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CHARACTERISTICS OF FRESH MIXTURE OF A NOVEL CEMENT-LESS WASTEPAPER-BASED LIGHTWEIGHT BLOCK AND ITS MOLDING PROCESSES

ORIYOMI M. OKEYINKA, DAVID A. OLOKE, and JAMAL M. KHATIB

School of Architecture and the Built Environment, University of Wolverhampton, West Midlands, United Kingdom

Cement-less wastepaper-based lightweight block (CWLB) is an eco-friendly lightweight non-loadbearing block newly developed from majorly waste materials. As part of efforts to enable the understanding of its mixture proportioning and production processes, this study presents the characteristics of its fresh mixture and its peculiar molding process. The fresh mix characteristics studied include; the texture, density, elastic modulus, percentage void/porosity and the peculiar molding process. The laboratory experimentation conducted covers; the preparation of the CWLB mix (from mixture of wastepaper aggregate (WPA), sand, waste additive, natural admixture and water), determination of physical and deformation properties of the mix and the molding of CWLB specimen. It was found that, for the mixes tested, the fresh mixture of CWLB is fibrous in texture, voluminous in nature and exhibits an average loose bulk density of 305.3 kg/m^3. Also, average compacted bulk density of 857.6 kg/m^3 and 792.38 kg/m^3, elastic modulus of 30.28 MPa and 28.38 MPa and percentage void of 77% and 76% (i.e., porosity of 0.77 and 0.76) were recorded for mixes containing 52% and 36% sand content (measured by weight of WPA) respectively. The molding procedure for CWLB was thus found to be slightly different from those available for conventional masonry blocks in terms of relationship between the mold size, mixture quantity and resulting specimen size. These findings therefore indicate the peculiarity of the physical and deformation properties of the fresh mixture of CWLB and the importance of awareness and understanding of same for efficient production of CWLB. Future work will involve the development of suitable numerical expression for determining the in-mold mass requirement for molding a typical CWLB sample and the design of an innovative, undemanding, cost and energy efficient manufacturing kit for CWLB.

Keywords: Mix, Proportioning, Loose bulk density, Compacted bulk density, Elastic modulus, Porosity, Texture, Waste additive, Sand, Wastepaper aggregate.

1 INTRODUCTION

CWLB is an eco-friendly lightweight non-loadbearing block newly developed from majorly waste materials. It is made from a combination of wastepaper, sand, waste additive, natural admixture and water. The motivation for its development was borne out of the need to address the various environmental impacts associated with the activities of the construction industry through the recycled use of waste in construction. As reported in the previously concluded experimental studies (Okeyinka 2017), the optimized weaker mix compositions of CWLB develops average compressive strength in the range of 2.59 MPa to 2.39 MPa and corresponding average densities in the range of 881.7 kg/m^3 to 914.5 kg/m^3. With regards to the compressive strength requirements (e.g., 1.5Mpa (BSI (British standards Institute) 2011)) and the density requirements (*viz*., 300 kg/m^3-1000 kg/m^3 (BSI (British standards Institute) 2011)) recommended by a number of international and national building codes for non-loadbearing lightweight blocks, the aforementioned properties recorded for CWLB indicates its suitability for use as non-loadbearing lightweight block in building construction. Other findings from its; mix proportioning/manufacturing process, factors influencing its properties, and optimum mix composition have been reported and published in the literatures (*viz*., Okeyinka *et al.* 2015, Okeyinka *et al.* 2016, Okeyinka *et al.* 2017).

Being a novel building material produced from peculiar constituents (majorly cellulosic waste), the production/molding processes of CWLB is slightly different compared to; that of the existing cement-based wastepaper blocks (e.g., papercrete) and that of conventional masonry blocks, thus, this paper presents the characteristics of CWLB's fresh mixture for the purpose of enabling an understanding of the implication of same for its manufacturing processes. The characteristics studied includes, porosity, bulk densities (in the loose and compacted states) elastic bulk modulus texture and color.

2 EXPERIMENTAL PROCEDURE

In this study, CWLB was produced from constituent materials which includes; wastepaper aggregate (WPA) (utilized as major aggregate filler), sand, waste additive (utilized as binder), natural admixture (stoneware clay) and water. The WPA was systematically produced from wastepaper (Okeyinka *et al.* 2016). The waste additive used as binder was obtained as a by-product of food processing industry; its chemical properties are presented in Table 1. Given the variation in the physical properties of the constituent materials (see Table 2), batching was carried out by weight in order to achieve accurate proportioning of materials for the CWLB mixes.

2.1 Mixture Proportioning

Based on previously concluded experimental studies (Okeyinka *et al.* 2015, Okeyinka *et al.* 2016, Okeyinka 2017, Okeyinka *et al*. 2017), two mix compositions of CWLB which contains 36% and 52% sand contents (measured by weight of WPA) were adopted to study the characteristics of its fresh mixture. The details of the adopted mixes are presented in Table 3.

