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Recycling of waste papers: yield and quality of the ash-derived materials

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HIGHLIGHTS

- Selected types of waste papers were incinerated under the same conditions.
- The ashes derived from the incineration of waste papers were quantified.
- The flowability of the derived ashes was characterized.
- Although non-pozzolanic, the ashes showed chemical similarities with cement.

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ABSTRACT

This research was designed to assess the yield and quality of ash prepared from different types of waste papers. Waste newspapers, writing papers, and cartons were selected for combustion to obtain the ashes and coded as WNPA, WWPA, and WCPA, respectively. The waste papers were incinerated simultaneously in separate but identical incinerators at 850 ℃. An experiment on the yield of the ashes was performed on two days before the ashes obtained were mixed based on the type of waste papers from which they were derived. The results showed that irrespective of the day and time, the WCPA was the most yielded (14.1%), followed by the WWPA (12.3%), and then the WNPA (11.9%). Also, it was found that all the ashes possessed flow properties acceptable for engineering applications. However, the WCPA would ensure the best performance if applied, especially as a partial replacement material for cement. While the WWPA was found to be richer than the WNPA, the WCPA was the richest in terms of the proportions of key oxides for strength development. In general, the percentages of various chemical components of each ash complied with the standard specifications for cement except in the case of losses on ignition of the WNPA and WWPA, which were about 0.53% and 0.02%, respectively, beyond the maximum stipulated value.

1. Introduction

On a daily basis, people engage themselves in various production and consumption activities to derive satisfaction. Consequently, waste is inevitably generated, though the amounts and kinds may vary. Waste generation is, therefore, an intrinsic part of human existence, and its rate is a function of growth in urbanization [1]. In less-developed and developing countries, solid waste management systems are either limited or very ineffective thereby warranting waste disposal by open burning, landfilling, and indiscriminate dumping [2]. These practices have negative impacts on the environment and public health.

For this reason, researchers have proposed the adoption of strategies like reduction of production/consumption, reusing, and recycling of waste items to address the situation. These three measures form what could be termed the 3Rs Principle. They

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are harmless and easy for every responsible citizen to follow in order to ensure sustainable waste management. However, the case of waste papers (and paper products) remains a serious matter of concern. This is because it is recycling only (which means one-third or simply, 33.33% of the proposed measures) that is found to be effective in this regard. In contrast, other measures are either inapplicable or unimplementable. Papers are used daily for a number of diverse applications such as drawing, packaging (cartons), writing, photocopying, printing (newspapers and books), and so on [3].

Though it seems making a transition to digital systems can greatly cut back on paper consumption, such an attempt has many unbearable disadvantages. Its demerits include the high cost of installation and software maintenance, human inaccuracy, legal and compliance issues, uneasiness in digitalizing existing documents, security risks and viruses, etc. As a matter of fact, huge amounts of paper are still utilized in the dominant countries like North America, Europe, and Asia, and low producers and consumers like African countries [4]. All these indicate that paper is one of the necessities of civilization, and so there can be no halt in its production [3]. On a global scale, 300 million papers are produced annually [5], and the average consumption is estimated to be around 55 kg per person [4]. As of 2017, China was the leading 10 countries that produced papers, followed by the United States and Japan, with production capacity of 99,300,000 tons, 75,083,000 tons, and 26,627,000 tons, respectively [6]. Due to the rapid increase in population, meeting the increasing demand for paper culminates in more amounts of waste paper. Adeniran et al. [7] estimated daily waste paper generation to be 4.83 tons. Through recycling, these wastes can be converted into new materials that have great usefulness.

