From Ashes to Riches: Utilization of waste materials for sustainable development in Africa:

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Abstract

Sustainable construction requires a critical review of prevailing sources, practices, and techniques, of utilizing the now precious raw material resources. This paper explores the potential of utilizing natural, industrial and agricultural waste materials in energy provision and subsequent application in civil engineering for the development of infrastructure. For Africa, the greatest potential for raw materials use in construction is not only in the unexploited natural resources, and also in waste in the agricultural sector where the bulk of the industrial output lies. The paper reports on the one hand the authors' involvement in the area of sustainability using industrial waste streams in the United Kingdom, and on the other hand the passion for the transfer and adaptation of this experience for applicability in Africa. The authors have a particular interest in sustainable developed in Africa and have been brainstorming on this agenda. In Cameroon, collaboration links have been finalized with peers within the *Mission de Promotion des Materiaux Local* (MIPROMALO) - a local materials promotion authority – and the Universities of Yaoundé I and of BUEA. In Kenya, similar collaborative links exist with local Higher Education (HE) institutions as well as with environmentally conscious local industries and environmental lobby groups, particularly those in the agricultural sector. There is undoubted potential and experience in the utilization of industrial waste in the UK. The initial findings on the transfer and adaptation of this experience to Africa are positive, especially for the utilization of significant quantities of agricultural waste. In this transfer and adaptability of experience, the authors propose inclusion of a more holistic approach, so as to provide not only a route for the utilization of the agricultural waste in construction, but to go a step further and loop this endeavor so as to start with the conversion of waste to energy, before closing the loop by applying the resultant secondary waste in construction. Results show potential for immediate exploitation for, among others, the case of sugar cane sector in Kenya, and Palm oil processing in Cameroon.

Keywords: Materials, Africa, waste, construction, agriculture, sustainability, infrastructure, development, poverty.

INTRODUCTION

Sustainable construction requires a critical review of prevailing practices, techniques and sources for raw materials. As the technological or development status of a country need not be a major stabling block towards sustainable construction, the said review is much more critical for the case of Africa where there is an acute lack of affordability of the conventionally processed construction materials such as steel and Portland cement. The desire generated by the lack of these materials (steel and Portland cement) has a negative impact, leading to reduced value and perceived inappropriateness of locally available materials. Notwithstanding, focus is rapidly turning and growing towards natural and industrial wastes and by-product materials that have previously received little or no attention. For most countries in Africa, the major industrial output is predominantly in the agricultural sector. For these countries, any major breakthrough in the development of sustainable industrial construction materials cannot afford to ignore waste from the agricultural sector. At the University of Glamorgan in the United Kingdom, a team of researchers of African origin with a particular interest in sustainable developed has been brainstorming on this agenda for some time. In Cameroon, the team has joined hands with like-minded and inspired researchers at the *Mission de Promotion des Materiaux Local* (MIPROMALO) - a local materials promotion authority – based in Yaoundé. Other collaborators include researchers at Yaoundé I University and at the University of BUEA. In Kenya, initial collaboration has also been with local Higher Education (HE) institutions as well as with the environmentally conscious local industries and environmental lobby groups, particularly those in the agricultural sector. The initial focus has been in sectors that have produce large agricultural waste streams, including the palm oil industry in Cameroon, and the sugarcane industry in Kenya.

In the UK, the researcher team has experience in a wide range of industrial waste and by-product materials. The large list of these marginal materials has included colliery spoil, pulverized fuel ash ((PFA) also known as fly ash) and a range of bottom ashes from the many years of coal mining and energy generation using coal fired power stations, slag and bottom ashes from processing of metals in the UK, various ceramic wastes and marginal or expansive clays in various parts of the United Kingdom [1 – 12].

Enthused by the success in the utilization of these waste materials in the development of sustainable civil engineering materials, the research team has carried out scoping studies to establish the key waste streams in Kenya and Cameroon. The team is aware of the fact that the findings in these two African countries are likely to be typical of many other developing countries, including the economic stature, social practices, level of technology, need for basic infrastructure and also commonality in future aspirations. Thus, there are minimal differences in the level of living conditions and reliance on agriculture for subsistence and development.

