Properties of Lightweight Papercrete Made with Pumice

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Abstract

This study assessed the strength and other properties of *papercrete* (a paper and mortar composite) produced by using pumice as fine aggregate instead of sand. *Papercrete* samples containing ordinary Portland cement (OPC), paper sludge and pumice as fine aggregate were produced (Sample PP) and compared to control samples containing OPC, paper sludge and sand (Sample SP). The experimental results show that Sample PP (3.86N/mm^2) recorded a 55% increase in compressive strength over Sample SP (1.74N/mm^2) at 28 days. Sample PP (563Kg/m^3) also increased in density over Sample SP (555Kg/m^3) at 28 days. In other tests, Sample PP showed a similar response to water absorption and fire reaction as Sample SP. Additionally, Sample PP recorded a lower thermal conductivity (0.630W/m^{o}K) than Sample SP (0.657W/m^{o}K). It was concluded that when pumice is used as fine aggregate to produce papercrete, it substantially improves strength and lowers thermal conduction in addition to behaving in similitude to ordinary *papercrete* in other properties.

Keywords: *Pumice, Papercrete, Compressive strength, Density, Thermal conductivity.*

Introduction

Concrete is inarguably the most widely used construction material (Mehta and Monteiro, 2005). Its attractiveness is attributable to several factors. Chiefly, concrete more than any other construction material can be used for a variety of structures such as dams, bridges, buildings, pavements etc. Additionally, concrete can be cast into a variety of forms and the ingredients for concrete production are readily available all over. Also, it can harden in water and requires less maintenance than most other materials. Still.

Despite its popularity, concrete has some properties which are not optimal for some applications for which it is appropriate. Primarily, concrete is very heavy thus requiring the construction of a strong formwork from other materials when concrete is to be cast in-situ. Also, concrete is highly thermally conductive thus requiring the need for insulation when used for the outside of buildings.

There is a quest for materials with specific properties such as low density, low thermal conductivity, ductility, fire resistance, high strength, etc. Consequently, other materials are used to substitute or complement other ingredients in concrete. One such effort is the use of lightweight aggregates such as pumice to produce concrete with low density. Pumice is a term used to describe a variety of porous vesicular materials produced during volcanic eruptions. Pumice has a very low density and often floats on water (Kilic, Atis, Teymen, Karahan and Ari, 2009) and thus is used as lightweight aggregate in concrete production.

Currently, there is a renewed effort to use paper fibres in concrete. To this end, waste paper is mixed in with Portland cement and sand to produce a paper-mortar composite called *papercrete* (McElroy, Thompson & Williams, 2010). The result is a material like concrete which is lightweight. Mohammed (2009) reported a *papercrete* density of 650Kg/m^3 at 28 days.

Additionally, due to its lightweight, *papercrete* has good heat and sound insulating properties (Kokkinos, 2010; Sangrutsamee, Srichandr, and Poolthong 2012). Waste papers are usually either thrown away or go into landfills thus constituting a substantial portion of solid waste. The International Institute for Environment and Development (IIED) revealed that when paper rots or composts, it emits methane gas which is 25 times more toxic than CO_2. Therefore, papercrete provides an environmentally friendly way of disposing of the massive amount of waste papers generated.

Traditionally *papercrete* is produced by mixing waste paper, cement and sand. For this study, crushed pumice was used as a fine aggregate in place of sand. The resulting *papercrete* was then examined for density, water absorption, compressive and tensile strength, thermal conductivity and fire reaction.

Methodology

Materials

The materials used in the study include; ordinary Portland cement (OPC), river sand, crushed pumice and paper sludge. The OPC used in the study was a Dangote brand conforming to BS EN 197-1 (2000). River sand was obtained from local dealers and sieve analysis was undertaken using sieves conforming to BS 410-1 (2000). Results of the sieve analysis were then used to grade the crushed pumice.