2.1.1 *Test conducted on fresh mixture of CWLB*

The tests conducted on CWLB's fresh mix to determine its physical and deformation characteristics includes; loose and compacted bulk density (in accordance with BSI (British Standard Institute) 1998), porosity/ percentage void (estimated in accordance with the standard tests for mechanical and physical properties of aggregates) (BSI (British Standard Institute) 1998), texture and color (through physical observation) and elastic bulk modulus through systematic observation of the applied molding pressure/stress and systematic measurement of corresponding volumetric strain in the direction of application of the molding pressure (the method is quite similar to the 1-D oedometer consolidation test (ASTM D2435).

3 RESULTS AND DISCUSSION

The physical and deformation characteristics of the fresh mixture of CWLB as determined from the tests conducted are summarized in Table 4. The detailed discussion of same and the engineering judgements (i.e., recommendations) made to that regard are presented in the sections 3.1 to 3.5 of this paper.

Table 1. Chemical characteristic of waste additive (binder).

Waste additive	Elements (ppm)						
	Al	Ca	Fe	K	Mg	S	Si
Solid part	0.03	5.42	0.08	6.60	0.40	0.78	65.71
Liquid part	0.01	6.09	0.02	28.87	3.06	2.15	27.20

Table 2. Other physical properties of constituent materials.

Properties	Material			
	WPA	Sand	Waste additive	Natural admixture
Specific gravity	0.118	2.63	1.04	0.895
Loose Bulk density (kg/l)	0.12	1.428	-	0.9112
Particle size range (mm)	(3 - 0.125)	(4 - 0.063)	-	-

Table 3. CWLB mixes adopted to study the characteristics of its fresh mixture.

Mix No.	Mix ID	Mix Proportion [WPA: Sand : Binder]	Sand content (% by wt. of WPA)	Binder content (% by wt. of WPA)	Water/Binder ratios	Natural Admixture (% by wt. of WPA)
1	M1	1:0.36:0.20	36	20	0.75	5
5	M5	1:0.52:0.20	52	20	0.75	5

Table 4. Characteristics of the fresh mixture of CWLB.

CWLB Mixes	Fresh mix characteristics					
	Loose bulk density (kg/m^3)	Compacted bulk density (kg/m^3)	Bulk Elastic modulus (MPa)	Percentage void (%)	Texture	Color
M1	305.3	792.38	28.38	78	Fibrous	Ash/greyish
M5	305.3	857.6	30.28	77	Fibrous	-

3.1 Color, Texture, and Porosity of the Fresh Mixture of CWLB

Based on physical observation, the fresh mixture of CWLB exhibits an ash/greyish color and the texture appeared fibrous cohesive (see Fig 1) and tested CWLB mixes M1 and M5 respectively displayed porosity of 0.76 and 0.77 (i.e., percentage void of 76% and 77%) (see Table 4). The fibrous texture displayed by CWLB's fresh mix may be attributed to the high percent of cellulosic material (i.e., WPA) and the absence of cement in its mix composition. The ash/greyish color may be due to the ink present in the recycled paper utilized as major aggregate filler. In contrast with conventional fresh masonry mix in which the incorporated cement and added water usually form pastes that coats the sand particles resulting in granular cohesive mix (Chindaprasirt and Cao 2015), the limited sand content in CWLB's fresh mix appeared to cling to the surfaces of the WPA particles (which apparently became fluffily upon mixing with other component for 27 minutes) resulting in a fibrous cohesive mix. The porosity displayed by CWLB fresh mixes is reckoned to be; comparable to that of fibrous peat which is said to range from 80% to 90% (Beata and Imre 2011) and maximally higher than the 20% reported by (Madara *et al*. 2016) for the fresh mixture of conventional masonry blocks.

Figure 1. Fresh CWLB mix (showing fibrous texture and ash/greyish color).

3.2 Loose Bulk Density and Compacted Bulk Density of Fresh Mixture of CWLB

As shown in Table 4, the tested CWLB mixes M1 and M5 containing respective sand content of 36% and 52% (measured by wt. of WPA) exhibits similar average bulk density of 305.3 kg/m^3 in the loosed state and respective average bulk density of 792.4 kg/m^3 and 857.6 kg/m^3 in the compacted state. Comparison of the recorded loose and compacted bulk densities implies respective volume reduction of 0.76 and 0.77 for the mixes M1 and M5 respectively after compaction. Thus, the bulk characteristics displayed by CWLB fresh mix can be regarded as an indication of its voluminous nature in the loose state and the requirement of larger mold size to accommodate same both of which in turn may be attributed to the high porosity and the lightweight of the fluffily WPA fibers.

