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# A REVIEW OF RECYCLED USE OF POST CONSUMER WASTE PAPER IN CONSTRUCTION

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**Abstract**

The productive use of waste materials represents a means of reducing some of the problems associated with solid waste management. The process minimizes the use of natural resources and in some cases results in the production of environmental friendly products. Ever since the invention of paper, it has formed an important part of human daily activities. With uses in many applications due to its versatile properties. The need to recycle it is thus paramount upon the fact that, the more it is being utilized for several applications, the more the amount of waste paper generate. However, the major percentage of these finds their way to the municipal solid waste stream. This review identifies and discusses some recent research that investigates the potential uses of post-consumer waste paper in several, civil engineering construction materials and then proffers a proposed direction for future work. Several research gaps were identified. These includes: the need to establish a standard mix proportion of papercrete for different application, high moisture absorption of building materials made from waste paper, addressing the contradiction between the hygroscopic properties of paper fibre and cement hydration moisture requirement. In the light of these, an investigation to develop an environmentally friendly, non-load bearing, lightweight building block from waste paper, without the use of cement and with properties suitable for use as walling unit has thus been proposed.

**Keywords:**

Waste paper, Concrete, Fiber cement composite, Particle board, Papercrete.

## 1 INTRODUCTION

Waste paper are paper that are no longer useful for the purpose for which it was made or that had already served such purpose and it meant to be disposed off , they originate from offices, household, public facilities, commercial activities, and industries [European recovered paper council (ERPC), 2014]. Post- consumer waste paper, pre-consumer and recovered waste paper are the known categories. According to the United States Environmental Protection Agency(US EPA), recovered fibre are post-consumer papers that have passed through their end-use as a consumer item, which includes, all paper types, paperboard, and fibrous materials that enter and are collected from municipal solid waste; and, manufacturing waste [US EPA,2014].

Paper and paper products represent a considerable percentage of municipal solid waste stream in most developed and developing countries. It forms the largest components of the municipal solid waste stream in the United States and Europe even as at the year 2012 [US EPA, 2014]; [Nepal and Aghawal, 2014]; [European Environment Agency (EEA), 2013]. Paper comes in many grades and from many sources. A significant portion of wastepaper is readily identifiable and can be easily sorted and collected for recycling into paper products. Old newspapers, office paper, and old corrugated containers are examples of these identifiable paper types. Packaging, plastic-coated paper; and mired paper may be difficult to sort and collect.

However, considering the increasing rate of per capital waste paper consumption (Fig 1) and the prediction of a possible increase of global paper production from the present 450million tons per year to 500million tons by 2020 [Ali et al, 2013], monopolizing the recycling of waste paper to paper production alone is not enough to solve the enormous quantity of waste paper generation. An evidence of this, is the amount of waste paper that is still going into landfill and incineration, despite the high recycling rate achieved in few developed countries. For instance, an estimated volume of 10million tonnes of paper and board which could have been recycled is still currently going into incineration and landfill in Europe, despite the 71.7% recycling rate achieved in 2012 [Confederation of European paper Industries

(CEPI), 2014], 48 million tonnes is being disposed in USA [Nepal and Aghawal, 2014] despite the 65.8% recycling rate.

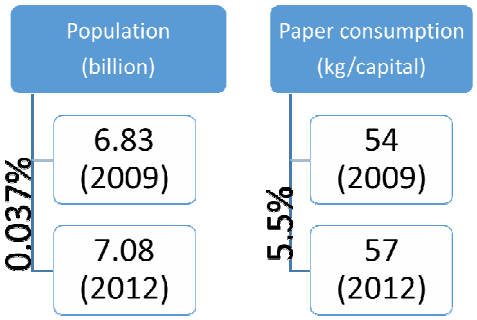


*Fig1: Percentage Increase of Global per capital paper consumption, compared with percentage global population increase (Sources: (The statistics portal, 2014); (World bank, 2012))*

In addition, the need to explore alternative means of recycling waste paper for productive use is paramount, considering the problems such as the removal of contaminants, fibre shortening and high sludge production, associated with the recycling of waste paper back into paper. Also, Organic materials, including paper, decomposes slowly in landfill and releases methane which is a potent greenhouse gas, and the scarcity of suitable land for landfill is already being experienced in highly urbanized areas such as the north-eastern US and most part of Europe. Presently, as part of the waste target review, the paper industry is proposing a wide ban on landfilling/ incineration of recyclable paper in Europe by the year 2020 [CEPI, 2014].

