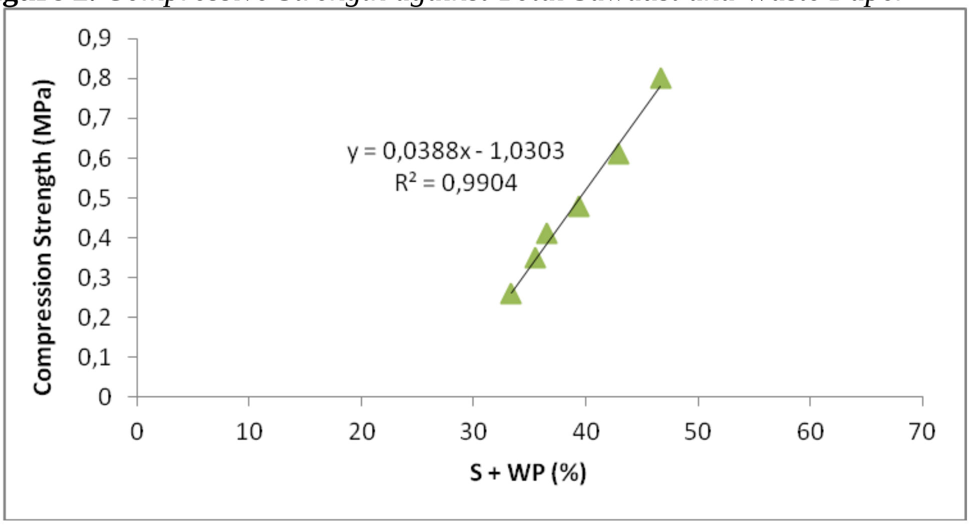


Considering that these developed lightweight materials, as other existing hempcretes, are intended to be used in combination with structural elements, such observed ductile behaviour may be attractive as it enhances the accommodation and adjustment between structural and non-structural elements which helps improve the absorption of small displacements and dumping, which always occur in houses and buildings [13].

Combined Effect of Sawdust and Waste Paper on Compressive Strength

It is evident that the combined effect of sawdust and waste paper had a significant effect on the compressive strength of Wood-Crete. With the total sawdust and waste paper increased from 33.3% to 46.7%, the compressive strength increased about 3.5 times, see Figure 2 (X-series) as an example. The combined effect reflects the compaction of sawdust and waste paper: relatively small particles and paper fibres at this point may have filled many gaps between and within them each other, thus enhancing stress transfer between both materials.

Figure 2. *Compressive Strength against Total Sawdust and Waste Paper*



Correlation of Density and Wood Species (sawdust)

An important factor for the difference in densities of wood-crete composites is due to individual wood densities of hardwood and softwood and their composition (Table 4). The effect of wood density on the density of wood-crete may result from two different aspects: one is the density of wood itself as a higher density means that more amount of wood and cell materials per unit volume to the wood sawdust within the wood-crete made; the other is the structure of wood. The density of wood is in general related to wood anatomy and hence the relative proportions of cell types or tissues most especially in hardwood species (vessel, fibre, axial and radial parenchyma), along with also their dimensions and distribution, which have indications of the penetration and setting of the lime matrix.

Table 4. *Mean Density and Compressive Strength of Wood-crete with Experimental Mixture Design*

Samples		Particle size (mm)	Compressive strength (MPa)	Density (Kg/m3)
Hardwood				
HW_B	Beech	1	3.93 (8.4)	934
		2	3.90 (7.0)	926
		3	3.44 (6.9)	929
HW_O	Oak	1	2.19 (3.7)	859
		2	2.07 (10.1)	821
		3	1.95 (9.2)	816
Softwood				
SW_P	Pine	1	1.37 (6.8)	696
		2	1.30 (4.5)	672
		3	1.23 (9.2)	655
SW_C	Cedar	1	0.07 (2.3)	543
		2	0.20 (8.6)	561
		3	0.18 (3.3)	539
Mixed				
MW		1	0.26 (19.4)	616
		2	0.18 (12.1)	610
		3	0.15 (8.1)	603