Partly due to the acute shortage of cement in most African countries, coupled by the areas of expertise by the authors, research has centered on fine particulate wastes. The use fine particulate wastes in concrete as filler and/or binder by way of replacement of Portland Cement (PC) has been a common option for many researchers. This has lead to the interest in the use of agricultural waste in civil engineering construction, as after using the waste to generate power, the secondary waste thus produced is fine-particulate or agglomerated ash. With determination, persistence and combined synergies with equally committed peers of varied backgrounds and expertise, this ash can be converted from ashes to riches, turning Africa from a beggar relying on handouts from the developed countries, to a continent associated with resourcefulness and hope. For the current authors, success in the utilization of fine-particulate waste started with the UK waste stream, briefed summarized below.

2.0 UTILISATION OF FINE-PARTICULATE WASTE IN CIVIL ENGINEERING CONSTRUCTION

2.1 Experiences in the United Kingdom

The UK has a large industrial base and it is naturally fitting to expect a wide variety of fine-particulate organic and inorganic or mineral waste. The authors' experience is in the inorganic waste variety, developing cementitious systems by utilizing a variety of binary and ternary blended systems for various applications. The successful applications have ranged from stabilizing the hitherto unmanageable expansive and/or contaminated soils, manufacture of building components such as bricks, concrete, mortar, brick and blocks, all with the use of little and sometimes no Portland cement (PC) at all. It is interesting to note that in some instances as demonstrated by the various examples below, blended mixtures containing waste or by-product materials have resulted in superior performance relative to conventional cementitious systems utilizing either lime or PC, both of which consume large volumes of precious natural raw material resources and also exacerbate carbon dioxide emissions in the atmosphere.

Wastepaper Sludge Ash (WSA)

The manufacture of Portland cement (PC) contributes about 10% of the carbon dioxide emissions into the atmosphere. Therefore, the partial or total replacement of PC is critical to the achievement of sustainable development of infrastructure. Figure 1 demonstrates the results of a successful research project, involving a patented technology developed by combining an industrial waste with a by-product material for both total and partial replacement of PC. The use of Wastepaper Sludge Ash (WSA), a waste from the recycling of paper [1 – 3], combined with ground granulated blastfurnace slag (GGBS), a by-product of steel manufacture, has enabled the development of a 'green' cement that performed better in concrete block making, in terms of appearance, strength and durability, compared with the traditional Portland Cement. In this example, utilization of a waste and a by-product material has resulted in superior performance relative to the use of a classical or traditional building material. Similar approaches are possible in Africa, using whatever waste and/or by-product materials available in significant quantities. Later in the paper it will be shown that this is indeed possible using agricultural waste that is plentiful in Africa.

Ground Granulated Blastfurnace Slag (GGBS).
Stabilization of sulphate bearing clay soils using the classical method of using what may be referred to as "traditional" stabilizers such as lime (or Portland cement) has in the past shown enormous problems. These soils, upon stabilization, usually result in significant reconstruction costs often within two years of original construction [13 – 15]. Using GGBS, the authors have managed to stabilize the "troublesome" soils as shown in Figures 2 – 4 [4 – 7]. Figure 2 shows that higher compressive strength values were obtained using a combination 5% slag and 3% lime (i.e. combination 5(3)) as opposed to using lime on its own (combination 0(8)). Considering that slag is by-product material that is cheaper than lime, and which causes significant environmental concerns during its manufacture, there are enormous benefits in using a blended binder that results in the use of reduced amounts of lime. Figure 3 shows that using blended binders incorporating GGBS, it was possible to combat the massive linear expansion associated with lime-stabilized sulphate-bearing clay soils, which cause failure leading to large expenditure in reconstruction costs. Once again in this example, utilization of a by-product material has resulted in superior performance relative to classical or traditional soil stabilization. Clearly, this is not by chance but after a careful and thorough understanding of the waste or by-product materials concerned, so as to establish possible applications of the materials either on their own or in combination with either the existing conventional materials or with other waste, by-product or marginal materials. Figure 4 demonstrates that the WSA used in the concrete block example shown earlier can also be used in soil stabilization. The figure shows reduced linear expansion by stabilizing soil with WSA on its own or in combination with GGBS, relative to stabilizing the soil with lime alone as is the classical manner.