Pumice used in the study was obtained from Jos. The pumice was crushed and sieved to particle sizes within the fine aggregate limit (4.75mm to 600µm). For the preparation of paper sludge, waste papers were soaked in water for 24 hours and ground until the desired consistency was achieved. Finally, water was drained from the ground paper to obtain paper sludge.

Plate 1: Soaked newspapers after grinding

Plate 2: Water drained from ground newspaper

Mixture Proportions, Casting and Curing of specimens

Two samples of *papercrete* mixtures were designed and labelled "Sample SP" and "Sample PP". Sample SP was the control mixture and contained Portland cement, sand and water. Sample B contained Portland cement and water while crushed pumice was used to completely replace sand. A mix proportion of 1:1:3 was employed for the study. Specimens cast for each sample comprise thirteen 72mm x 72mm x 72mm cubes for the compressive strength, water absorption and thermal conductivity tests, six 100mm x 200mm cylinders for splitting tensile strength test and six 250mm x 75mm x 25mm rectangular prisms for fire reaction test.

Sample specimens for compression test were assessed for density before crushing. In all, fifty specimens were cast for testing. Sample specimens were cured by covering with polythene sheets for seven days and the samples were allowed to air-dry.

Plate 3: Pumice papercrete specimens

Test Methods

The density of the *papercrete* cube samples was assessed using *papercrete* cubes in accordance with BS EN 12390-3: 2009. The density was assessed at 14 and 28 days. The water absorption test was conducted on cube specimens according to ASTM C642. The specimens were tested at 14 and 28 days. For the absorption test, the oven-dry mass (A) and saturated mass (B) were determined. The absorption percentage was then calculated thus:

$$\text{Absorption after immersion (\%)} = \frac{B-A}{A} \times 100$$

The compression and splitting tensile test was carried out on cube and cylinder specimens respectively using a compression machine. Test specimen were placed centrally in the compression machine and loaded until fracture. The strength tests were conducted at 14 and 28 days. The compressive strength test was carried out in accordance with BS EN 12390-7: 2009. The tensile test was assessed using an indirect tension test called the splitting test or Brazilian test. In this method, compressive loads are applied along two axial lines that are diametrically opposite (Plate 4) and the tensile strength calculated using the expression;

$$\text{tensile strength} = \frac{2P}{\pi LD}$$

Plate 4: Strength test on papercrete specimen

The thermal conductivity of the samples was determined using a free and forced heat transfer apparatus comprising a hot plate and a controller. *Papercrete* samples were fixed to the hot plate which is powered by the controller. Temperatures at two points of the samples were recorded and thermal conductivity computed using an equation based on Fourier's law:

$$K = \frac{Q \times L}{A \times (\Delta_1 - \Delta_2)}$$

Where: K = thermal conductivity; Q = heat transfer; L = distance between two sections of specimen at which temperature is taken. A = area of specimen; Δ_1 = temperature at first point of specimen; Δ_2 = temperature at second point of specimen. Single Flame Ignitability test (SFI) was used to assess the reaction of *papercrete* samples to fire in accordance with BS EN 11925-2 (2010). The flame was applied for 30 seconds to the surface and edges of papercrete samples fixed in an upright position with filter paper underneath.