One such material is waste paper pulp/paste. For instance, waste newspaper paste can be utilized with rattan particles [8], coconut husks [9], cement, and gum [10] to develop high-performance thermal insulation panels for structural applications. Bochare et al. [11] mixed waste newspaper pulp with varied proportions of standard sand and cement to produce mortar suitable for brickwork. Composite boards fabricated by combining waste carton paste with tiger nut fiber [12], Musanga cecropioides heartwood [2], melon seed husks, and groundnut shell [13] are promising alternatives to conventional ceilings and walling panels for building applications. Ash is another form of useful material derived from the recycling of waste papers. Recently, it has been reported that waste paper ash (WPA) can be used to modify the plaster of Paris (POP) ceiling for improved performance [14]. Also, the utilization of WPA as a partial cement replacement material can improve the compressive strength of masonry materials such as concretes [15–18] and concrete blocks [19]. WPA is an effective stabilizer of clay soil for either road construction [20] or building design [3]. In the production of geo-polymer concrete, WPA is a suitable substitution for fly ash [21]. This research aims to assess the yield and quality of WPA prepared from different types of waste papers. This paper will be the first to report on such findings. Specifically, the focus will be on cartons, newspapers, and writing papers which have been discarded as waste items. These paper types are selected due to their distinctiveness in appearance and weight. It has been observed from the studies reported on waste paper recycling that the lignocellulosic constituents (cellulose, hemicelluloses, and lignin) remain in the obtained pulps/pastes. However, their proportions might vary due to the types of waste papers utilized. Also, it has been noticed that WPA is a new product entirely characterized by oxides, and any technique employed for its preparation usually changes the original material (waste paper) structure. Additionally, the oxide proportions of ash derived from the waste of any paper type depend on the incineration temperature adopted.

However, there is no information on the possible effects of waste paper types on WPA, and this situation gives room for speculations, which, of course, are unhealthy for the scientific community. From a techno-scientific point of view, knowledge of the investigations proposed for this research would ensure proper comparison of a set of inherent characteristics of WPA with the requirements for a particular application. In turn, the awareness gained would serve as a useful guide on recycling waste papers for the achievement of a set goal involving the utilization of WPA.

2. Experimentation

2.1 Materials

In this research, newspapers, writing papers, and cartons discarded as waste items were used. These waste items were picked from various dumpsites, marketplaces, and educational institutions within Uyo Local Government Area, Akwa Ibom State, Nigeria. All accompanying impurities were removed from the papers. The waste papers were dried under direct, intense sunlight for several days and then sorted according to the types of papers gathered for the study.

2.2 Preparation of ash from the waste papers

Burning of the waste papers to obtain ash was carried out over two days. On the first day, a reasonable quantity of each type of waste paper was weighed and noted. The different types of waste papers were shredded and then burnt simultaneously but in separate incinerators at a temperature of 850 °C to derive ash. Such high temperature was chosen to ensure clear distinctions in the appearances of the ashes. Three schedules were implemented for each of the waste paper types. At the end of every schedule, the ash produced was allowed to cool completely. Similar procedural steps were repeated on the second day to incinerate the different waste papers. On each day, the ashes were put in separate air-tight containers and labeled according to their incineration schedules. Figure 1 shows the appearance of the ash obtained from each waste paper type, while the steps followed for the preparation of the ashes are summarized in Figure 2.