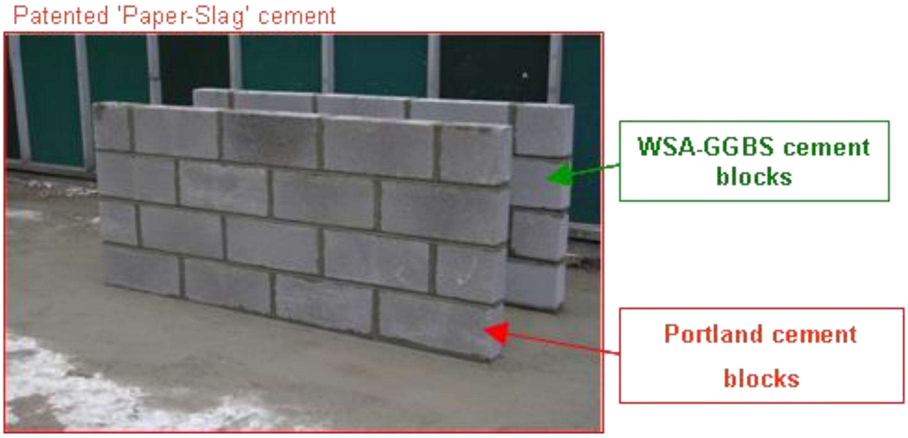

Figure 1 – Demonstration of two concrete block wall show-casing the utilization of Wastepaper Sludge Ash (WSA) in the development of "green" cement, for the manufacture of building blocks.

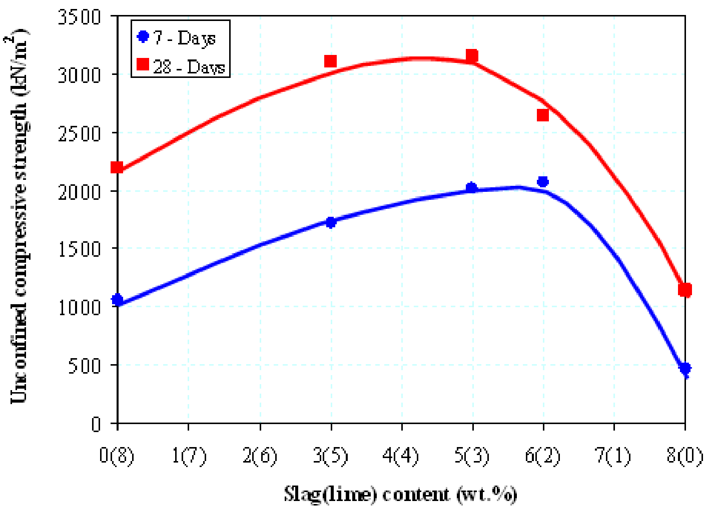

Figure 2 – Evidence of superior performance in terms of compressive strength of compacted cylinders, for mixtures of a troublesome sulphate-bearing clay soil, stabilized by sustainable blended binders containing GGBS (slag), relative to those containing the traditional lime stabilizer.

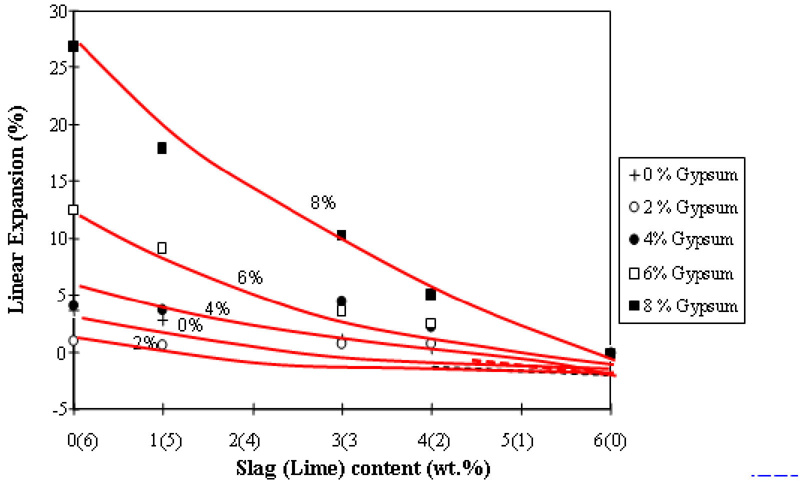

Figure 3 – Evidence of superior performance in terms of reduced linear expansion and hence swelling potential, for mixtures of a troublesome sulphate-bearing clay soil, stabilized by sustainable blended binders containing GGBS (slag), relative to those containing the traditional lime stabilizer.