Plate 5: Fire reaction test

Results and Discussions

Density

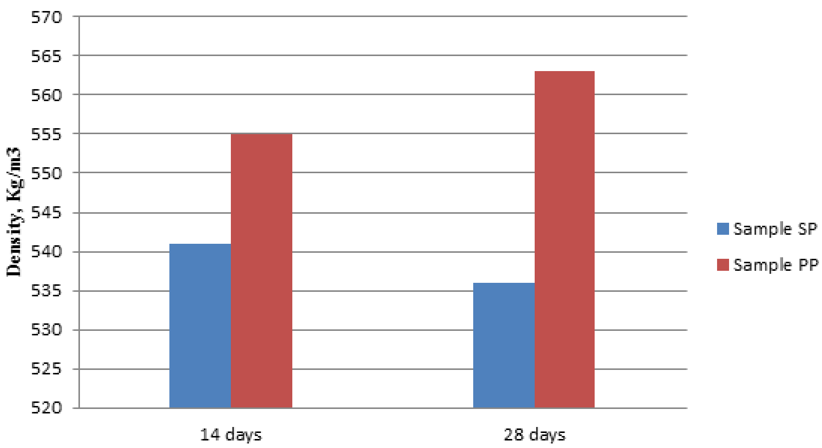

Figure 1: Density of Papercrete Samples

Figure 1 presents the density of the *papercrete* samples at 14 and 28 days. Samples containing pumice had higher densities than the control at both ages. The density of samples PP at 14 and 28 days was 555 Kg/m^3 and 563 Kg/m^3 at 14 and 28 days respectively. While those of Samples SP was 541 Kg/m^3 and 536 Kg/m^3 at 14 and 28 days. This signifies 3% and 5% increases in the density of Samples PP over Sample SP at 14 and 28 days. The increase in density could be due to the phenomenon known as a ball-bearing effect. According to Joy (2005) and Mindess, Darwin, and Young (2003), when aggregate with very fine particles are used, they will be able to fit into cement grains thus resulting in more efficient paste packing and more rounded particles hence the terminology ball-bearing effect. This ball bearing effect lowers the mean capillary size of pores thereby reducing bleeding and producing a material with a denser microstructure (Joy, 2005).

Water Absorption

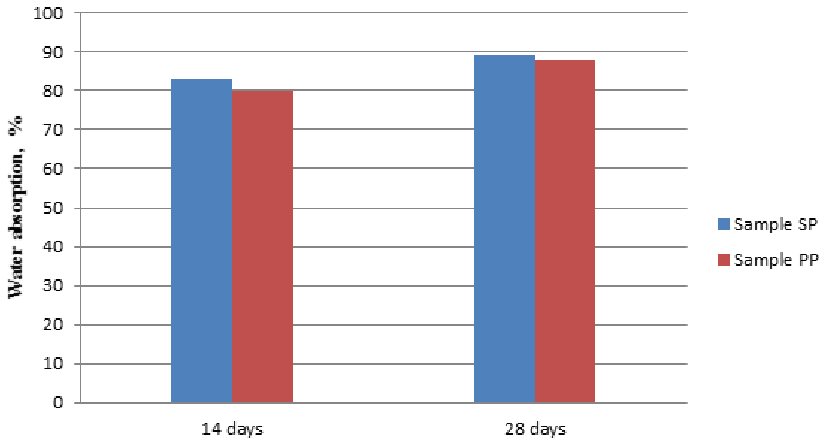

Figure 2: Water Absorption of Papercrete Samples

The result of the water absorption test in figure 2 indicates that all samples are highly water absorbent. The water absorption capacity of samples SP is 83% and 89% at 14 and 28 days while those of samples PP are 80% and 88% at 14 and 28 days. The results tend to suggest that water absorption of *papercrete* increases with age. Similarly, in an earlier study by Suganya (2012), water absorption values as high as 74.78% was recorded for papercrete bricks containing rice husk ash. The high water absorption recorded in this study could be attributed to the high content of paper used in the mix. Titzman (2006) noted that dried papercrete behaves like a sponge when exposed to water unless some kind of water-resistant treatment is applied. Still, control samples

SP absorbed more water than Samples PP. This could be a result of the improved microstructure of the samples containing fine pumice particles.