Therefore, to achieve an effective solution to the problem of waste disposal and the associated environmental concern, the need to economize resources through the recycled use of waste paper in construction and other engineering field stand as a viable option for its disposal. This will also indirectly offset some of the environmental impact of the construction industry such as high natural resources consumption, high energy usage and greenhouse gas emission.

## 2 GENERAL USE OF WASTE PAPER

Most recovered paper is recycled back into paper and paperboard products, with a few exceptions, recovered paper is generally recycled into a grade similar to, or of lower quality than, the grade of the original product. For example, old corrugated boxes are used to make new recycled corrugated boxes. Recovered printing and writing paper can be used to make new recycled copy paper [ERPC, 2014].

Besides easily recognizable paper products (e.g, writing paper or paper towels), more than 5,000 products can be made from recycled paper, including, Masking tape, Paper money, Globes, Bandages, Dust masks, Hospital gowns, Coffee filters, Lamp shades, Car insulation, Animal bedding, Planting pots for seedlings, Egg cartons. (Technical Association of the Pulp and Paper Industry (TAPPI), 2001), waste paper fibre can also be used in car brake lining to hold the lining material together.

## 3 USES OF WASTE PAPER IN BUILDING MATERIALS

Waste paper have been used profoundly in several aspects of civil engineering materials, some of the products of such uses includes particle board, fiber cement composite (ceiling) and wall insulation, and roofing [TAPPI, 2001].

### 3.1 Use of Waste Paper in concrete

Traditionally, concrete is made from mixture of cement, fine aggregate, coarse aggregate and water [Zongjin li, 2011]. Reinforcement, admixture and pozzolans are sometimes required depending on application. However, the awareness of the environmental impact of concrete production and the need for sustainable disposal of solid waste such as waste paper, has prompted several investigation on utilizing waste paper in concrete.

Waste paper, can be used to produce lightweight concrete with desirable weight-to-strength ratio, insulation properties, sound insulation and toughness characteristics. It has been included in concrete to serve purposes such as aggregate replacement, binder replacement, additional filler, papercrete, plastering, block (hollow and solid) etc. Soroushian et al ,(2003) reported that the use of waste paper as discrete reinforcement systems in concrete significantly improved the restrained shrinkage, crack control and impact resistance comparable to those of virgin fibers.

Research findings have also reported the development of a building material known as Papercrete, which is produced from waste paper pulp, sand, cement and other optional material such as; fly ash, Styrofoam, glass etc [Fuller et al,2006]. Papercrete can be applied as lightweight concrete [Tizmany, 2006; Fuller et al, 2006; M. Kokkinos, 2011], mold into block [Modry, 2001], fabricate into panels [Canola et al,2012], and used as infill in composite wall (Mohammed,2009).It properties for different application as reported by different research findings are summarized in table1.

As can be understood from table (1), its strength for hollow block and as additional material in concrete shows it suitability for nonload bearing application. Plastering mortar produced from waste paper exhibit compressive strength of almost the same value with bending strength(1.11-2.43N/mm$^2$) unlike conventional mortar, whose compressive strength is 10-20% of its bending strength [Acui et al 2014]. Papercrete in all its applications displayed lower thermal conductivity compared to the 1.25-1.75W/(m.k) for conventional concrete which indicate its desirable insulating properties. Papercrete exhibit lightweight unlike normal concrete, Yun et al, [2007] reported a decrease in its density with increasing waste paper content, a similar observation was made by Tizmany,2006; Acui et al 2014, and Akinwumi et al,2014, these properties indicate it suitability for use as partition walling element in high rise building, dome and aches. It also possess desirable fire resistance, Akinwumi et al [2014] reported less than 1N/mm$^2$ reduction in compressive strength of papercrete subjected to 10000C burning temperature. Modry, [2001] found that sound insulation of papercrete block conformed to the requirements of CSN ISO 717-2 for partition walls.