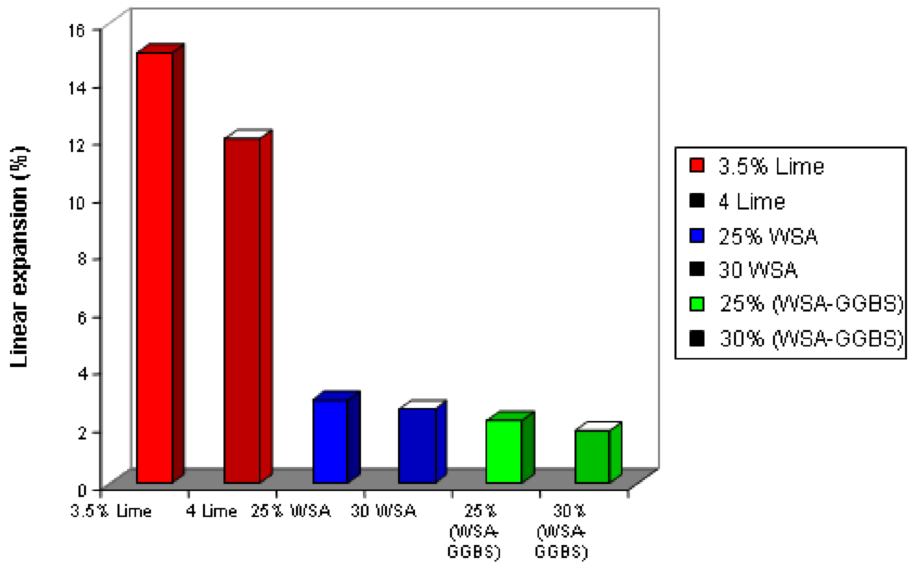

Figure 4 – Significant reduction in linear expansion by the combined use of Wastepaper Sludge Ash (WSA) and Ground Granulated Blastfurnace Slag (GGBS) in the stabilization of an expansive sulphate-bearing clay soil

The stabilization of soils with either lime, PC or WSA in combination with GGBS was so successive, that the technology was further developed for transfer from applicability in highway construction to the building industry, where much more strength and durability may sometimes be necessary [8, 9]. Figure 5 shows unfired building bricks made with combined lime and GGBS. Obviating firing and reduced use of traditional binders of lime or PC is significant breakthrough. There is no reason why such attempt cannot be made in Africa, using agricultural or other abundant waste materials.

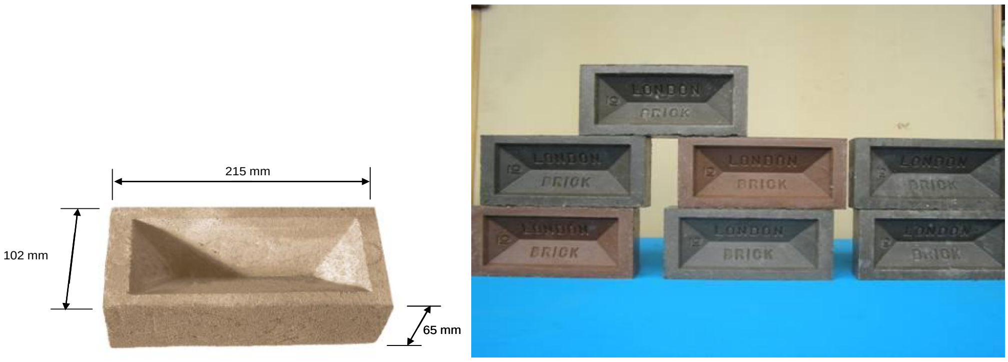

Figure 5 – Unfired building bricks made with combined lime and GGBS *(Industrial pilot-scale trials carried out at Hanson Brick Company, using their "London brick" mould.)*