Compressive strength

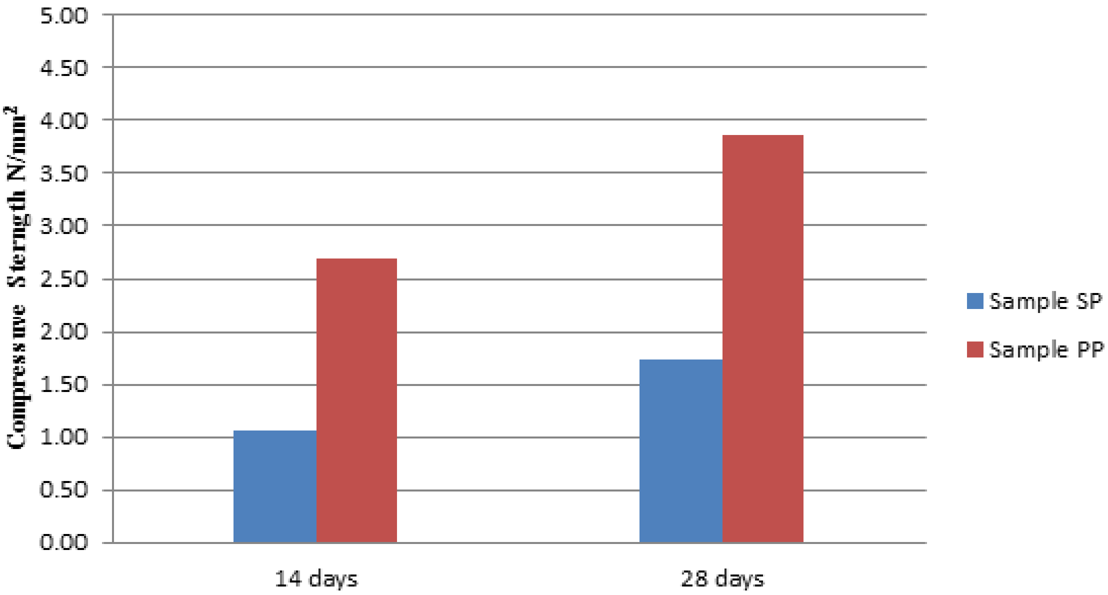

Figure 3: Compressive Strength of Papercrete Samples

The result of the compressive strength test is presented in Figure 3. The result shows an increase in strength with age for both samples. At 14 days, Sample PP (2.70 N/mm) recorded a 39% increase in strength over Sample SP (1.06 N/mm). At 28 days, Sample PP (3.86 N/mm) recorded an even greater strength (45% increase) over control Sample SP (1.74). The result is similar to 3.80 N/mm^2 obtained by Siva Prasad et al. (2015) using a very strong mix of 1:1:1 i.e. one part cement to one part sand to one part paper. The massive increase in strength of Samples PP could be attributed to continuous hydration as according to Ugur (2003), pumice aggregate tend to absorb water within their pores which are then released for further and continuous hydration. Another factor could be the pozzolanic action of fine pumice particles. Aggregate such as pumice and crushed fired bricks if fine enough behave like pozzolans. Lin, Wu, Shie, Hwang, and Cheng (2010) pointed out that the primary effect of pozzolans is the reduction of calcium hydroxide (CH) from the hydrating cement paste. Oxides such as silica (SiO_2), alumina (Al_2O_3) and ferrite (Fe_2O_3) from pumice tend to react with CH to produce other compounds that improve strength.