Figure 1: Appearances of the ashes obtained

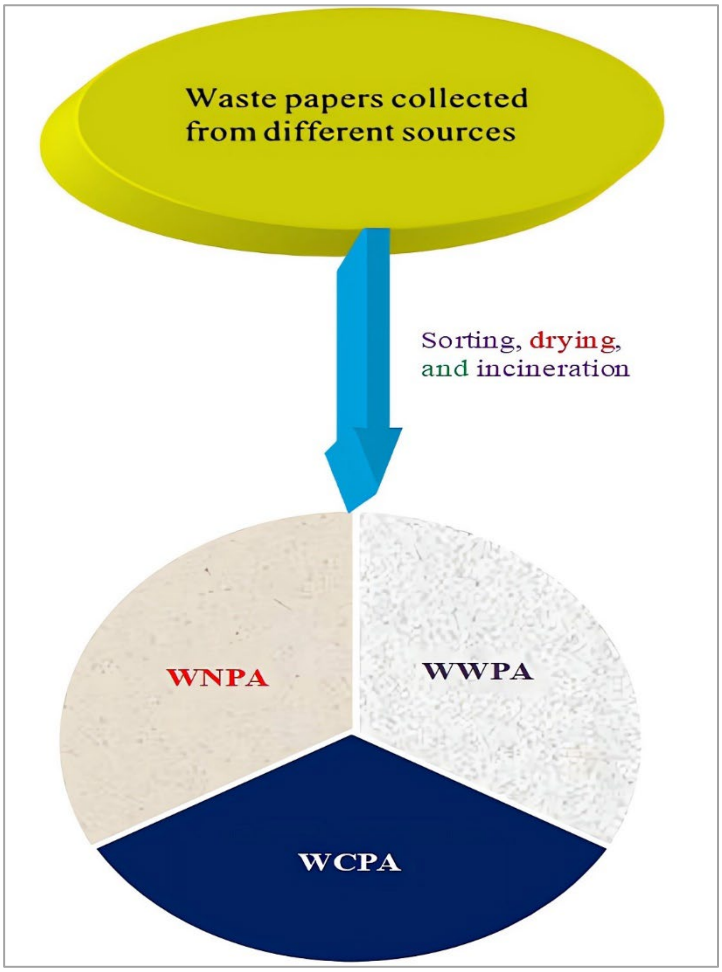

Figure 2: Process flow diagram for the ash's preparation

2.3 Determination of yield and quality of the ashes

The yield of each ash per day was calculated as the ratio of ash mass to the mass of the papers incinerated to obtain the ash. This, mathematically, is expressed in Equation 1:

$$Y_a = \left(\frac{M_A}{M_p}\right) 100\ \% \quad (1)$$

where Y_a = ash yield, M_A= total mass of the ash formed and M_p = total mass of the waste

Next, the ashes obtained on both days were mixed according to the type of waste papers from which they were prepared. They were also coded for ease of identification. The quality of each ash was assessed in terms of flowability and chemical composition. For characterization to determine flowability, two indices were considered, one of which was the Hausner ratio. In assessing the Hausner ratio, 100 g of ash was poured into a 250 cm^3 measuring cylinder that fitted into a jolting volumeter.

This device allowed measurement of the initial (bulk or untapped) volume and the final (tapped) volume after mechanically tapping the cylinder using a constant velocity-rotating cam until there was no change in the volume of the ash. The bulk density and tapped density of the ash were computed. Hausner ratio, H_r was calculated from the two densities [22] based on Equation 2:

$$H_r = \left(\frac{d}{D}\right) \tag{2}$$

where,d = tapped density, and D = bulk density

Another index used for the flowability evaluation was the static angle of repose. This was determined using a fixed funnel method with slight modifications as described elsewhere [3]. A plastic funnel was fixed such that its downward opening was at a height of 10 cm from a selected base with known roughness. After that, the ash was carefully poured from the funnel, ensuring that it formed a heap on the base. While a conical shape of the ash heap was forming, the radius (half of diameter) and height of the heap were measured at irregular intervals until seven pairs of values of such parameters were obtained. Using the obtained values, a graph of the height against radius was plotted. The slope of this graph permitted the determination of the static angle of repose based on the inverse tangent rule, as expressed in Equation 3:

$$\emptyset = \tan^{-1}(S) \tag{3}$$

where, $\emptyset$ = static angle of repose, and S= slope of the graph

Using an X-ray fluorescence (XRF) analyzer by the name Spectro X-lab 2000, the ashes were analyzed for chemical composition [23]. This XRF machine uses polarized energy dispersion. About 4 g of the ash, in each case, was mixed with wax and then milled until a homogeneous mixture was obtained. The mixture was converted into a pellet before it was placed under the instrument for determination of the oxide contents and their proportions. The loss on ignition of the ashes was determined as the decrease in mass during firing [24].