Pulverized Fuel Ash (PFA)
For many years, coal has been dominant source energy in America, Europe, Asia, Australia and parts of Africa. The waste from this big industry ranges from the unusable mining debris, collectively referred to in various terms such as simply coal mining waste, colliery spoil, colliery waste, coal mine tailings, and possibly other terms, to the waste resulting from the burning of coal as a fuel. The burnt waste is predominantly the fine particulate materials collected from the flue gasses mainly by electrostatic precipitation, mainly referred to as fly ash in America and other places, or pulverized fuel ash (PFA) as in the United Kingdom and some other places in Europe and beyond. There is also the relatively coarser waste referred to as the bottom ash which, as the name suggests, is collected at the bottom of the coal burning boilers. The researcher team has experience in the use of PFA in the classical application in concrete, where the benefits include enhanced workability, reduction in the amount of Portland cement used, improved later strength, enhanced durability such as increased resistance to sulphate and chloride forms of attack, reduction in heat generated during hydration (which for mass concrete castings can cause micro-cracking), and possibly other benefits such as environmental advantages of using waste or by-product materials which would otherwise go to landfill. The team also has experience in other more specialized applications of PFA. Figure 5 for example demonstrates that by a careful balancing act of using a ternary blended binder comprising of Portland cement, metakaolin (a product from the calcinations of kaolin clay) and PFA, it is possible to make a high performance concrete that neither expands nor shrinks (autogenous shrinkage) upon prolonged curing, relative to the concrete utilizing 100% Portland cement as binder. The implications of this property of super volume stability are obvious to practitioners in the concrete industry [10].

Other research projects utilizing waste from coal are well documented [11, 12]. There is a long list of other possible beneficial uses of waste in the UK waste stream, that will not be discussed here, but the few examples demonstrated above are enough to demonstrate the scope of benefits and range of applications. The challenge therefore, is in the transfer and adaptation of this knowledge using the different waste streams in Africa.

2.2. Experiences in Africa

2.2.1 Kenya

Waste streams: Kenya has minimal mining industrial output, relying predominantly on agriculture and tourism for the realization of its infrastructural and other development. Among the non-agricultural industries or activities of potential application in civil engineering that have so far been reviewed by the authors include production of building stones by cutting stone, such as that currently taking place for the case of limestone is some parts of the Kenyan coast province (Figure 6), waste from coral limestone and from the cutting of stone from limestone and other quarrying activities, quarrying of limestone chalk (diatomite) in the Rift Valley Province and burning of red clay to produce building brick, an activity spread throughout the country.

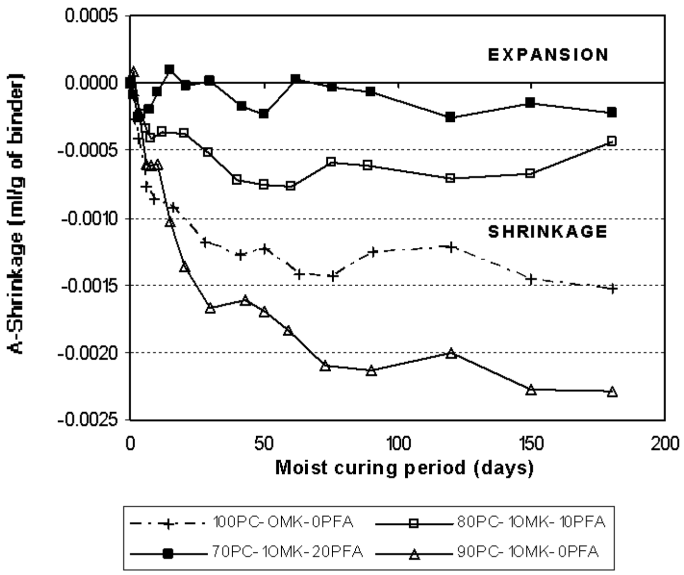

Figure 5 – Self-compensating concrete (i.e. no shrinkage and no expansion) when a combination Pulverized fuel ash (PFA) and metakaolin are used to replace Portland cement.