Tensile strength

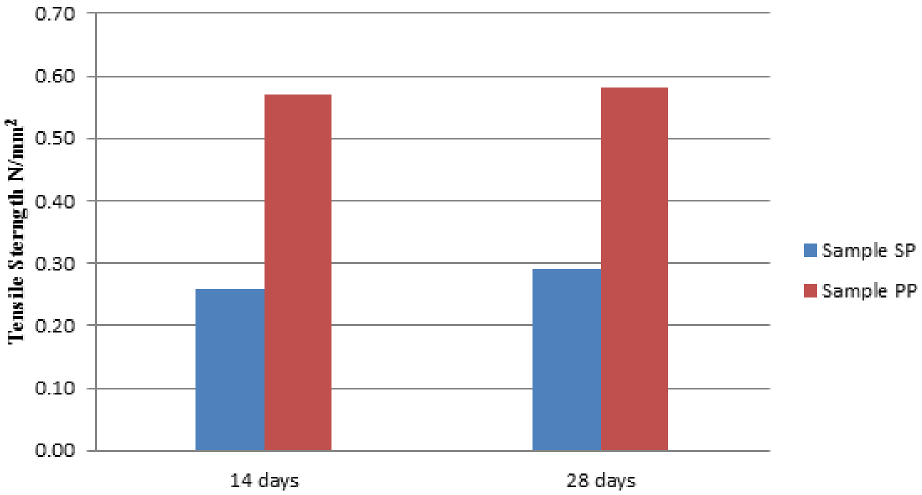

Figure 4: Tensile Strength of Papercrete Samples

Figure 4 presents the result of the tensile strength. The tensile strength of all the samples was low. The tensile strength of Sample PP at 28 days was just 15% of its compressive strength while the tensile strength of Sample SP was about 17% of its compressive strength. Still, it can be seen clearly from Figure 4 that samples containing pumice still recorded much higher tensile strengths than the control. The increases in Samples PP over Sample SP are 46% and 57% at 14 and 28 days respectively. Just as in compressive strength, the continuous hydration and pozzolanic action of fine pumice particles could be responsible for the increases in tensile strength.

Thermal conductivity and fire reaction

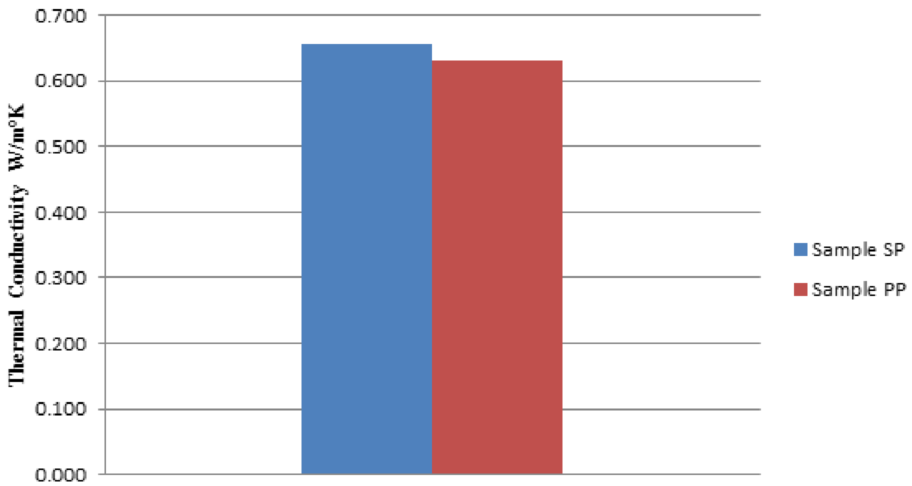

Figure 5: Thermal Conductivity of Papercrete Samples

Figure 5 presents the thermal conductivity of the *papercrete* samples. The thermal conductivity of Sample SP is 657 W/m°K which is 4% higher than that of Sample PP (631 W/m°K). The thermal conductivity of the samples was in tandem with those of previous studies. Earlier studies by Masjuki, Mohammed and Al-Mattameh (2008) recorded a thermal conductivity of 0.85W/m°K, while Sangrutsamee, Srichandr, and Poolthong (2012) obtained values ranging from 0.289W/m °K to 0.625W/m°K for different mixes of *papercrete*.

Furthermore, Samples PP exhibited a similar and good reaction to fire just as the control. The samples did not ignite upon application of flame. All the samples begin to smoulder when the flame was applied but none of the samples kindled thus there were no flaming droplets nor any ignition of the filter paper underneath the samples.