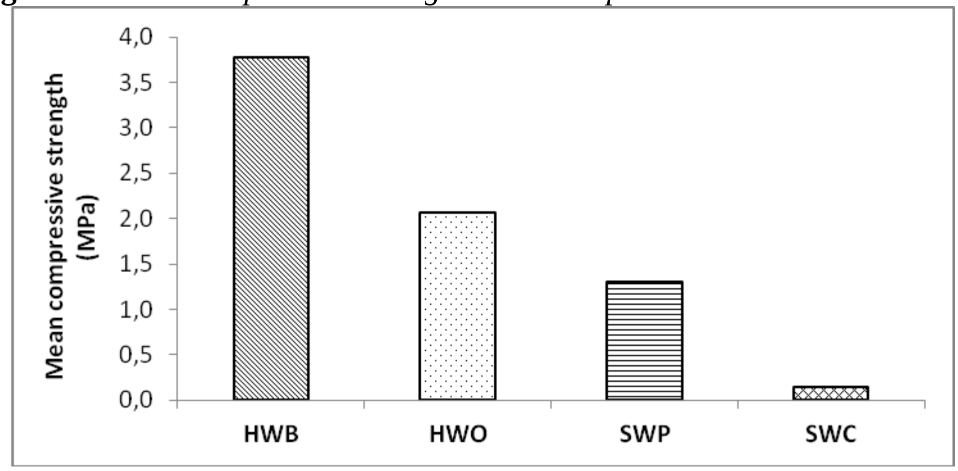
* Values in ( ) are cov in %. ***S = Sawdust, TL = Tradical Lime, HW_B = hardwood beech, HW_O = hardwood oak, SW_C = softwood cedar, SW_P = softwood pine, MW = mixed wood***

Furthermore, it was also noticed during wood-crete manufacturing that the blocks made out of sawdust from softwood was fluffier, which made compaction in the mould more difficult than when using sawdust from hardwood which was more finer and made compaction more compact. Wood-crete made from the mixed wood sawdust showed 18% reduction in density compared to wood-crete made from hardwood and 0.08% increase in density compared to wood-crete made from softwood (Table 4).

Correlation of Compressive Strength and Wood Species

Fig 3 shows the correlation of compressive strength and wood species. It can be seen that the compressive strength of wood-crete beech is 29.1% higher than the compressive strength of oak and compressive strength of wood-crete pine is 79.3% higher than the compressive strength of wood-crete cedar. Overall, wood-crete made from hardwood had a much higher compressive strength than wood-crete made from softwood, on average 60.2% higher for the former compared to the latter. This may be due partly to the difference in the density (17.5%) between hardwood and softwood. A higher density of wood generally gives rise to a higher compressive strength and such the wood-crete would have a higher compressive strength due to the contribution of wood itself. It has also been reported that hardwoods are usually strong in compression, tension and shear while softwoods are strong in tension but weak in shear [13]. This difference may also contribute to the higher compressive strength of hardwood wood-crete made.

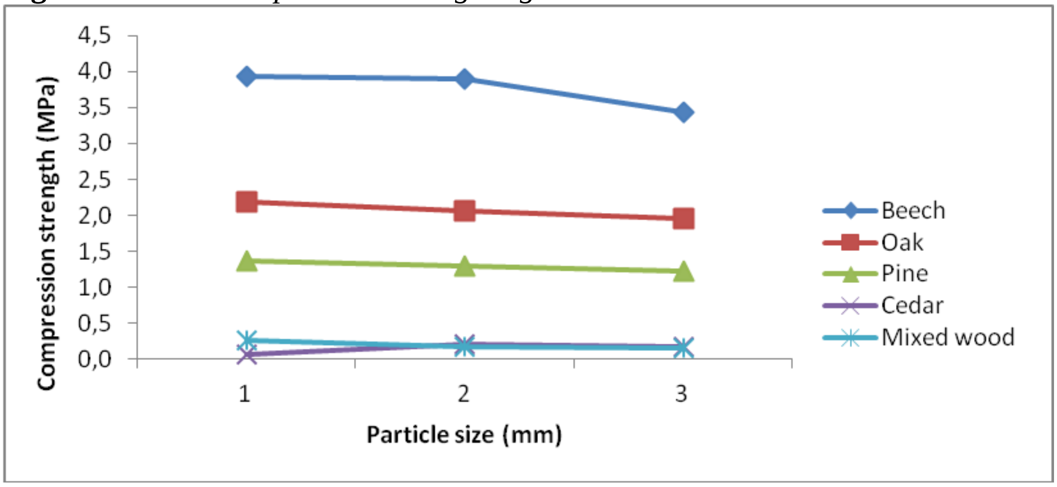
Figure 3. *Mean Compressive Strength vs Wood Species*



