Structural Evaluation of Lightweight Concrete Produced Using Waste Newspaper and Office Paper

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Abstract

The construction industry consumes a large amount of non-renewable resources. On the other hand, more waste paper ends up in landfill or dump sites than those recycled. Consequently, recycling waste paper for use as a construction material constitutes a step towards sustainable development. This research effort aims at determining the density, water absorption capacity, compressive strength and fire resistance of papercrete produced using waste newspaper and office paper in order to ascertain their suitability for use as a building construction material. For each of the mix proportions considered, the bulk density, water absorption, compressive strength and fire resistance of papercrete made with newspaper were found to be higher than those made with office paper. The water absorption and fire resistance of papercrete were found to be high and increased with increasing waste paper content while the bulk density and compressive strength of papercrete were low and decreased with increasing waste paper content. Papercrete was recommended to be an effective and sustainable material for the production of lightweight and fire-resistant hollow or solid blocks to be used to make partition walls of especially high-rise buildings. Mix proportions were recommended for production of hollow and solid blocks using papercrete.

Keywords: green-construction, low-cost housing, recycling, sustainability, waste paper

1. Introduction

More than 450 million tons of paper is produced worldwide per annum and it is expected that the demand for paper will reach 500 million tons per annum by the end of 2020 (Ali *et al.* 2013). The environmental impact of pollution caused by discarding paper and paper products is also quite significant. In recent years, paper and paperboard constituted the largest portion of the United States (US) municipal solid waste generation (U.S. EPA 2010; 2011; 2013; 2014). In 2006, for example, paper and paperboard accounted for 33.9% (85.29 million tons) of the US municipal solid waste generated. Of this waste generated, 12.36 million tons of newspaper and 6.32 million tons of office-type paper were generated (U.S. EPA 2007). Most waste paper ends up in landfill sites while some are incinerated. Thus, they pollute the air, water and land. Waste paper recycling has not been able to match waste paper generation. One unique recycle opportunity is using waste paper as a construction material. The construction industry has been identified as one of the largest consumer of non-renewable resources (Wallbaum & Buerkin 2003). Consequently, using waste paper for construction not only has the potential of waste paper recycling keeping pace with its generation but it will also reduce the demand pressure on global natural resources.

In recent years, there has been a resurgence of interest in traditional building materials (Akinwumi 2014), especially those made from renewable or recycled materials (Seyfang 2010). “Papercrete” is one of such materials attracting public interest.

Papercrete is a composite material comprising of Portland cement, waste paper, water and/or sand. It is like replacing coarse-grained fraction and/or sand of Portland cement concrete with waste paper. Paper adobe or padobe is another material sometimes referred to as a form of papercrete. It is produced by mixing waste paper with earth materials (such as mud or sandy-clay).

Papercrete have been reported: to be a cheap alternative building construction material; to have good sound absorption and thermal insulation; to be a lightweight and fire-resistant material (Annesley 2014; Fuller 2014; Nepal & Aggarwal 2014; Santamaria *et al.* 2007; Solberg 1999). Despite having a lot of information about how to use papercrete as a construction material, few research works have been done to determine their structural suitability (Fuller *et al.* 2006).

This paper aims at determining the density, water absorption capacity, compressive strength and fire resistance of papercrete produced using waste newspaper and office paper in order to ascertain their suitability for use as a building construction material.

2. Materials and Methods

2.1 Materials and Preparation

Ordinary Portland cement of grade 32.5, obtained commercially, and river sand (passing 4.75 mm sieve but retained on 0.075 mm sieve) and, discarded newspaper and office paper were used for sandcrete and papercrete cubes production. For the papercrete, each of the waste newspaper and waste office paper was separately shredded and soaked in water for 48 hours in order to reduce its capacity to absorb mixing water used for the papercrete production. The soaked paper was mixed at an interval of 6 hours to ensure a mushy consistency. After the completion of soaking, water was sieved out. Potable water was used for both mixing and curing of the sandcrete and papercrete cubes.