3.3 Bulk Elastic Modulus of Fresh Mixture of CWLB

As presented in Table 4, the tested CWLB mixes M1 and M5 respectively displayed average elastic bulk modulus of 28.38 MPa and 30.28 MPa when subjected to increasing molding pressure range of 0 MPa, 3.92 MPa, 7.85 MPa and 11.77 MPa. The low elastic bulk modulus and the corresponding respective compressibility of 0.035 and 0.033 displayed by the tested M1 and M5 CWLB fresh mixes may be regarded as an indication of softness and very slight compressibility characteristic.

3.4 Implication of the Characteristics of Fresh CWLB Mix for its Molding Process and Corresponding Recommendations

The earlier discussed characteristics displayed by the fresh mixture of CWLB indicates the potential for peculiarities in its molding procedure (especially in terms of relationship between mold size, mixture quantity and resulting specimen size) compare to those available for conventional masonry blocks. For instance, the voluminous nature expressed by its loose bulk density and the high air content expressed by its porosity necessitates the need to ensure accurate measurement of in-mold mixture to achieve uniformity in molded CWLB specimen and need for larger mold size to accommodate the fresh mix in the loose state prior to application of molding pressure. Therefore, the following molding procedures for (50 mm x 50 mm x 50 mm) cubic CWLB specimen (Figure 3) (which can be simulated accordingly for any targeted CWLB block size) have been recommended to ensure efficient processing of CWLB:

- Weigh a predetermined quantity of CWLB mixture and filled into a 50 mm x 50 mm x 150 mm mold (i.e., a mold whose height is two to three times higher than its width depending on the targeted specimen size).
- Use a hydraulic press (either manual or automatic) fitted with a pressure measuring gauge and piston (see Figure 2.) to compress the mixture against the other end of the mold to form the required 50 mm x 50 mm x 50 mm cubic CWLB specimen. Note that the 50 mm x 50 mm x 150 mm mold was initially utilized to cater for the fibrous and the voluminous nature of the mixture.
- Apply appropriate amount of compacting pressure depending on requirement. (Note: 2.5 metric tons (9.8 MPa) is recommended as a starting compacting pressure)
- Demold the specimen immediately and place in the curing section, (Figure 2 presents the resulting 50 mm x 50 mm x 50 mm CWLB specimen and Table 5 shows the corresponding 28 days compressive strength and the bearing resistance for CWLB specimen produced from mixes M1 and M5 using a 13.7 MPa compacting pressure and the recommended molding procedure).

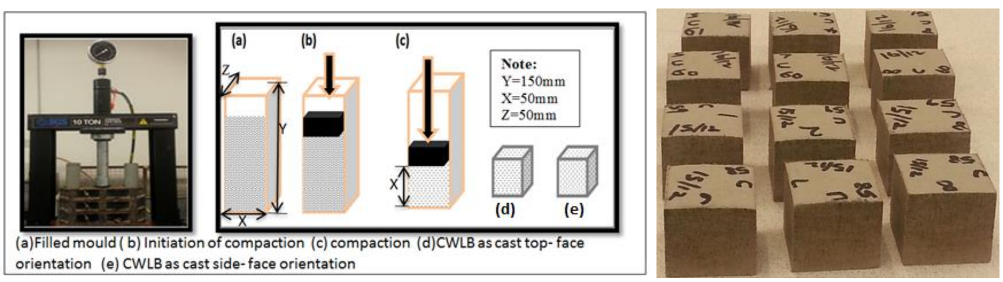

Figure 2. Schematic of molding procedure for CWLB and the resulting 50 mm x 50 mm x 50 mm cubic CWLB specimen (Okeyinka 2017, Okeyinka *et al.* 2017).

Table 5. Strength properties of CWLB adopted mixes and its eco-friendliness and cost effectiveness indicators.

Mix ID	**Compressive Strength (MPa)**	**Bearing Resistance (kg/cm^2)**	**Eco-friendliness and Cost Effectiveness Indicators**
M1	2.59	26.41	70% to 77% Waste Content,
M5	2.39	24.37	0%Cement and Lightweight

4 CONCLUSION

The following conclusions were made based on the outcome of the experimentations conducted. The fresh mix of CWLB is greyish/ash in color, fibrous in texture, highly; porous, voluminous (in the loose state) and compressible. Its porosity ranges from 76% to 77%. It exhibits an average loose bulk density of 305.3 Kg/m^3 and compacted bulk density range of 792.4 kg/m^3 and 857.6 kg/m^3. Its elastic bulk modulus range from 30.23MPa to 28.38MPa and its compressibility range from 0.033 to 0.035. Its porosity and compressibility are comparable to that of fibrous peat soil.

The molding/manufacturing procedure for CWLB is peculiar compare to those available for conventional masonry blocks in terms of relationship between mold size, mixture quantity, and resulting specimen size.

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