Correlation of Particle Size and Compressive Strength

The mean compressive strength of different particle size of hardwood, softwood and mixed wood are compared in Fig 4. It is evident that the compressive strength of wood-crete made with 1mm particle size hardwood had about 56% increase in strength properties when compared to same particle size of softwood. A 54% increase and 47% increase was also noticed in 2mm and 3mm particle sizes respectively. The effect of particle size on compression strength has been reported [14] where composite strength increased with decreasing particle size. Smaller particles have a higher total surface area for a given particle loading which indicates that strength increased with increasing surface area through a more efficient stress transfer mechanism [14].

Figure 4. *Mean Compressive Strength against Particle Size*



Effect of Sawdust Treatment on Wood-Crete

Results and Discussion

Effect of Water Boiling Treatment on the Compressive Strength of Wood -Crete

Table 5 shows that the compressive strength of wood-crete increased gradually as the water-boiling time increased from 100mins to 140mins and then decreased at 160mins. The average compressive strength of wood-crete without an addition of NaOH increased from 0.25 to 0.33 MPa and then decreased to 0.28MPa. It is apparent that the boiling time less than 120mins has little effect on the compressive strength but rather tends to weaken the bonding between sawdust and binder.

Table 5. *Experimental Design and Mean Value of Wood-crete Property (without waste paper)*

NaOH (%)	Boiling time (min)							
	100		120		140		160	
	CS (MPa)	Den (kg/m3	CS (MPa)	Den (kg/m3	CS (MPa)	Den (kg/m3	CS (MPa)	Den (kg/m3
0	0.25 (8.0)	640	0.27 (1.9)	627	0.33 (18.6)	610	0.28 (5.3)	629
1	0.15 (12.3)	617	0.39 (16.7)	641	0.41 (2.2)	640	0.29 (9.9)	628
2	0.15 (8.9)	639	0.16 (10.9)	632	0.63 (3.7)	640	0.59 (2.1)	635
3	0.73 (2.4)	622	0.78 (6.6)	622	0.79 (12.0)	603	0.57 (15.8)	614
4	0.67 (5.3)	609	0.75 (8.3)	615	0.87 (5.1)	619	0.39 (10.4)	611
5	0.65 (5.7)	602	0.68 (7.2)	611	0.26 (17.0)	623	0.24 (16.9)	631

6	0.30 (9.1)	610	0.58 (11.6)	605	0.24 (4.5)	610	0.24 (5.0)	614
MEAN	**0.41 (7.4)**	**620**	**0.52 (9.0)**	**622**	**0.50 (9.0)**	**621**	**0.37 (9.3)**	**623**

CS = Compressive Strength, Den = Density, NaOH = Sodium Hydroxide, Values in ( ) are cov. in %

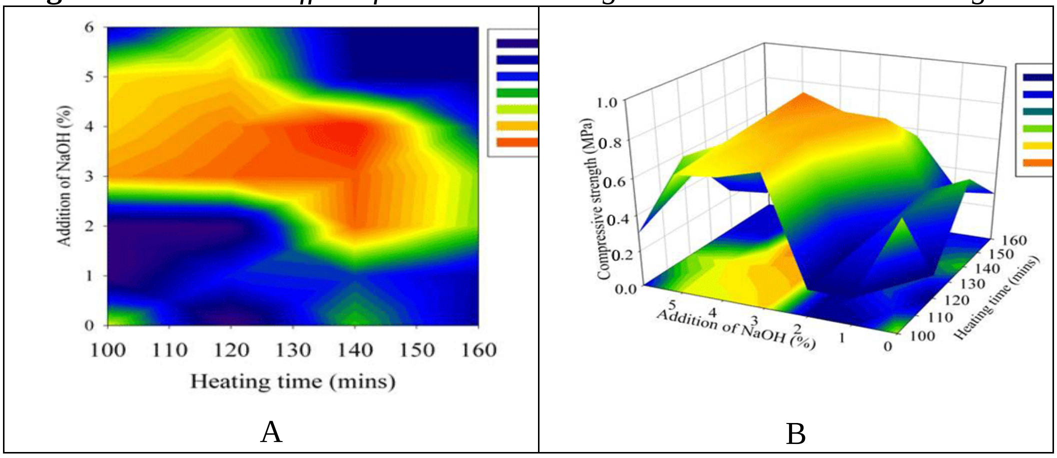
Effect of Naoh Treatment on Compressive Strength of Wood-Crete

