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Study of the use of Agricultural Waste as a Supplementary Cementitious Material

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ABSTRACT

The use of supplementary cementitious materials has attracted attention in recent years both for their potential applications and beneficial cost in the construction industry. Supplementary cementitious materials can be of mineral or plant origin. Agricultural waste (agro-waste) is under focus especially in low and middle income countries as a source for fuel and also as a construction material. Such use comes either as a stand-alone material or as a cement replacement in concrete materials. The wider use of such materials in construction is considered as potential sustainable alternatives to Portland cements. This paper discusses the prospective use of certain agro-wastes as a partial replacement for cement in concrete mixes and stabilised earth bricks. The materials considered in this study have included: corncob, sorghum husk, sorghum stalk, peanut husk and sesame stalk ashes. Selected agro-wastes have been incinerated under controlled temperature conditions at 500°C and 700°C. The resultant ashes have been characterised using Thermal Gravimetric Analysis (TGA), Energy Dispersive X-Ray Analyser (EDX) and X-Ray Diffraction Analysis (XRD) methods. Silica, used as a pozzolanic indicator, was found to be present in varying quantities. More tests to verify suitability and determine the feasibility of these agro-wastes are currently underway. The paper presents the preliminary results and outcomes, and describes proposed methodology for future tests.

1. INTRODUCTION

Producing sustainable materials has been a concern ever since the construction industry has recognised itself to be one of the largest contributors of greenhouse gas (GHG) emissions. The construction sector is also one of the largest consumers of non-renewable raw materials, and a top contributor to energy consumption, GHG emissions, and waste flow worldwide (IEA, 2019). In developing countries, such as Sudan, the challenge to produce sustainable construction materials is exacerbated by the cost of materials. In the search for cheaper alternatives agricultural wastes, such as rice husk and bagasse, have been researched to assess their suitability as a cement component in concrete (Habeeb and Mahmud, 2010; Chao-Lung, Anh-Tuan and Chun-Tsun, 2011; Ahsan and Hossain, 2018; Xu *et al.*, 2018) or brick production (Sutas, Mana and Pitak, 2012; Shakir *et al.*, 2013). These studies proved the potential use of agricultural waste as a cementitious material due to their pozzolanic nature. For a material to be categorized as pozzolanic it should react with hydrated lime in the presence of water to produce cement hydrates. this reaction is mainly caused by amorphous silica, which does not react with other compounds until its network is broken by the alkaline environment of the cement paste (Papatzani, Badogiannis and Paine, 2018). Typically pozzolanic materials should have a combined content of amorphous silica (SiO_2), iron oxide and aluminium oxide greater than 70% of total mass (Aprianti *et al.*, 2015).

Agricultural materials are mainly constructed of cellulose, hemicellulose and lignin in different percentages, with the cellulose and hemicellulose occupying up to 80% of the composite (Mlonka-Mędrala *et al.*, 2019). Burning the wastes of agricultural crops results in decomposition of these three components, and the elimination of carbon. This has potential to , produce a waste product rich in amorphous silica.

Research has shown that different burning and cooling temperatures affect the quality and composition of the ash. For example, the amount and phase of silica, as well as fineness, particle size and surface area are affected (Zain *et al.*, 2011). These properties in turn affect the reactivity of the resultant ash, and hence how quickly a concrete mix will gain strength, as well as affecting the other green concrete properties (Givi *et al.*, 2010; Cordeiro and Kurtis, 2017).

For the purpose of this study, the waste of the four most commonly cultivated plants in Sudan (sorghum, corn, peanut and sesame) were selected to study their pozzolanic behaviour and potential to use them as supplements to cement.

2. Materials

Materials used in this study were sesame husk, sorghum husk and stalk, peanut husk and corncob husk ashes. Corncobs were bought from the local markets in Bath, UK; all of the other materials were imported from Sudan from relevant production sites in Algadarif, Portsudan, and Khartoum.

2.1 Material Treatment

Initially agro-waste materials were washed thoroughly to remove any residual contaminants from harvest or storage. They were then dried in an oven at 105°C and weighed regularly until constant mass was reached, which indicated all water had evaporated. The materials were then ground to fine powder using a domestic coffee grinder, and finally screened through a 100mm sieve.