2.2 Methods

The two categories of papercrete cubes were produced using either waste newspaper or waste office paper. For each of the waste newspaper and waste office paper mixtures, the ratios of cement:sand:wastepaper used were 1:1:0.2, 1:1:0.4, 1:1:0.6 and 1:1:0.8. The ratio of sand to cement was chosen because the results obtained by Yun *et al.* (2007) and Aciu *et al.* (2014) showed that the sand-binder ratio of 1.0 (out of the considered sand-binder ratios they considered) had the best mechanical properties, with economy also in view. Cement and sand of equal proportion were also mixed and used to produce sandcrete cubes, whose structural properties were also compared with those of the papercrete cubes. One hundred and twenty (120) papercrete cubes and 15 sandcrete cubes were cast for the various laboratory tests that were carried out.

The materials were batched by weight and thoroughly mixed to ensure even distribution of the constituents within the mixtures. The cubes produced using each of the papercrete mix ratios and those of the sandcrete were cured for 7, 14 and 28 days, by immersion in water. The curing period was limited to 28 days in alignment with the recommendation by Akinwumi & Gbadamosi (2014).

2.2.1 Density

The sandcrete and papercrete were cast in cubical moulds with internal dimensions of 150x150x150 mm^3. Their bulk densities were determined by dividing their mass, after their removal from the mould, by its volume.

2.2.2 Water Absorption

After completely immersing the cubes for 24 hours, water was wiped-off the surfaces of the cubes. Each of the cubes was then weighed. The mass of each of the cubes before curing was subtracted from its mass after 24 hours of curing in water in order to determine the mass of water absorbed. The water absorption in percent was determined by, considering in percentage terms, the ratio of the mass of water absorbed to the initial mass of the sandcrete or papercrete cube before it was cured in water.

2.2.3 Compressive Strength

Compressive strength of each of sandcrete and papercrete cubes at curing ages of 7, 14 and 28 days was determined. The average of three compressive strength results, for each curing period, category and mix proportion, was determined. The compressive strength of the cubes was determined in compliance with BSI (1983), using YES-2000 digital display compression machine.

2.2.4 Fire Resistance

Sandcrete and papercrete cubes cured for 28 days and air-dried for 1 hour were burnt to a temperature of 1000^{o}C for 10 minutes in a furnace. In literature, a similar test procedure for the determination of thermal insulation property of papercrete was conducted by subjecting its cubes to 1000^{o}C for 5 minutes (Aciu *et al.* 2014). The cubes were allowed to cool for 1 hour in the open air before the determination of their residual compressive strength.

3. Results and Discussion

3.1 Bulk Density

The bulk densities of the papercrete made using newspaper and office paper are shown in Figures 1 and 2, respectively. From these figures, it was observed that the bulk densities of the papercrete vary inversely with the waste paper content of the mixtures.