Table 4 shows that overall mean compressive strength of various treating durations of wood-crete gradually increased as the percentage of NaOH increased from 0 to 3% and then decreased as the percentage of NaOH continued to increase from 4 to 6%. Whilst the treatment of sawdust with NaOH helps form a good bond and promote the ionization of hydroxyl group, treating sawdust with more than 4% of NaOH tends to create a weaker bond and weakens individual wood particle fibres, hence results in low compressive strength of the wood-crete made from the treated sawdust.

Combined Effect of Naoh and Boiling Time

Observed is that there was an increase in the compressive strength of blocks as the percentage of NaOH increased as well as boiling time (Table 5 and Fig 5). High compressive strength areas on Figure 8 are indicated with red zone and as strength decreases, colour changes from yellow, to green and blue. As reported by Vaickelionis and Vaickelioniene 2006, a longer extraction time and a higher temperature (up to 100°C) afford a higher concentration of soluble materials [15]. The treatment of wood fibre prevents sugar and tannins in the wood from reacting with the matrix which interferes with proper curing [15]. It can thus be inferred that the reason for the significant increase in strength of composite after treatment of sawdust is that there has been a change in the interface quality of sawdust which has consequently improved the bonding of sawdust and matrix resulting to better compressive strength. Figure 5 indicates that to achieve good compressive strength, the treating regimes for sawdust should be within the range of 3 to 4% with boiling duration between 135 and 140 minutes (red zone on Figure 5).

Figure 5. *Combined Effect of NaOH and Boiling Time: A=2D and B=3D Images*



Combined Effect of Boiling Time and Waste Paper on Compressive Strength of Wood-Crete

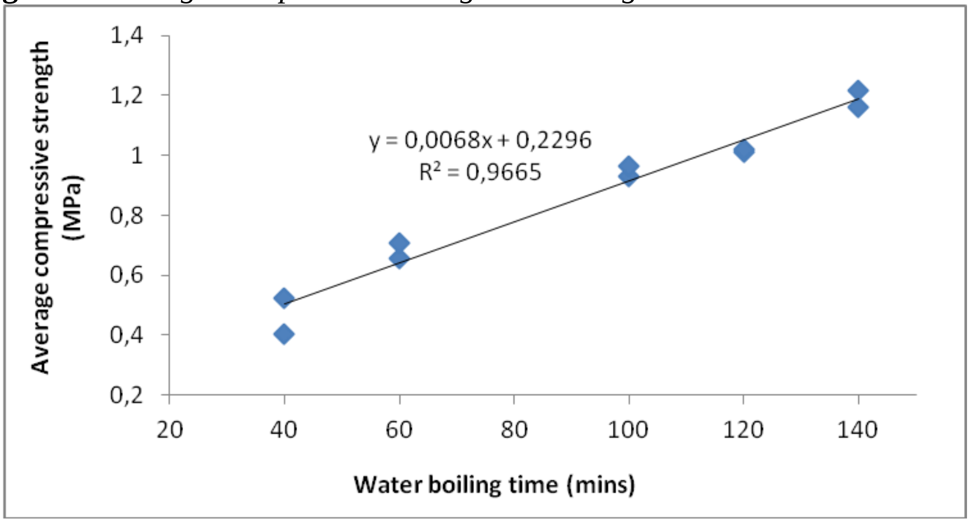
Figure 3 shows overall mean compressive strength across different water boiling times of both de-fibered and paper strip. The results for each individual regime of treatment are given in Table 6. It can be seen that the strength consistently increases with the boiling time increase, from 0.40 to 1.22MPa when the boiling time from 40 to 140 minutes. The correlation can be established with a good fit of linear regression (Figure 6).