3. Results and Discussions

3.1 X-ray Diffraction (XRD)

XRD test was carried out on the specimens, the results are as depicted in Figure 1, the samples under study were found to be amorphous. The peaks are not well defined, with the X-rays diffracted in different directions and at different intensities. This is a typical pattern expected for an amorphous material with no distinct pattern of atoms (Cullity, 1978). This result is encouraging to believe that silica existing in the material is amorphous among other components.

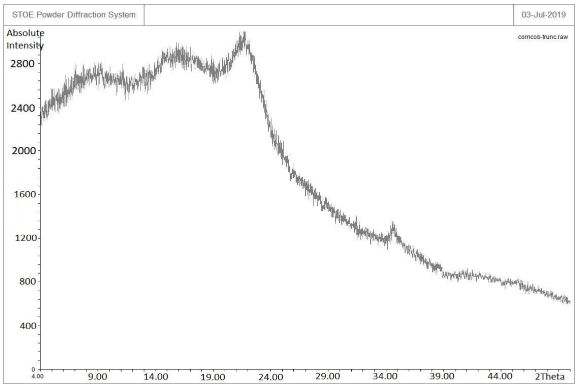


Figure 1: X-Ray Diffraction pattern of a corncob sample

3.2 Thermogravimetric Analysis (TGA)

The TGA test was conducted for the five specimens. For each material, the test was carried out twice on a 25-35mg sample. For the first round, the materials were burnt until 500°C, while burning for the second round continued up to 700°C. Test was carried out to determine the expected mass loss, chemical composition and the thermal decomposition of the waste. Specimens were burnt in air at a heating rate of 10°/min. To preserve the initial amorphous state of the samples, the cooling rate was gradual.

From the TGA, and the derivative thermogravimetric (DTG) curves, shown in Figure 2a, it can be seen that the results were consistent with the literature. The bound water evaporation slightly affected the mass loss curve at the start until a temperature of 160°C. The pyrolysis of the samples was expected to go through four stages, starting with the water evaporation then continuing to decomposition in the order of hemicellulose, cellulose and lignin (Yang *et al.*, 2007). Decomposition of the hemicellulose is concurrent with the major loss in mass (~0.80wt.%/°C) at 240°-320°C. The next small convex in the TGA curves between 310℃ and 450°C is coinciding with the decomposition of cellulose (Yang *et al.*, 2007).

The mass loss can be seen from the TGA curves presented in Figure 2, with the highest loss to reach 97-98% of mass in peanut husk and corncob. Sorghum stalk and sesame stalk showed the median loss of 93-96% of mass. The sorghum husk showed the least mass loss (89-90% of mass). From the curves it is obvious that the difference in mass is negligible between 500°C and 700°C, also no significant change on the curve occurs, which means no significant decomposition is taking place in samples after 500°C.

Differential Scanning Calorimetry (DSC) works on the principle of measuring the difference in temperature between a reference crucible and the sample (Lawrence, 2006). As can be observed from Figure 2 (b, d, f, h and J) the decomposition of two of the material components (hemicellulose and lignin) coincided with the DTG curves at 240-320ºC, and it can be described as an exothermic reaction. While the decomposition of the cellulose, resulted in a small convex in the DSC curve at 310-450ºC, and is supposed to be an endothermic reaction (Yang *et al.*, 2007) it shows as exothermic. This could be attributed to the fact that the material has all three components and the results are overlapping, the endothermic (negative) curve of hemicellulose might be the reason the next exothermic (positive) convex is considerably small.