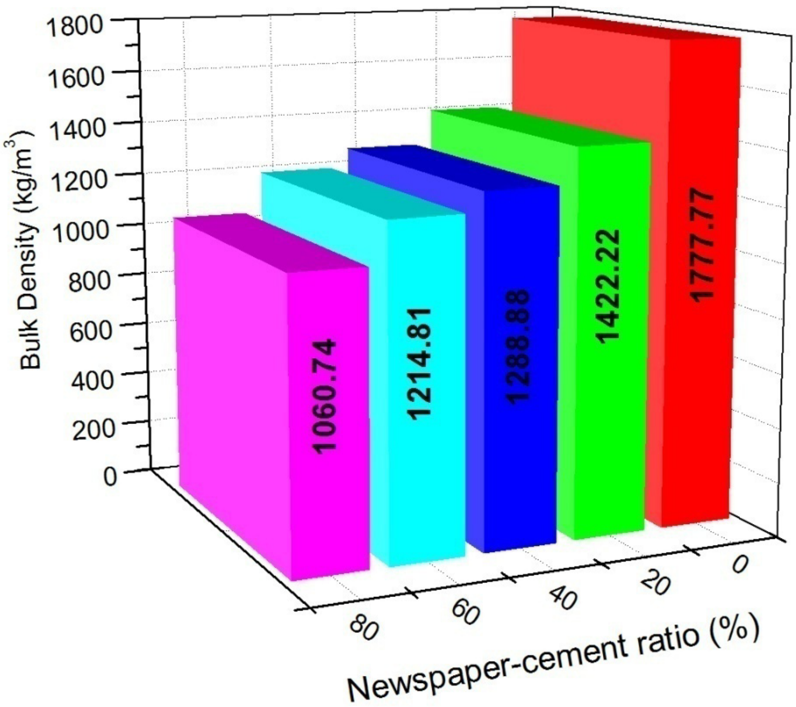

Figure 1. Variation of bulk density of papercrete with newspaper-cement ratio

Comparing Figures 1 and 2 shows that the bulk density of papercrete made with newspaper is higher than those made with office paper. They also show that the density of the sandcrete blocks were higher than those of the papercrete.

3.2 Water Absorption

The results of the water absorption tests for sandcrete and papercrete cubes made using newspaper and office paper is presented in Figure 3. Figure 3 shows that the water absorption of the cubes increased with increasing waste paper content. It also shows that papercrete made with newspaper generally absorbed more water than those made using office paper, except for that of 60% newspaper – cement ratio. Newspaper is thought to have absorbed more water than office paper due to its lower grams per square metre (grammage). This made it easier for the inter-fiber bonding of the cellulose fibers of newspaper to get relaxed and weakened, thereby, absorbing more water.