The water absorption of papercrete is high, Akinwumi et al, 2014, report similar to Tizmany, 2006, and Acui et al, 2014, that the water absorption of papercrete increases with increasing waste paper content, this constraint indicate its restriction from application in external walls and near-ground walls, unless the wall surface is waterproofed and damproofed prior to the application of papercrete block above 1m to the ground level. The compressive strength of papercrete decreases with increasing waste paper content due to corresponding water content increment [Abdul Ghani and Shukeri, 2008] and is less than the value required for structural application (table 1). Though Fuller et al, (2006) observed that its stiffness (i.e, the extent to which it compresses under load) is a more useful measure of its properties, stating that its stiffness is sufficient for the support of roof load in some low height building despite being less than that of conventional concrete.

*Table 1: Properties of Concrete Containing Wastepaper (as collated from previous research)*

| Paper Uses in concrete | Paper content (%) | Compressive strength (MPa) | Thermal conductivity (W/m.k) | Fire resistance | References |
|---|---|---|---|---|---|
| **Papercrete** | - | 0.96-1.1 | - | - | [Nepal and Aghawal, 2014] |
| | - | 1.7 | - | - | [Nepal and Aghawal, 2014] |
| | - | 1.12-2.36 | - | - | [M. Kokinos, 2011] |
| | 5% | 34.0 | - | - | [Yun et al, 2007] |
| | 20%-40% | 0.195-0.990 | 0.10 | - | [Titzman ,2006] |
| **Hollow block** | 40% | 1.84 | 0.35 | Degree “A” | [Modry ,2001] |
| | 60% | >2.5 | - | Good | [Akinwumi et al ,2014] |
| **Solid block** | 80% | >1.5 | | Good | [Akinwumi et al ,2014] |
| **Infill material for CSW** | 72% | 5.56 | 0.85 | 2hrs | [Mohammed, 2009] |
| **Additional material in concrete** | 5%-20% | 14.7 - 4.0 | - | - | [Decard et al, 2001] |
| | 15% | 15.67 | - | - | [Abdul Ghani and Shukeri, 2008] |
| **Plastering Mortar** | 40%-38% | 2.51-1.86 | - | Good | [Aciu et al, 2014] |
| **Papercrete brick** | - | 3.5 | - | - | [Jegatheeswara, 2011] |

Also, the use of waste paper in building materials has enable the construction of houses at a cheaper rate compared to the conventional materials, for example, Solberg Gordon (2002) reported that in 1998 a house built by Sean Sand in USA with this material costs 75cent per square foot instead of the $100 per square foot normal cost. Other examples of structures constructed from waste paper are; the Andy Hopkins 512-square-foot house in Crestone and the Virginia Nabity’s 800-square-foot addition to her Strawbale house in Cortez, Colorado which were both built in 1999.

A company based in England, Econovate Limited with the support of Cambridge and Bath University has developed a papercrete formular and production process for breeze blocks to be accepted by the British Standards and green certification for Europe, which after certification will be produced for commercial purpose. This product is presently undergoing certified tests to achieve product certification from Local Authority Building Control (LABC) / National House Building Council (NHBC). According to the United Kingdom accreditation Service (UKAS) testing data, it possess 4.5N strength and 60days strength of 7N. and over 1.5hrs fire resistance (Econovate Limited,2015)

These studies reveal that concrete containing waste paper possesses desirable insulating properties and acoustic properties, fire resistance and moderate strength suitable for non-load bearing application in building structures, but more their conclusions are not consistent particularly regarding, the compressive strength, therefore more research is needed to develop a standard mix proportion and a stable compressive strength which according to [Neville, 2000] is of intrinsic importance in the structural design of concrete structures.

### 3.2 Waste Paper use as Particle Board

One of the major ways that wastepaper can be utilized is through the production of particleboard, Studies by [Ellis et al, 1993], [Massijaya and Okuma, 1996], and [Esmeralda et al. 2000], to

produce low density boards from shredded wastepaper bonded with various types of resins, reported that the mechanical properties of the boards were influenced by the percentage of bonding resins.