Figure 6 – Stone cutting for building from limestone bed rock in Kilifi, Coast Provence, Kenya.

In the agricultural sector where the current publication is rather biased towards, the industries identified so far to produce significant agricultural waste have included coffee, sisal and sugar cane growing. Other minor waste streams include nut shells from the growing of cashew nuts. The growing of cereals such as maize, wheat and barley is seen as leaving no waste, as the waste is used for animal feed. The authors have not managed to assess the potential of waste from rice growing, but it is not envisaged to be that significant to leap-frog regional economies in Kenya.

By far the biggest potential for giant steps towards rejuvenating the regional and national economy in Kenya using an agricultural activity are likely to result from the widespread use of biogas generation using livestock, followed by sugar cane growing and possibly also by coffee growing. The potential for coffee growing and biogas production in Kenya and Cameroon will be covered in a future edition of Materials Solutions, when all the data collection is at an advanced stage, therefore now concentrating on the potential in the growing of sugarcane, where the scenario is relatively clearer.

Sugar cane growing in Kenya: Sugar cane processing in Kenya is carried out by various companies, many of which are in the Western parts of Kenya - Muhoroni, Chemelil, Kibos, South Nyanza (SONY), and Mumias sugar companies), and also at the Coast province (Ramisi). Muhoroni, Chemelil and Kibos are all along one route corridor, resulting in what is fairly common in Kenya referred to as the "Sugar belt". Of these companies, the largest is Mumias, a private-government joint venture company, handling about 60% of all the sugar processed in Kenya. The authors have visited four of the sugar processing plants, Muhoroni, Mumias, Kibos and SONY, and are therefore fairly familiar with the broad issues relating sugar cane growing, processing and distribution. It is generally agreed that Mumias Sugar Company (MSC) is the best run in terms of the efficient processing of sugar as well as application of Clean Development Mechanism (CDM) technologies. MSC utilizes bagasse, a waste from the sugar processing, to generate steam for power generation. Through a series of plant improvements and expansion, they are now capable of generating about 38 MW of power, far much more power than they need for running the entire plant, so as to remain with power to not only supply their staff quarters, but also to feed back into the national power grid. Considering that to run their plant and supply to staff consumes a hefty 12MW, a power demand that would cripple most companies in Africa, this is by all means a small achievement. They therefore provide an excess of about 26 MW of power, a sizeable amount of power to supply a medium African City or region. Figure 7 shows the sugar cane delivery section at MSC. The sugarcane is automatically weighed via a multi-lane weighing bridge system that minimizes any delays in the delivery process.

Figure 7 – Reception of sugar cane from the farms at Mumias Sugar Company (MSC) in Western Province Kenya.

Figure 8 shows the sugar cane waste generated at South Nyanza (SONY) Sugar Company, where they generate only about 4MW. When the authors visited the management team at SONY who expressed their ambition and endeavor to follow the example at Mumias.

Figure 8 – Large volumes of waste from sugar cane processing at South Nyanza (SONY) Sugar Company in South Nyanza Province in Kenya.

The main handicap at SONY (and many other plants in Africa) at present is the use of old and hence inefficient boiler systems, compared the state of the art one at MSC (see Figure 9). In addition, the processing of receiving the sugar cane from the farms is not as efficient, and long queues by sugar-cane carrying tractors are common. The authors are currently working with both companies to develop mechanisms and technologies for the utilization of any waste in civil engineering construction, thus closing the loop of power generation and waste ash generation so as to has achieve a zero-waste clean development strategy

Figure 9 – State of the art processing of sugar cane and combustion of bagasse at Mumias Sugar Company (MSC), Western Province in Kenya.

Potential from the sugar industry: Using sugar cane ash from Muhoroni Sugar Company in Kenya, 50mm mortar cubes were cast where the control binder used was Portland cement. Other cubes were made with 50% of the PC replaced with ash from Muhoroni (See Figure 10). Figure 11 shows that it was possible to achieve relative compressive strength values of the order of up to 30-40% at between 7 and 14 days of curing (i.e. Strength achieved in PC-Ash concrete compared with that achieved using undiluted PC).