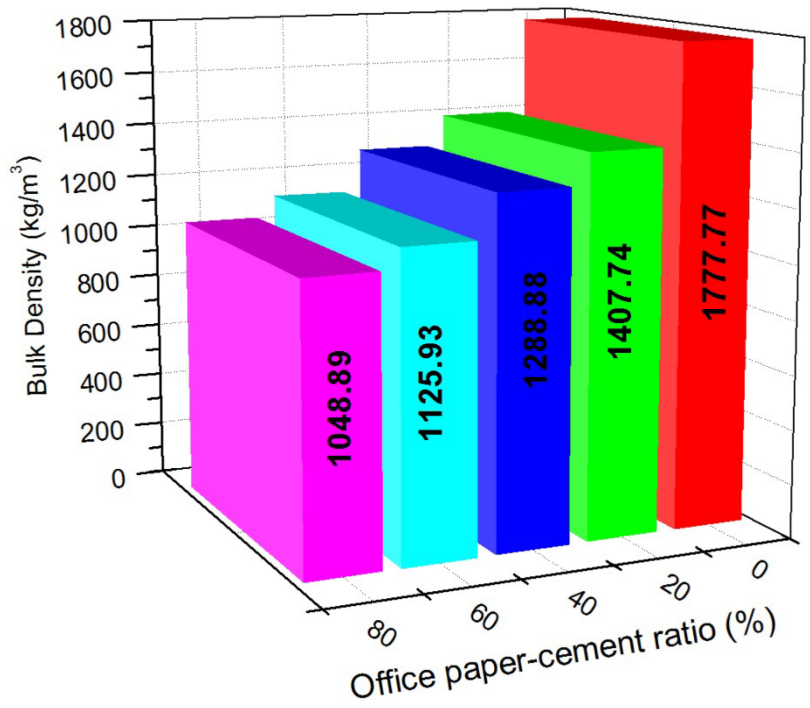

Figure 2. Variation of bulk density of papercrete with office paper-cement ratio

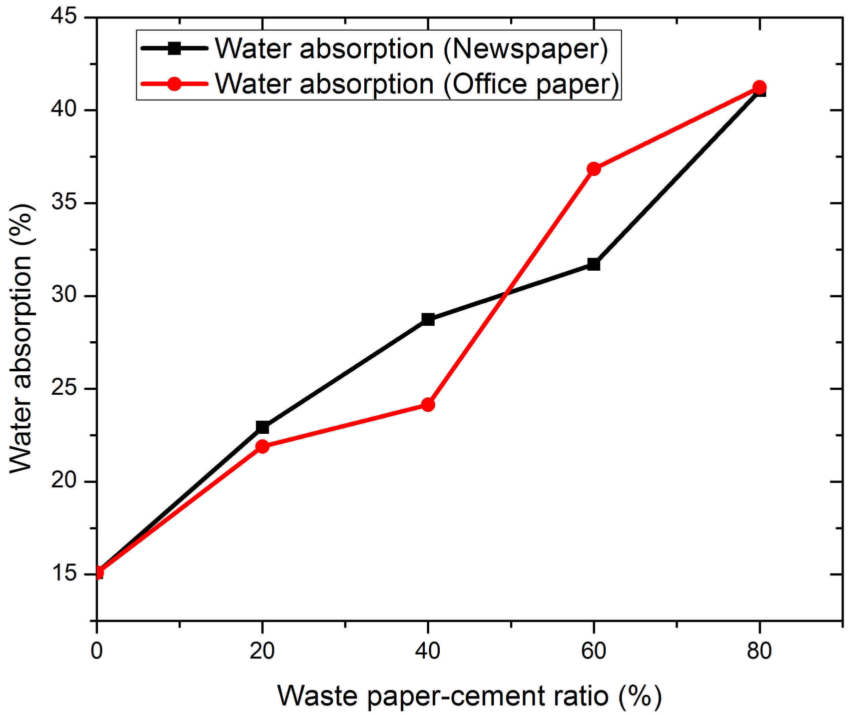

Figure 3. Variation of water absorption of papercrete with waste paper-cement ratio

3.3 Compressive Strength

The compressive strength results for sandcrete and papercrete cubes, after 7, 14 and 28 days of curing, are presented in Figures 4, 5 and 6, respectively.

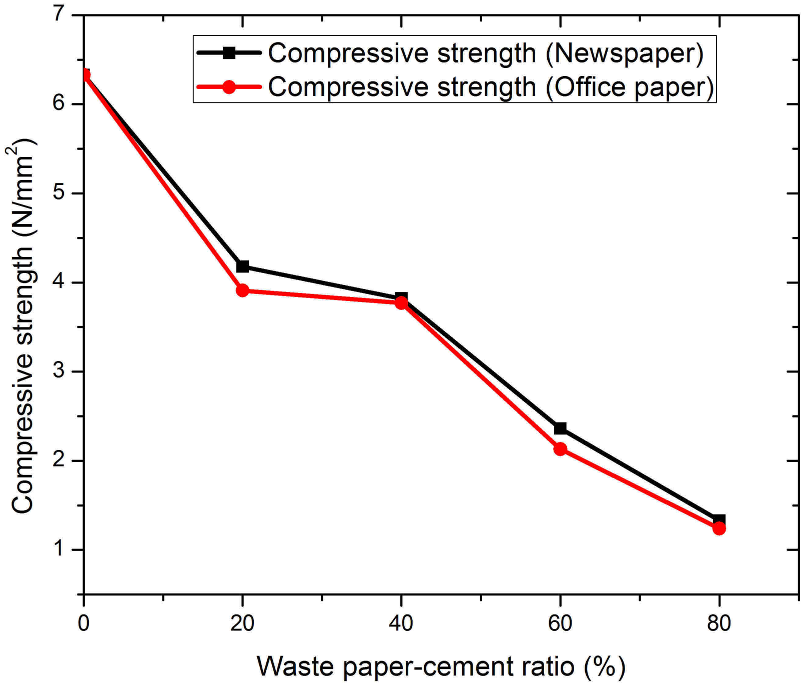

Figure 4. Variation of 7-day compressive strength of papercrete with waste paper-cement ratio