Each parameter was determined in triplicate and the values obtained were averaged and tabulated with their corresponding standard error.

3. Results and discussion

3.1 Yield of the ashes

Table 1 shows the percentage of ash derived from the incineration of each type of waste paper. Waste cartons render the highest ash yield, while waste newspapers give the least ash yield. This trend is unchanged for the two days. The difference in the mean yield for the two days is 0.01%, 0.01%, and 0.03% for the WNPA, WWPA, and WCPA, respectively. These differences are insignificant, thus implying that the ash yield depends on the type of waste papers incinerated and, by extension, the quality of fiber used in making the papers. For both days, the respective yields could be approximated to 11.9%, 12.3%, and 14.1% for the WNPA, WWPA, and WCPA. Comparatively, the least yield, in this case, is greater than 6 – 10% reported for ash obtained by burning wood [25]. However, Siddique [26] posited that the conditions of combustion affect the composition and amount of the residue ash with higher temperatures reducing the ash yield.

Table 1: Yield of the ashes derived from the waste papers

Waste paper type	Code of the ash derived	Day	Yield (%)			
			1	2	3	Mean ± Std. error
Newspaper	WNPA	1	11.86	11.85	11.88	11.86 ± 0.01
		2	11.87	11.89	11.86	11.87 ± 0.01
Writing paper	WWPA	1	12.33	12.31	12.34	12.33 ± 0.01
		2	12.34	12.32	12.31	12.32 ± 0.01
Carton	WCPA	1	14.10	14.12	14.09	14.10 ± 0.01
		2	14.14	14.11	14.13	14.13 ± 0.01

3.2 Quality of the ashes

From Table 2, it is noticed that the WNPA has the highest Hausner ratio, followed by the WWPA and then the WCPA. A Hausner ratio greater than 1.34 indicates a poor flow property of powder or granular material [27]. As such, it can be remarked that these ashes (WNPA, WWPA, and WCPA) possess the flow characteristic that is acceptable for engineering applications. It can also be deduced from the ratios that, if utilized under the same conditions, the WCPA would be about 4.04% and 1.87% better than the WNPA and WWPA, respectively, in their flow tendencies. The angles of repose of the ashes lie between 36° and 40°. In the scale of flowability, this range is interpreted to mean a fair flow [28]. Thus, the WNPA, WWPA, and WCPA have suitable flow behavior for the content uniformity required in manufacturing processes. This supports the finding earlier adduced from the Hausner ratios on the acceptability of the ashes. In the context of particle sizes, the angles of repose also give very useful information for correct prediction. For instance, it is known that the angle of repose relates inversely to the particle sizes of a material [29–31]. As the ashes are not sieved, such correlation rightly provides credence to remark that some particles of the WNPA are finer compared to those of the WWPA, whereas certain particles of the WCPA are the largest.

Table 2: Flowability of the ashes

Code of the derived ash sample	Hausner ratio	Static angle of repose±, Ø (°)
WNPA	1.311 ± 0.01	39.95 ± 0.01
WWPA	1.282 ± 0.01	39.58 ± 0.01
WCPA	1.258 ± 0.01	38.96 ± 0.02

Table 3 shows the chemical components and their proportions as obtained for each ash sample in this research. The rankings in the proportions of the oxides for all the ashes are similar to the case with cement. However, the percentages differ, and they even vary among the ashes. The key chemical constituents (SiO_2, Al_2O_3, and Fe_2O_3) in the chemistry of cement are also present in the ashes, but the summation of their proportions is 33.42%, 34.18%, and 34.58% for the WNPA, WWPA, and WCPA respectively. Each of these totals is less than 70%, which is the minimum value required for a pozzolan according to the ASTM C618 specification [32]. Therefore, the ashes cannot serve as a substitute for cement, but they can be used to replace cement partially.