Table 6. *Experimental Design and Mean Value of Wood-crete Property at Different Heating Times and NaOH*

Boiling time (min)	NaOH (%)	50%DF		75%DF		50%PS		75%PS	
		CS (MPa)	Den (kg/m3)	CS (MPa)	Den (kg/m3)	CS (MPa)	Den (kg/m3)	CS (MPa)	Den (kg/m3)
40	2	0.26 (3.0)	547	0.32 (6.8)	522	0.45 (4.1)	652	0.58 (6.6)	594
40	4	0.35 (4.9)	549	0.47 (4.0)	529	0.59 (6.4)	658	0.69 (3.0)	591
60	2	0.62 (2.5)	554	0.63 (14.4)	521	0.64 (18.0)	656	0.74 (16.0)	593
60	4	0.63 (1.5)	545	0.69 (8.7)	516	0.74 (10.8)	648	0.77 (6.5)	588
100	2	0.63 (3.2)	550	0.80 (9.2)	511	0.97 (6.3)	649	1.32 (10.3)	580
100	4	0.70 (4.5)	546	0.83 (8.6)	509	0.10 (2.7)	645	1.33 (15.2)	582
120	2	0.87 (9.1)	540	0.91 (11.4)	502	0.99 (2.2)	648	1.27 (4.3)	590
120	4	0.90 (10.2)	539	0.98 (3.6)	498	1.04 (6.5)	642	1.16 (5.7)	584
140	2	0.94 (1.8)	536	1.04 (5.5)	503	1.11 (9.7)	644	1.56 (2.4)	576
140	4	1.01 (9.0)	535	1.06 (7.8)	508	1.17 (12.3)	630	1.62 (10.6)	562

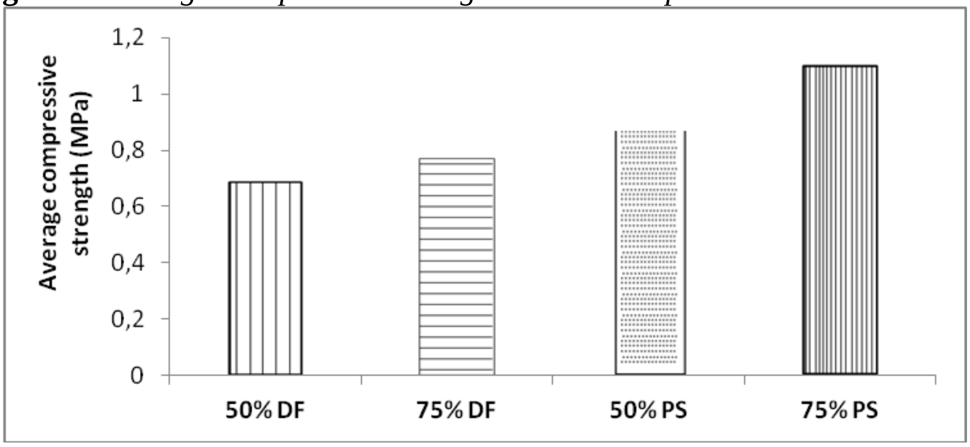
CS = Compressive Strength, Den = Density, NaOH = Sodium Hydroxide, DF = de-fibred, PS = Paper Strip, Values in ( ) are cov. in %

Figure 6. *Average Compressive Strength vs Boiling Time*



Waste paper has also had an effect on the property of wood-crete (Figure 7). Overall the wood-crete with paper strips had a better compressive strength than those with de-fibred waste paper (Table 6).

Figure 7. *Average Compressive Strength vs Waste Paper*



Conclusion

A new building material has been developed by using waste wood, waste paper and tradical lime. Overall performance of wood-crete was very similar to that of hempcrete. It is seen that wood-crete made from specific types of wood can as well be used as in-fills in construction just like hempcrete. However, in reality, it is not practicable to have sawdust from specific kinds of wood as most sawmills do not separate their sawdust during milling process.