Conclusion

This study was undertaken to assess how papercrete containing other ingredients will perform in comparison to ordinary papercrete. To this end, *papercrete* was produced using pumice as fine aggregate in place of sand. Results from the experiment indicate that *papercrete* produced with pumice as a fine aggregate will increase the strength of *papercrete* without significantly increasing the weight of papercrete which makes it a desirable material. Also, papercrete containing pumice will neither aggravate the water absorption capacity nor reduce the fire resistance of *papercrete*. However, experimental results show that pumice *papercrete* will increase the thermal conductivity of *papercrete*. Generally, it is observed that *papercrete* performs excellently particularly in terms of strength when produced with pumice instead of sand.

References

American Society for Testing and Materials ASTM C 642 (1997). Standard Test Method for Density, Absorption and Voids in Hardened Concrete. 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States.

BS Standard BS EN 197-1 (2000). Cement: Composition, specifications and conformity criteria for common cements. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS Standard BS 410-1 (2000). Test sieves: Technical requirements and testing. Test sieves of metal wire cloth. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS Standard BS EN 11925-2 (2010). Reaction to Fire Tests: Ignitability of Products Subjected to Direct Impingement of Flame, Single-Flame Source Test. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS Standard BS EN 12390-3 (2000). Testing Hardened Concrete: Compressive Strength of Test Specimens. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS Standard BS EN 12390-7 (2000). Testing Hardened Concrete: Density of Hardened Concrete. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

International Institute for Environment and Development (nd). *A changing future for paper: A summary of the study, towards a sustainable paper cycle*. Retrieved from http://pubs.iied.org/pdfs/x137IIED.pdf (accessed 14 January 2013)

Joy, M. J. (2005). *Evaluation of metakaolin for use as supplementary cementitious materials*. (MSc Thesis), Georgia Institute of Technology.

Kilic, A., Atis, A. D., Teymen, A., Karahan, O., & Ari, K. (2009). The effects of Scoria and Pumice aggregates on the strengths and unit weights of lightweight concrete. *Journal of Scientific Research and Essay*, 961-965

Lin, L., Wu, H., Shie, J., Hwang, C., & Cheng, A. (2010). Recycling waste brick from construction and demolition of buildings as Pozzolanic materials. *Waste Management and Research*, 1-7.

Masjuki, S. A., Mohammed, B. S., & Al-Mattameh, H. M. A (2008). Hybrid composite wall system by using local waste: Panel of cement bonded wood infilled with Papercrete. Paper presented at the International Conference of Construction and Building Technology (ICCBT), 239-250.

McElroy, G., Thompson, C., & Williams, K. (2010). *Making it complete with Papercrete*. Retrieved from http://papercrete_215WS_S10_DOC/pdf (accessed 22 May 2012).

Mehta, P.K. & Monteiro, P.J.M. (2005). *Concrete microstructure, properties and material*. Tata McGraw-Hill Publishing Company Ltd., Delhi, pp. 121-198.

Mindess, S., Darwin, D., & Young, J. F. P. (2003). *Concrete*. (2nd ed.). New Jersey: Prentice Hall.

Mohammed, B. S. (2009). Papercrete as infill materials for composite wall system. *European Journal of Scientific Research,* 34(4), 455-462.

Siva Prasad, G. V. S., Reddy, P. P., Swathi, M., Kiran Kumar, P. D. V., Praveenraja, T., & Naveen, M. (2015). Study and behaviour of some properties of Papercrete brick with modular brick. *International Journal of Engineering Research,* 267-275.

Sangrutsamee, V., Srichandr, P., & Poolthong, N. (2012). Re-pulped waste paper-based composite building materials with low thermal conductivity. *Journal of Asian Architecture and Building Engineering,* 147-151.

Suganya, S. (2012). Lightweight bricks made up of wastepaper. *International Journal of Computing and Organization Trends*, 29-40.

Titzman, L. C. (2006). *Analysis of low-cost building material for the Mixalco process*. (MSc thesis), Texas A & M University.

Ugur, I. (2003). Improving the strength characteristics of the Pumice aggregate lightweight concretes. 18th International Mining Congress and Exhibition of Turkey (IMCET).