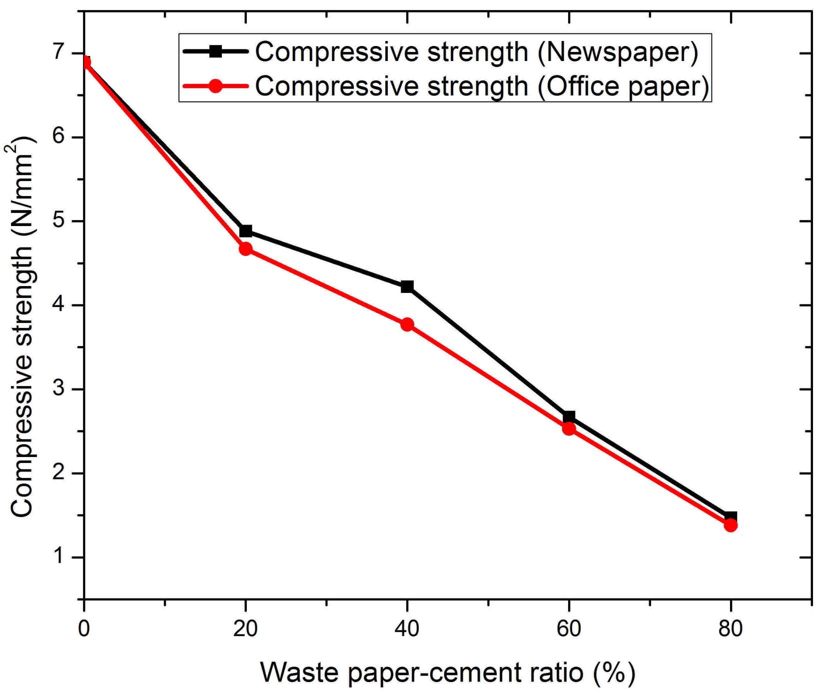

Figure 5. Variation of 14-day compressive strength of papercrete with waste paper-cement ratio

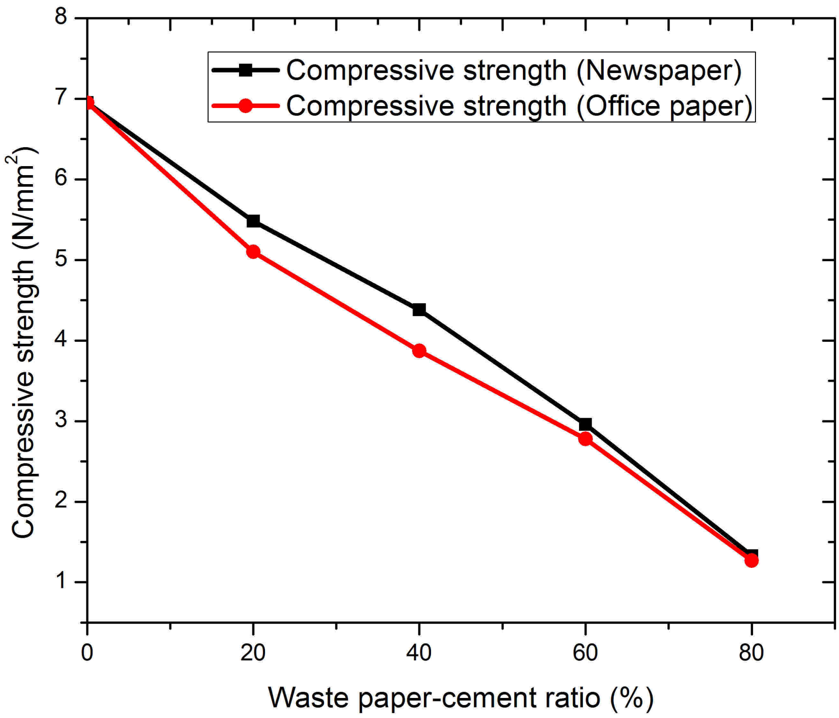

Figure 6. Variation of 28-day compressive strength of papercrete with waste paper-cement ratio

These Figures show that for both papercrete made with newspaper and office paper, their compressive strength reduces with increasing waste paper content. It also shows that, for all the curing periods, papercrete made with newspaper have a higher compressive strength than those produced with office paper. This may be attributed to the higher density of papercrete made using newspaper.