The properties of wood-crete were related to its composition and type of sawdust from different kinds of wood species. Conclusively,

I. Wood-crete made from hardwood resulted in higher strength compared to those made from softwood having a 53% difference in the compressive strength on average. Hardwood beech wood-crete recorded a 61% increase in compressive strength when compared to hardwood oak wood-crete; likewise softwood pine recorded a 79% increase in compressive strength when compared to softwood cedar wood-crete.

II. The constituents of wood (lignin, cellulose, hemicelluloses and extractives) all contributed to the strength properties of wood-crete composites.

III. Wood-crete made from softwood has a lower thermal conductivity compared to wood-crete made from hardwood with a 19.4% reduction in thermal conductivity value.

Wood-crete made from treated sawdust conclusively shows that;

I. Hot water treatment resulted in a significant improvement of wood-crete, with the compressive strength being increased by about 30% and 260% for hot water boiling treatment and hot water with 4% NaOH treatment respectively. The magnitude of increase was related to the treatment time;

II. An addition of NaOH was able to extract the soluble content of sawdust effectively, resulting in a gradual increase of compressive strength of wood-crete, but excess NaOH tended to weaken individual wood particle fibres for an adverse effect on the strength of wood-crete;

III. The combined effect of boiling time of sawdust and addition of waste paper on compressive strength of wood-crete was significant. The correlation of the waste paper reinforced wood-crete with boiling time of saw dust was linear from 0.40 to 1.23MPa for the blocks developed; a higher percentage of waste paper also gave rise to a higher compressive strength;

Bibliography

Y. M. Wei, Y. G. Zhou and B. Tomita, "Hydration Behavior of Wood Cement-Based Composites I: Evaluation of Wood Species Effects on Compatibility and Strength with Ordinary Portland Cement," *Wood Science,* vol. 46, pp. 296 - 302, 2000.

F. C. Jorge, C. Pereira and J. M. F. Ferreira, "Wood-Cement Composites: A Review," *Published Online,* vol. 62, no. 5, pp. 370 - 377 , 2004.

J. H. Grabber, "How do Lignin Composition, Structure and Cross-linking affect Degradability? A review of Cell Wall Model Studies," *Crop Science,* vol. 45, no. 3, pp. 820 - 831, 2005.

J. Pourchez, P. Grosseau, R. Guyonnet and B. Ruot, "HEC Indluence on Cement Hydration measured by Conductometry," *Cement and Concrete Research,* vol. 36, no. 9, pp. 1777 - 1780, 2006.

G. A. Zaikov and A. Jimenez, Polymer Analysis, Degradation and Stabilization, New York: Nova Science Publishers, Inc, 2004.

X. Li, L. G. Tabil and S. Panigrahi, “Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites,” *Journal of Polymers and the Environment,* vol. 15, pp. 25 - 33, 2007.

N. Lopattananon, K. Panawarangkul, K. Sahakaro and B. Ellis, “Performance of Pineapple Leaf Fiber–Natural Rubber Composites: The Effect of Fiber Surface Treatments,” *Journal of Applied Polymer Science,* vol. 102, pp. 1974 - 1984, 2006.

A. Prompunjai and W. Sridach, “Preparation and Some Mechanical Properties of Composite Materials Made from Sawdust, Cassava Starch and Natural Rubber Latex,” *World Academiy of Science, Engineering and Technology,* pp. 930 - 934, 2010.

P. D. Bruijn, *Hemp Concretes Mechanical Properties Using Both Shives And Fibres,* Sweden, 2008.

Forest Products Laboratory USDA Forest Service, “Wood Handbook - Wood as an Engineering Material,” Madison, Wisconsin, 1999.

A. Mitani and I. Barboutis, *Tensile Strength by Compression Loading of some Hardwoods Bonded with PVAc and Casein Adhesives,* Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment,Department of Harvesting and Forest Products Technology, pp. 1352 - 1360.

E. P. Aigbomian and M. Fan, “Development of Wood-Crete Building Materials from Sawdust and Waste Paper,” *Construction and Building Materials,* vol. 40, pp. 361 - 366, 2013.

K. Wilson and D. J. B. White, The Anatomy of Wood: Its Diversity and Variability, London: Stobart & Son Ltd, 1986.

S.-Y. Fu, X.-Q. Feng, B. Lauke and Y.-W. D. Mai, “Effects of Particle Size, Particle/Matrix interface adhesion and Particle Loading on Mechanical Properties of Particulate–Polymer Composites,” *Composite B - Engineering,* 2008.