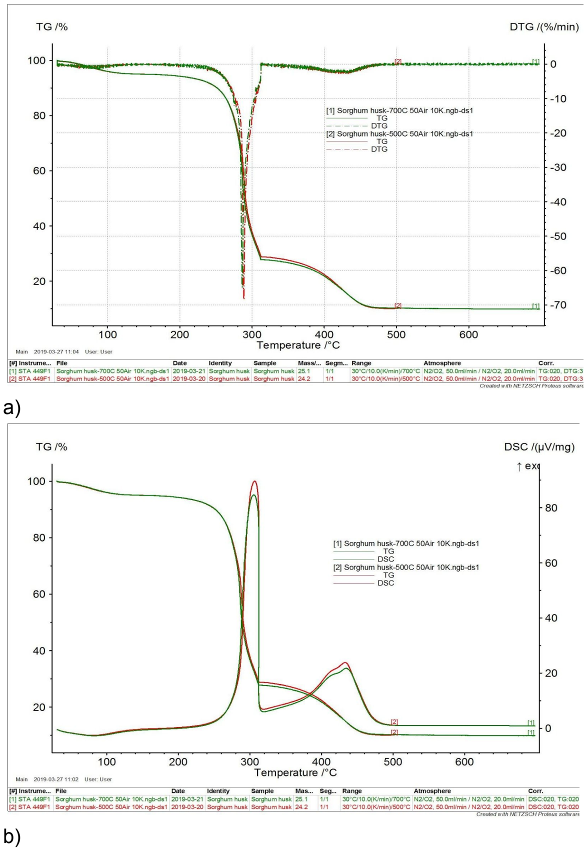


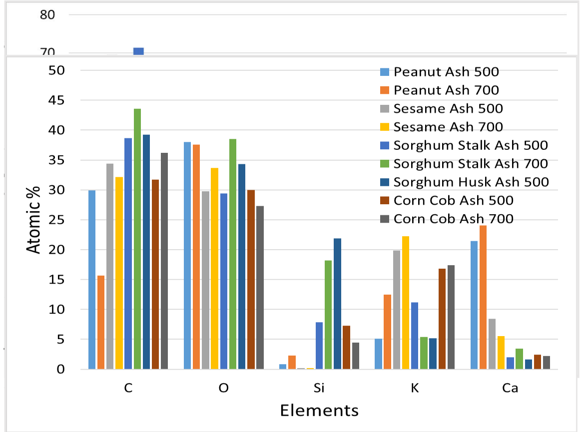
Figure 2: TGA-DTG-DSC results: a) Sorghum husk TGA-DTG b) Sorghum husk TGA-DSC

3.3 Energy Dispersive X-Ray Spectroscopy (EDX)

Samples were prepared on a carbon tape and tested using Scanning Electron Microscope. The equipment used was a Jeol 6480LV SEM, with an Oxford instrument X-ACT 10mm^2 Si drift detector. Both raw and burnt materials were tested; results are as presented in Figures 3a and b respectively. Specimens were compared with rice husk which literature showed as having good potential for partially replacing cement. Other elements like Na, Mg, Al, P, S and Cl were present on the specimens, but they have been omitted from presentation due to their very low concentration.

From Figure 3 it can be seen that burning decreased the amount of carbon present. Even so, a large amount was present (around 40%); this could be attributed to the fact that the specimens were tested on a carbon tape. The burnt materials possessed relatively high amounts of Si, K and Ca. The highest amount of silicon (~20%) was present in the sorghum husk, followed by the sorghum husk and corn cob in 500°C (~7%). Peanut husk showed very small amounts of silicon, whilst sesame hardly presented any silicon at all. It is noted that EDX shows materials not compounds. As such, this present silicon does not confirm conclusively the existence of silicon dioxide.

The process of peeling sorghum husk from the stalk could be inconvenient for field application. Hence, future tests are to be conducted on the sorghum stalk and husk as a one entity.



tested as an unburnt material in brick production or insulating materials.

From the tests it was found that there was no need to burn materials beyond 500°C; this will be the target temperature in future work. With the help and support of the BRE Chair of Fire Safety Engineering located within the University of Edinburgh, the materials are to be prepared and burnt. Future tests are to be conducted in collaboration with the University of Edinburgh, School of Engineering.

Particle size, surface area and fineness are to be tested. X-ray fluorescence tests are going to be applied to evaluate the presence of silicon dioxide and other compounds in the materials.

Samples are going to be prepared in order to test the pozzolanicity. Targeted tests include: calorimetry, Portlandite consumption and bound water. Afterwards samples with lime and cement are to be prepared and tested for physical including compressive and tensile strengths.

Development of a computer model, using GEM-Selektor v3.4, a thermodynamic modelling software, is planned. After preparing a model, and verifying it with the tested samples, other properties of the cement paste and concrete are going to be studied, such as heat of hydration and reactivity. Sensitivity analysis is going to be applied using the model regarding the change in the materials percentages in the paste.

Future work also includes a Life Cycle Assessment (LCA), where the environmental impact of using these wastes in concrete production is going to be assessed with the aid of OpenLCA software. For this step, product category rules are going to be collected and studied for the involved products, and data quality assessment should be conducted as the LCA goes on. Sensitivity analysis is going to be performed to see how the change in material percentage will affect the mid-point and end-point results of the assessment. Cost benefit is also planned as the final step of this research.

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