However, Massijaya and Okuma [1996] went further to report that, newspaper boards bonded with 10% of Urea-formaldehyde (UF) and para-formaldehde(PF) resins appears to be suitable for interior applications, though with conclusions that dimensional properties must be improved for exterior application. Also, the investigation carried out by Esmeralda et al [2000] to use shredded newspaper, magazine and office wastepaper bonded with urea-formaldehyde(UF) and tannin para-formaldehyde(TP) adhesives to manufacture low density board revealed a similar trend with the result of Rowell and Harrison(1992), in that, best mechanical properties of the office wastepaper and newspaper, and the best thickness swelling properties of the office waste paper UF and TP bonded boards were obtained at 12% resins level, with observation that, the UF bonded boards has better dimensional stability properties than the TP bonded boards and that the increase in resin level generally leads to increase in MOR and MOE. However the utilization of formaldehyde based resin can be considered to offset the environmental friendliness of these boards. According to the US EPA and the International Agency for research on Cancer, formaldehyde has been reported to be casinogenic to human health (Minesotal Department of Health, 2015).The green guard environmental Institute specified that Formaldehyde emission must not exceed 0.05ppm within168hours of testing. Therefore caution should be taking regarding its use as binding agent for interior building material, MDH (2015) suggested that the use of soy-based binder could be a suitable alternative.

On the other hand, Fuwape et al [2007], employed the use of Portland cement as binder and particles of wastepaper and sawdust as fillers to study technical assessment of three layered cement bonded boards (CBBs), with target density levels of 1000, 1200 and 1300 kg/m3 and at four cement/particle ratios of 2.0:1, 2.5:1, 3.0:1 and 3.5:1 on a weight to weight basis. The technical properties evaluated were modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) and thickness swelling (TS). They reported, that the board exhibited a MOR values which ranged from 4.85 to 11.69 MPa and MOE values ranged from 2.80 to 5.57 GPa. The mean values of WA and TS after 24 h of water soaking of the CBBs ranged from 18.18% to 40.49% and 3.55% to 12.13%, respectively. They also observed that MOR and MOE of the CBBs increased with increase in board density, but MOR decreased with the increase in cement/particle ratio, while WA and TS decreased with increase in board density and cement/particle ratio. The authors however concluded that CBBs produced from wastepaper and sawdust at cement/particle ratios of 3.0:1 and 3.5:1 are suitable for building construction such as paneling, ceiling and partitioning. Boards produced from 50% and 25% old corrugated containers were reported to satisfy the minimum MOR requirement of EN 312, [2003] for heavy duty load bearing boards for use in humid conditions, the MOE of the boards also satisfies the minimum requirement for load bearing boards for use in humid condition according to the same standard [Eshraghi and Khademieslam, 2012].

The conclusions of these studies are consistent particularly with regards to the optimum resin level, and the suitability of the boards for interior applications though more research is required to improve its properties for exterior applications.

### 3.3 Waste Paper use as Hybrid Composite

Waste paper had been combined with several other waste material of different composition to produce hybrid composites. A study by Ashori and Nourbakhsh, [2009] to investigate the feasibility of using recycled high density polyethylene (rHDPE), polypropylene (rPP) and old newspaper (rONP) fiber to manufacture experimental composite panels showed that, the use of maleated polypropylene as coupling agent improved the compatibility between the fiber and both plastic matrices and the mechanical properties of the resultant composites compared well with those of non-coupled ones. They, however concluded that composites with rHDPE provided moderately superior properties, compared with rPP samples. This indicate the potential of combination of waste paper with other waste materials of different composition to manufacture value-added panels.

Ding et al [2011], reported that boards produced from mixture of 1:1 Robiniapseudoacacia and waste paper exhibit 11.8MPa MOR and 20.6% thickness swelling at 20% resin, $160^0$C pressing temperature at 8min. Oladele et al [2009] used the mixture of natural sponge fibre (Acanthus montanus), waste paper (old newspaper), and cement as reinforcement for ceiling materials. They reported that, by using mixture of cement and waste paper in the ratio 70:30 by weight high reinforcing effect and best mechanical properties were obtained at 4% optimum fibre mass fraction based on the flexural and water absorptivity tests carried out on the board.