G. Vaickelionis and R. Vaickelioniene, “Cement Hydration in the Presence of Wood Extractives and Pozzolan Mineral Additives,” *Ceramics − Silikáty,* vol. 50, no. 2, pp. 115 - 122, 2006.

D. J. Cown and M. L. Parker, “ Comparison of Annual Ring Density Profiles in Hardwoods and Softwoods by X-ray Densitometry,” *Canadian Journal of Forestry Research,* vol. 8, pp. 442 - 449, 1978.

H. Kinoshita, K. Kaizu, M. Fukuda, H. Tokunaga, K. Keisuke and K. Ikeda, “Development of Green Composite consists of Woodchips, Bamboo Fibers and Biodegradable Adhesive,” *Composites,* pp. 607 - 612, 2009.

S. Migneault, A. Koubaa, F. Erchiqui, A. Chaala, K. Englund, C. Krause and M. Wolcott, “Effect of Fiber Length on Processing and Properties of Extruded Wood-Fiber/HDPE Composites,” *Journal of Applied Polymer Science,* pp. 1086 - 1092, 2008.

P. R. Blankenhorn, P. J. Labosky, M. Dicola and L. R. Stover, “Compressive Strength of Hardwood-Cement Composites,” *Forest Products*, vol. 44, no. 4, pp. 59 - 62 , 1994.

L. K. Aggarwa and J. Singh, “Effect of Plant Fibre Extractives on Properties of Cement,” *Cement and Concrete Composites,* vol. 12, pp. 103 - 108, 1990.

A. K. Bledzki and J. Gassan, “Composites reinforced with cellulose based fibres,” *Progress in Polymer Science,* vol. 24, p. 221, 1999.

R. W. Wolfe and A. Gjinolli, “Cement-Bonded Wood Composites as an Engineering Material,” in *USDA Forest Service and the Forest Products Society,* Madison, Wisconsin, 1996.

A. K. Afuwape, “Design and Testing of Sawdust Compactors,” Ile-Ife, Nigeria, 1983.

L. Arnaud, V. Cerezo and C. Boutin, “Physical Properties of Concrete and Vegetable Particles. In Boutin C, Lefik M, editors. Experimental Knowledge versus Theoretical Models, Soils and Composites Materials.,” 2004.

L. O'Dowd and D. Quinn, “Investigating Properties of Concrete of Hemp and Lime Construction,” Dublin, 2005.

A. K. Afuwape, *Design and Testing of Sawdust Compactors,* BSc Thesis, Department of Agriculture and Engineering Obafemi Awolowo University, Ile Ife, Nigeria., 1983.

L. Arnaud and V. Cerezo, *Physical evaluation of construction materials based on hemp,* 2001.

A. Zziwa, S. Kizito, A. Y. Banana, J. R. S. Kaboggoza, R. K. Kambugu and O. E. Sseremba, “Production of Composite Bricks from Sawdust using Portland Cement as a Binder,” 2006.

British Standard BS EN 12087:1997, “Thermal Insulating Products for Building Applications. Determination of Long Term Water Absorption by Immersion,” BSI, United Kingdom, 1997.

T. A. Plekhanoca, J. Keriene, A. Gailius and G. I. Yakovlev, “Structural, Physical and Mechanical properties of Modified Wood-Magnesia Composite.,” *Building Construction and Materials,* vol. 21, pp. 1833 - 8, 2007.

E. P. Aigbomian and M. Fan, “Development of Wood-Crete Building Materials from Sawdust and Waste Paper,” *Construction and Building Materials,* vol. 40, pp. 361 - 366, 2013.

A. K. Bledzki, M. Letman, A. Viksne and L. A. Rence, “Comparison of Compounding Processes and Wood type for Wood Fibre-PP Composites,” *Composites Part A: Applied Science and Manufacturing,* vol. 36, no. 6, pp. 789 - 797, 2005.

G. Lulianelli, M. B. Tavares and L. Luetkmeyer, “Water Absorption Behabior and Impact Strength of PVC/Wood Flour Composites,” *Chemistry and Chemical Technology,* vol. 4, no. 3, pp. 226 - 299, 2010.