Figure 10 – 50mm cubes made with partial replacement of Portland cement with Sugarcane Waste Ash (SCWA)

A partial replacement of PC of 50% may be considered a very significant achievement indeed. It is not fair to expect most wastes to perform in a manner similar to PC which has undergone many years of development and improvement, at least not during the initial stages of investigation. Therefore, with a minimum compressive strength of 2 N/mm^2 in 7 days obtained using the sugarcane waste at 50% PC replacement, there is obvious scope for utilization in construction – blinding concrete, concrete block making and pipe-bedding concrete besides other uses. Lower PC replacement values and various treatments and/or additives to this and other agricultural ashes are currently being investigated using ash from various agricultural sectors in Kenya and Cameroon, with a bid to achieve higher strength values.

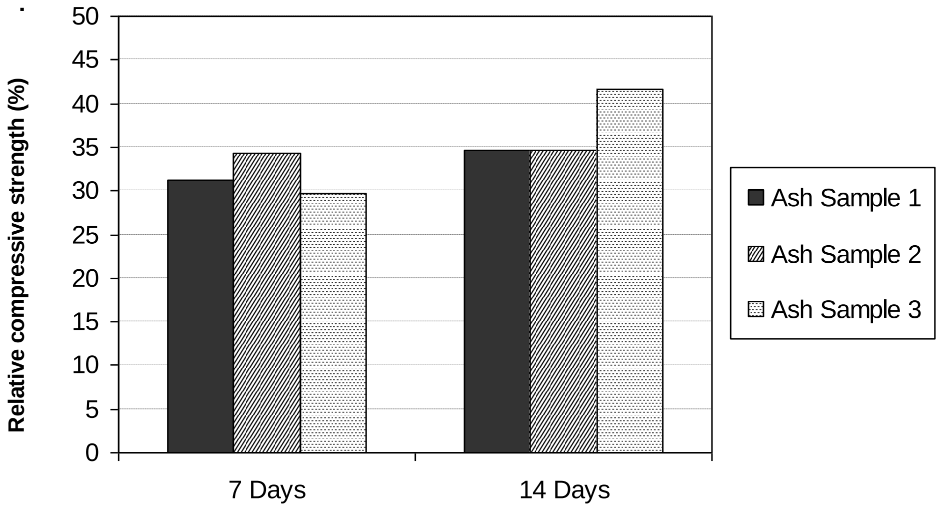

Figure 11 – Relative compressive strength of concrete cubes where 50% of the PC was replaced with ash from sugarcane waste.

2.2.2 Cameroon

Waste streams: Unlike Kenya, Cameroon has significant oil deposits and does not solely rely on agriculture for infrastructure development. It also has a large, potential for tourism, although relative to Kenya, this potential is yet to be fully exploited. Other non-agricultural related industries or activities of potential in civil engineering applications that have so far been reviewed by the authors include production of building stones by cutting natural stone, production of fired building bricks by heating clay, and also unfired brick making by cementing soil with Portland cement. There is also potential in the calcination of limestone to produce lime which, for a country that is only in its early stages of achieving locally manufactured Portland cement, would go a long way to augment the availability of binding materials for civil engineering applications. There are other minor materials-related income generating activities throughout Cameroon, such as manual stone processing into aggregates as shown in Figure 12.

The authors are currently carrying out assessment of the potential of utilizing waste alumina, emanating from the processing of aluminium at a metal processing plant near Douala. It is critical that a more comprehensive and thorough scoping study on the availability of other non-agricultural potential is carried out, especially one that covers further north of Cameroon, as most of the current scoping by the authors has tended to cover the South, South West and Central parts of Cameroon.

In the agricultural sector the key industry identified so far with potential for significant agricultural waste is that involving palm oil processing. Other minor waste streams include waste from the growing of sugar cane [16], although the authors have so far not collected much information from this sector and therefore cannot comment comprehensively of the potential. However, by far the biggest potential for giant steps towards rejuvenating the regional and national economy in Cameroon using an agricultural activity is still likely to result from the widespread growing of palm oil. The authors are also in the process of carrying out pilot trials and exploring the logistics and acceptability of the use of biogas generated from livestock as in Kenya, as a key source of power for rural electrification. It is anticipated that a publication on this potential in Materials Solutions will be available at a time when the on-going pilot trials and data collection is at an advanced stage. This paper will therefore now concentrate on the potential in the processing of palm oil.