Table 3: Chemical composition of the ashes

Chemical Constituents		Proportion (wt.%) per ash		
Name	Formula	WNPA	WWPA	WCPA
Silicon dioxide (Silica)	SiO_2	29.03 ± 0.01	29.78 ± 0.02	30.04 ± 0.01
Aluminum trioxide (Alumina)	Al_2O_3	2.63 ± 0.01	2.66 ± 0.01	2.78 ± 0.01
Ferric oxide	Fe_2O_3	1.76 ± 0.01	1.78 ± 0.02	1.81 ± 0.01
Calcium oxide (Lime)	CaO	50.82 ± 0.02	50.94 ± 0.01	53.49 ± 0.01
Magnesium oxide (Magnesia)	MgO	0.86 ± 0.01	0.86 ± 0.02	0.86 ± 0.01
Sulphate	SO_3	0.53 ± 0.01	0.54 ± 0.01	0.57 ± 0.02
Loss on ignition	LOI	12.53 ± 0.02	12.02 ± 0.02	11.42 ± 0.01

The chemical activity of cement depends on lime, silica, and alumina for hydration and strength development. Observably, each of the ashes has such oxides as principal constituents. Among the ashes, the WCPA has the highest proportions whereas the WNPA contains the lowest percentages of the principal constituents. This indicates that the WCPA would produce the most satisfactory results in terms of strength enhancement. The ferric oxide influences the color impartation, and so the inequality in its proportion could be responsible for the differences in the textures of the WNPA, WWPA, and WCPA, as evident in Figure1. By existing in equal proportion (about 0.86%), magnesia would contribute the same impact of strength in the ashes. A similar scenario is possible in terms of the soundness of the WNPA and WWPA, as their SO_3 content is almost the same.

LOI correlates with the extent of the carbonaceous component of a material. According to the standard specification for good quality cement [33], the LOI must be at most 12% in addition to the oxide contents such as SiO_2 (17 – 26%), Al_2O_3 (3 – 8%), Fe_2O_3 (0.5 – 6%), CaO (60 – 67%), MgO (1–2%), and SO_3 (2% Max). Apart from the LOI of each of the WNPA and WWPA, which, of course, is not threatening, the results reveal that the proportions of the chemical components of the ashes reflect absolute compliance with the recommended data. In view of the fact that the WNPA, WWPA, and WCPA can only be a part of cement, they have some potential applications. For instance, the ashes can be applied as calcium-based stabilizers for clay soils. They can also be utilized to partially replace cement in the preparation of masonry materials (such as concrete blocks, concretes, cement mortar, and pastes).

4. Conclusion

The results of this research have shown that ashes derived from different types of waste papers such as newspapers (WNPA), writing papers (WWPA), and cartons (WCPA) differ in texture in addition to yield and quality. The waste cartons gave the highest ash yield (about 14.1%), while the waste newspapers yielded the least amount (11.9%) of ash when incinerated at 850 °C, irrespective of the day and time. Among the ashes, the WCPA exhibited the best quality, followed by the WWPA and then the WNPA. All the ashes exhibited acceptable flow properties for engineering applications. Rankings of the principal oxides of each ash were similar to the case involving cement. Though none of them met the mandatory requirement in order to be declared as a pozzolanic material, they could produce satisfactory results if utilized to stabilize clay soil or partially replace cement for strength improvement. The variations in the yields and quality tendencies of the ashes were due to the differences in waste paper types.

Author contributions

Conceptualization, U. Robert. and S. Etuk; data curation, R. Adewumi.; formal analysis, S. Etuk and O. Agbasi.; investigation, U. Robert.; methodology, U. Robert.; resources, P. Ambrose and R. Adewumi.; software, O. Agbasi.; supervision, U. Robert and S. Etuk.; validation, U. Robert., S. Etuk and O. Agbasi.; visualization, O. Agbasi and P. Ambrose.; writing—original draft preparation, U. Robert and P. Ambrose.; writing—review and editing, U. Robert.; project administration, S. Etuk. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

On request, the data that support the findings of this research are available from the corresponding author.

Conflict of interest

The authors declare that there is no known conflict of interest.

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