Figures 4, 5 and 6 also show that for 80% waste paper-cement ratio (i.e., 1:1:0.8 mix proportion), the compressive strengths for papercrete made with both types of waste paper were similar. Consequently, the compressive strength lines for papercrete made with newspaper and office paper, for each of the curing periods, formed an envelope.

3.4 Fire Resistance

The fire resistance was described as a measure of the residual compressive strength of papercrete cured for 28 days, dried and afterwards subjected to heat of 1000^oC. The 28-day compressive strength result for sandcrete and papercrete cubes, before and after burning, is presented in Figure 7.

Figure 7 shows that for both papercrete made with newspaper and office paper, there is a general reduction in their compressive strength after burning. The gap between the compressive strength lines for each of the papercrete made with newspaper and office paper became narrower with increasing waste paper content. This indicates that the fire resistance of papercrete increased with increasing waste paper content.

The reductions in compressive strength of the papercrete cubes after burning were less than 1 N/mm^2. This may be attributed to the thermal insulation of the interior of the burnt papercrete cubes, consequently, accounting for the high residual compressive strength.

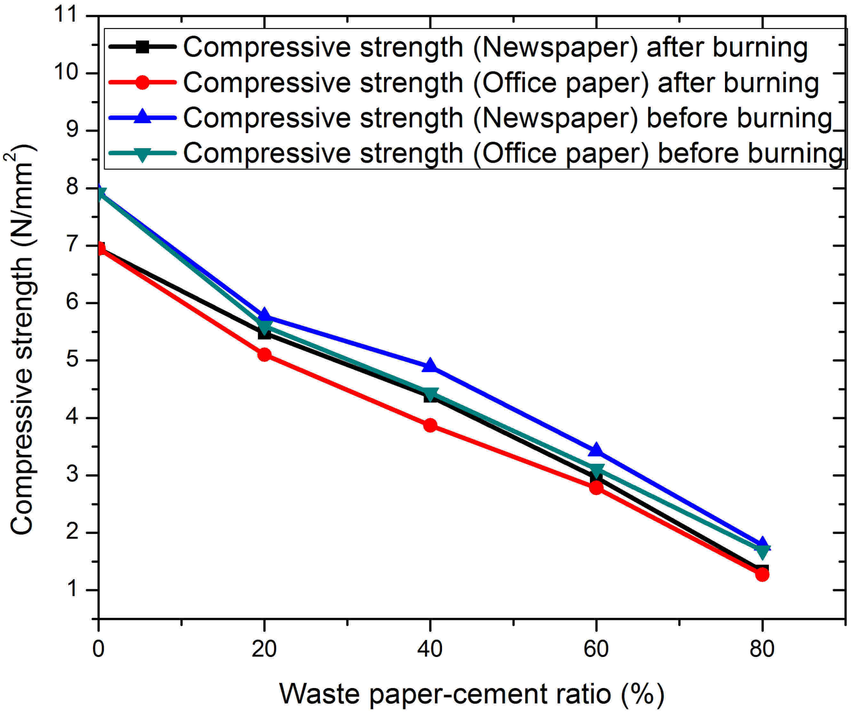

Figure 7. Variation of 28-day compressive strength of papercrete (before and after burning) with waste paper-cement ratio

4. Conclusion

From the results obtained, the following conclusions were made:

(i) The low bulk density of papercrete indicates that they are lightweight and can be used in the form of either hollow or solid blocks for making walls of buildings, especially, high-rise buildings. This property also makes papercrete good for building arches and domes.