Figure 12 – Manual stone processing into aggregates near Bamenda, Cameroon.

Potential from the processing of palm oil: Figure 13 shows the typical waste from Pamol Palm Oil processing Company. As can be seen also from Figure 14, this category of palm oil waste is typical of both large-scale and small scale palm oil processing. The only differences are minor contents of residual oil in the “porcupine” bunch waste, which is dependent on the efficiency of squeezing the palm fruit bunches to remove the oil-containing nuts.

Figure 13 – Large volumes of fibrous waste from palm oil processing at PAMOL Palm Oil Company in South West Cameroon.

Using palm oil waste ash from one of the medium-sized palm oil processing plants near Limbe in Cameroon, initial investigation are on-going to establish the possibility of utilizing this and other similar ashes in construction. As was the case for the sugar cane ash in Kenya, its applicability would be of great potential.

3.0 DISCUSSION AND CONCLUDING REMARKS

Pursuance of sustainable construction is a common goal for both developed and developing countries [17 – 18]. It is therefore possible to transfer experiences and technologies from those who have them, and adapt them to suit local conditions. There is an added impetus towards this goal for Africa in particular, where the presence of processed building materials is dependent on ability to import or produce Portland cement locally at affordable prices. The examples shown for the UK waste stream are transferable to Africa. It has been demonstrated for a few of the major agricultural wastes in Kenya and Cameroon that it is possible to generate significant power to run the plants either producing the waste or brought in from nearby out growers. In order to maximize output, the realization of Clean Development Mechanisms (CDM) strategies will be necessary. Some of the reasons for low output include old and outdated burning technologies. Such as that shown in Figure 15 for a palm oil processing plant in some part in Cameroon. The running costs of such old burners mask the enormous potential that equivalent volumes of waste are capable of achieving.

Figure 14 – Fibrous waste from a small-scale palm oil processing at community-based CDF project in South West Cameroon.

Figure 15 – Old and outdated burning technology at a palm oil processing plant in Cameroon.

Agreeably, large CDM projects are not easy to pull through. It requires good intentions from the relevant central government and government ministries, committed staff and researchers, and perhaps a little help from willing donors. International organizations such as the United Nations Industrial Development Organization (UNIDO) have clearly identified the need for this assistance, and it is up to the governments concerned to be pro-active and tap from this and other similar or available help. The goal towards zero waste and realization of such big goals as co-generation of power do not come easily or in a short period. It requires joint efforts from university researchers, private and government initiatives to remove the bottle-necks, such as the lack of clear mechanisms for both feed-in or provision of power to or from the national grid systems, so as to accelerate the move towards future development.

3.0 CONCLUSIONS AND RECOMMENDATIONS

1. It is clearly possible that Africa can enhance development by a adopting a more innovative engagement in clean development mechanisms from waste. While this may not necessarily be easy to achieve over a short period, smaller-scale endeavors to progression towards zero waste are achievable by encouraging researchers to pursue these goals.

2. There is a wide range of agricultural activity in most African countries, with some sectors producing significant amounts of unused waste. Some companies in the agricultural sector in Africa have already demonstrated the possibility and capability of utilizing waste from agriculture in a beneficial manner, such as co-generation of electric power. The more efficient of these companies have started to co-generate excess power, over and above their industrial needs, thus clearly demonstrating progression towards a more developed Africa.

3. It is possible to utilize the secondary waste produced in the co-generation of power, so as to result in a zero-waste. The looped operation strategy results in no waste at all. The journey to the realization of clean and efficient development strategies should start incrementally, starting with active local research with or without the assistance or interest from researchers in the diaspora. Notwithstanding, the injection of pace by researchers in the diaspora can play a key role in accelerating the transfer and adaptation of the related technologies for a rapid face change in Africa.

4.0 ACKNOWLEDGEMENTS

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