Eires et al [2006], studied the development of new hybrid composite materials using granulated cork, a by-product of cork industry, cellulose pulp, from recycling of paper residues, and hemp fibres. The binder used is either cellulose pulp or lime-pozzolan mixture .the granulated cork/paper pulp composites was proven to have adequate properties for several non-structural applications, such as, coverings walls, dry walls and ceiling. It displayed good thermal insulation characteristics and could be produced to have low water absorption. By using 15KN compactive effort and thermal curing at $110^0$C temperature for 3hrs/room temperature for 3days, the composite displayed 400KPa flexural strength, 4% deformation under compression, 28% recovery under decompression. The application of linseed oil as waterproofing agent reduced water absorption to 50% from the initial 160%.The obtained average thermal conductivity 0.084W/m$^0$C may be considered good when compared with similar materials produced from polystyrene and Rockwool which exhibit 0.03W/m$^0$C and 0.045W/m$^0$C respectively. Also, the combination of the cork/paper pulp composites with polypropylene honeycombs was found to improve significantly the flexural behaviour of the developed sandwich panels.

The result of a study by [Ellis et al, 1993] to investigate the possibility of producing composites boards from recycled telephone directory paper bonded with polyethylene and polyvinylidene, ground plastic, and conventional wood adhesives, indicated that the bending properties of boards were comparable to commercial wood-based panels.

### 3.4 Waste paper Use as Fibre cement composite

Conventional fibre cement composite sheet are made from mixture of cellulose fibre, cement, ground sand and water, it was originally invented in the 19th century from a mixture of 90% cement, 10% asbestos fibres and water subjected to pressing in a cardboard machine. The use of cellulose fibre for its reinforcement began after the prohibition of asbestos fibre due to its hazardous effect on human health. However, the increasing worldwide shortage of wood resources has brought about the need to produce composite products from non-wood plant materials such as recycled paper, [Sudin et al, 2006].

Research findings on the development of composite plates made of cement and wastepaper fiber have reported waste paper fibre as suitable reinforcement for fibre cement composite and thin cement sheet. According to Coutts, [2005] the use of different kinds natural fibers from plants and cellulose fibers obtained from wastepaper, in cement mortar or concrete for reinforcement can effectively improve flexural behavior, ductility, toughness, and shrinkage characteristics of the cement composite product. In an experiment that investigates the suitability of paper pulp as complete or partial replacement of asbestos in cement sheet, Coutts, [2005] reported that brown paper (kraft) was identified as the best pulp source that produce greatest strength in composite material compared to fibre from bagasse, ground wood, wheat straw and cement bags. A similar report by Owoyemi and Ogunrinde [2013], also state that boards made from kraft paper displayed higher strength than those made from recycled newsprint papers.

A recent investigation on manufacturing and mechanical properties of recycled paper panel, report that, by using white Portland cement and recycled waste paper in the ratio 1:3 by weight with 60% water content, a recipanel with 4MPa average flexural strength,1.08W(m.k) thermal conductivity, that satisfy the NTC 4373 flexural requirement for class B panel was produced, capillary absorption coefficient of 0.8 ( $kg/m^2$ min1/2), displayed by the panel, indicate the influence of hygroscopic nature of waste paper fibre [Canola et al, 2012].

The parameters that affect the properties of composite panel made from waste paper are; preparation of the paper fibers e.g immersing time of paper into water, the form of paper or natural fibre used,( whether discrete or continuous) Sujivorakul et al [2006]. Though, in a study of wastepaper fibers, wire mesh, Portland cement to paper ratio, shape, size, and layers of wire mesh as parameters, It was observed that, the layers and shape of wire mesh used as reinforcement, significantly influenced the flexural behavior and shrinkage of the composite plate containing waste paper [Sujivorakul et al, 2012].

The use of admixture in conjunction with waste paper fibre to influence the properties of fibre cement board made from waste paper have also been investigated. In an investigation of the fire retardancy of lightweight building panel made from waste paper, Bastal et al [2002] reported that, the treatment of newsprint waste paper with 6% sodium silicate improved the fire retardancy and the compressive strength f the panel. This treatment also reduces the bulk density by 28.6% compared to gypsum panel and lowered the water absorption. In a study of the reinforcing effect of recycled newsprint paper (RNP) in cement boards, Ashoria et al [2011] reported that, at a target density of 0.7kg/m3,the addition of 5% CaCl2 affected positively both the mechanical and physical properties (e.g rupture elastic modulus) of the board at 10% optimum waste paper content.