(ii) A mix proportion for cement:sand:waste paper of 1:1:0.6, which has 28-day compressive strengths greater than 2.5 N/mm^2, is recommended for hollow papercrete block production. A mix proportion of 1:1:0.8 is recommended for solid papercrete block production.

(iii) Papercrete has a high fire resistance. This is evident in the residual compressive strength of papercrete obtained after been subjected to heat of high temperature.

(iv) Papercrete made with newspaper have better structural properties than those made with office paper but it also has a higher water absorption capacity.

(v) Papercrete should not be used for external walls and near-ground walls because of its high water absorption capacity. If it has to be used for external walls, the surface of the walls must be waterproof. It should not be used within 1 m above ground surface. Also, a damp-proof membrane should be placed before its use to prevent the absorption of water due to capillary rise.

References

Aciu, C., Ilutiu-Varvara, D.A., Cobirzan, N. & Balog, A. (2014), "Recycling of paper waste in the composition of plastering mortars", *Procedia Technology* **12**, 295-300.

Akinwumi, I.I. (2014), "Earth building construction processes in Benin City, Nigeria and engineering classification of materials used", *Indian Journal of Traditional Knowledge* **13**(4) [In Press].

Akinwumi, I.I. & Gbadamosi, Z.O. (2014), "Effects of curing condition and curing period on the compressive strength development of plain concrete", *International Journal of Civil and Environmental Research* **1**(2), 83-99.

Ali, A., Hashmi, H.N. & Baig, N. (2013), "Treatment of the paper mill effluent – A review", *Annals of Faculty Engineering Hunedoara - International Journal of Engineering* **11**(3), 337-340.

Annesley, J. (2014), "Papercrete / paper-adobe: Insulation and thermal mass", Available online: http://annesley.wordpress.com/papercrete-paper-adobe-insulation-thermal-mass/ (accessed on 12th May 2014).

BSI (1983), "Method for determination of compressive strength of concrete cubes", BS 1881: Part 116. British Standards Institution, London.

Fuller, B.J., Fafitis, A. & Santamaria, J.L. (2006), "The paper alternative", *Civil Engineering* **76**, 72-77.

Fuller, B.J. (2014), "Living in paper – 2014", Available online: http://livinginpaper.com/index.htm (accessed on 12th May 2014).

Nepal, B. & Aggarwal, V. (2014), "Papercrete: A study on green structural material", *International Journal of Applied Engineering Research,* **9**, 253-260.

Santamaria, J., Fuller, B. & Fafitis, A. (2007), "Structural properties of a new material made of waste paper", *Computational Methods and Experimental Measurements XIII, WIT Transactions on Modelling and Simulation* **46**, 557-567.

Seyfang, G. (2010), "Community action for sustainable housing: Building a low-carbon future", *Energy Policy* **38**, 7624-7633.

Solberg, G. (1999), "Papercrete and paper adobe: A revolutionary new way to build your own home for next to nothing", Remedial planet communications.

U.S. EPA (2007), "Municipal solid waste in the United States: 2006 Data Tables", United States Environmental Protection Agency, Washington.

U.S. EPA (2010), "Municipal solid waste in the United States: 2009 Facts and figures", United States Environmental Protection Agency, Washington.

U.S. EPA (2011), "Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2010", United States Environmental Protection Agency, Washington.

U.S. EPA (2013), "Municipal solid waste in the United States: 2011 Facts and figures", United States Environmental Protection Agency, Washington.

U.S. EPA (2014), "Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2012", United States Environmental Protection Agency, Washington, United State, 2014.

Wallbaum, H. & Buerkin, C. (2003), "Concepts and instruments for a sustainable construction sector", *Industry and Environment*, **26,** 53-57.

Yun, H., Jung, H. & Choi, C. (2007), "Mechanical Properties of Papercrete Containing Waste Paper", *18th International Conference on Composite Materials*, Architectural Institute of Korea, Korea.