The long-term durability of wastepaper fiber-cement composites subjected to repeated cycles of wetting, drying, and carbonation, Carbonation was considered a key element in the natural aging of cellulose fiber cement composites Soroushian et al [1994].They suggested reducing the calcium hydroxide content and improving the water-tightness and the structure of interface zones. The authors observed fiber pullout as the dominant mode of failure of the unaged composites, while fiber rupture was the dominant failure mode for the aged composites.

## 4 DISCUSSIONS

Considering the significant insight into the behavior and properties of building material containing waste paper provided by the investigations discussed in this review, the use of waste paper in making civil engineering construction materials and other engineering products seems to be a viable option for their disposal, provided that the less adequate properties are improved upon. In comparison to their disposal in landfill, which eventually leads to release of methane into the ground, the primary advantages of using waste paper especially in building materials are the low density, low cost, stiffness, high filling levels possible, energy conservation, desirable strength to weight ratio and high availability resulting from increasing consumption (fig 1) throughout the world.

The main drawback of using waste paper in concrete is the high moisture absorption of the paper fibers and composites produced, which sometimes leads to reduced mechanical properties. The reason for this, could be connected to the hygroscopic nature of paper fibre, which makes it to absorb more moisture than the amount required for cement hydration, thereby reducing the strength properties. The low density board produce from waste paper also suffers from lack of dimensional stability for exterior application.

Extensive research, however, shows that using chemical admixtures, such as sodium silicate [Bastal et al,2002], calcium chloride) [Ashori et al, 2011] in adequate proportion can lead to a wide range of waste paper (fiber) reinforced cement composites desirable properties in terms of water absorption, fire retardancy and modulus of rupture. In addition, to offset the moisture absorption behavior, literatures suggested exposure of the

lignocellulosic fibre (of which paper is one) to severe alkaline, acidic and strong sulphate solutions, impregnation of the cell wall with water soluble polymer and surface coating with PVA and using pozzolanic materials or certain cement replacement materials to improve the composite durability [Karade 2010]

Finally, despite the associated disadvantages, the reviewed studies, showed that the building materials made from waste paper possess desirable properties for several non-structural applications like partition, sound absorption, thermal insulation and low cost housing.

## 5 CONCLUSIONS - RECOMMENDATIONS

The reviewed studies show that it is indeed possible to utilize waste paper as constituent of building materials. Literatures have shown the possibilities of its use for the production of low cost housing and production for commercial purposes. It uses bring about significant improvement in the thermal insulation sound absorption of building material which directly or indirectly will amount to conservation of energy that is required for heating or cooling as the case may be. Depending on the application, the use of waste paper in the adequate proportion with other materials will result in suitable physical and mechanical properties. However, more research is needed to improve on the high moisture absorption and thickness swelling of building materials containing waste paper. Also, in order to totally achieve green building material, and to address the contradiction that exist between the hygroscopic property of paper fibre and the moderate moisture required for cement hydration, investigation should be conducted to find out the possibility of using waste paper in concrete without the use of cement.

Therefore, an investigation to produce an environmentally friendly, non-load bearing, lightweight building block from recycled waste paper, without the use of cement and with properties suitable for use as walling unit is being proposed. Laboratory experimentation and modeling are the intended research tools to be use to address the aforementioned research gaps. Aside the plan of the proposed study to attempt to reduce the moisture absorption of the proposed building block, the idea of its intended use for non-load bearing application which is expected to limit its use to internal and partition walls which will be covered with plastering, will reduce its exposure to moisture and this is also expected to reduce the dead weight of the structures, especially the multi storey building structures. Also, the success of this investigation is expected to promote environmental sustainability in the sense that, it could result into reduction in; the consumption of natural resources, environmental pollution, energy usage, construction cost, utilization of Portland cement and conservation of valuable land spaces.

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