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A Review on the Usage of Ceramic Wastes in Concrete Production

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***Abstract*—**Construction and Demolition (C&D) wastes contribute the highest percentage of wastes worldwide (75%). Furthermore, ceramic materials contribute the highest percentage of wastes within the C&D wastes (54%). The current option for disposal of ceramic wastes is landfill. This is due to unavailability of standards, avoidance of risk, lack of knowledge and experience in using ceramic wastes in construction. The ability of ceramic wastes to act as a pozzolanic material in the production of cement has been effectively explored. The results proved that temperatures used in the manufacturing of these tiles (about 900⁰C) are sufficient to activate pozzolanic properties of clay. They also showed that, after optimization (11-14% substitution); the cement blend performs better, with no morphological difference between the cement blended with ceramic waste, and that blended with other pozzolanic materials. Sanitary ware and electrical insulator porcelain wastes are some wastes investigated for usage as aggregates in concrete production. When optimized, both produced good results, better than when natural aggregates are used. However, the research on ceramic wastes as partial substitute for fine aggregates or cement has not been overly exploited as the other areas. This review has been concluded with focus on investigating whether ceramic wall tile wastes used as partial substitute for cement and fine aggregates could prove to be beneficial since the two materials are the most high-priced during concrete production.

***Keywords*—**Blended, morphological, pozzolanic properties, waste.

I. Introduction

CONSTRUCTION and Demolition (C&D) wastes contribute the highest percentage of wastes worldwide. Furthermore, ceramic materials, which include brick walls, ceramic tiles and all other ceramic products, contribute the highest percentage of wastes within the C&D wastes [1]. The current option of disposal for this type of waste is landfill. Unavailability of standards, avoidance of risk, lack of knowledge and experience led to there being no active usage of ceramic wastes in construction. The operating policy for the disposal of the land-derived water containing waste to the marine environment in South Africa (SA) listed refractory ceramic fiber among the list of toxic substances [2]. Initiative for Zero Waste in Africa (IZWA) also described ceramic waste as a problematic material [3]. Much research has been conducted worldwide on the usage of ceramic wastes as an additive in structural and non-structural concrete. The study was also conducted in specialized concrete such as high performance concrete and sulphate resistant concrete. Positive results were obtained from these studies.

The ongoing research has interest in ceramic wastes from a particular factory in South Africa, SAMCA. SAMCA is a Wall Tile manufacturing company under Ceramic Industries Limited. They produce a minimum of 400 tons and a maximum of about 800 tons of ceramic waste in every 2 weeks, which is disposed as landfill. However, using ceramic wastes, as landfill may not be the best option, depending on whether there can be leaching of chemicals that can be detrimental to the environment. This also negates the concept of sustainable development, and hence the need to investigate alternative beneficial use of these wastes, to recover energy that is been used to produce these ceramics somehow, in a positive manner.

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II. Waste and Waste Management

Waste is defined in Section 1 of the South African Environmental Conservation Act (ECA) No. 73 of 1989 as ‘any matter whether gaseous, liquid or solid, or any combination, which from time to time may be proclaimed by the Minister of Environmental Affairs and Tourism by notice in the Gazette as an undesirable or superfluous by-product, emission, discharge, excretion, or residue of any process or treatment [4]. For instance in construction industry, C&D wastes make up significant percentage in many countries as shown in Table I. From these, it is apparent that the Clay Bricks and Ceramic Industry have the highest percentage of wastes produced under the category of stony fraction (see Table I).

A. Ceramic Wastes Classification

Ceramic wastes are classified as non-recyclable wastes in South Africa, except for the normal use as filling material. Based on research regarding recyclable Construction and Demolition (C&D) wastes, ceramic wastes have the potential to be used in concrete production. However, there are no guidelines and standards to the usage of these wastes in concrete. In addition, the local construction industry does not have knowledge and experience to utilize the material.

B. Ceramic Wastes Properties

Ceramic wastes have special properties, which can contribute positively in other areas of recycling. Reference [5] conducted research on the properties of ceramic waste forms to establish whether it was suitable to provide a stable geological formation, which can act as barrier to contain nuclear wastes (radionuclides) for long periods. The main problem was the toxic radioisotopes with very long half-lives, such as plutonium 239 (^{239}Pu), which has half-life of approximately 24 200 years. Half-life means the time it will take to decay half of the material, not necessarily meaning it will take twice the time to decay the whole material. For instance, from 1kg of plutonium, after half-life there will be 0.5kg plutonium and 0.5kg uranium, since plutonium decays to uranium). Material such as ^{239}Pu has to be disposed in a protected environment, such that the radioisotopes (radionuclides) are not likely to be leached into the groundwater over long periods. The research concluded that ceramic waste had degradation capacity potential to provide such stability, though further research still need to be done to confirm that. This is mostly due to difficulties in modeling and investigation of ceramic waste forms behavior over long periods. Thus, research indicated that ceramic wastes have potential application in nuclear waste management [5].

In South Africa, the National Waste Management Strategy Implementation (NWMSI) Recycling Component Project aims at developing a realistic and practical approach to increase and extend recycling [6]. According to the strategy, provision is made for the investigation and possible pilot implementation of an industrial waste exchange initiative, as a mechanism for bringing about waste reduction through reuse, reducing and recycling. It is in this light that ceramic material has potential to be used in the production of concrete [1]. In essence, concrete is one of the most utilized materials in South Africa. Many of the construction projects utilize concrete as the main material for the structures. Concrete contains about 75% (by volume) of aggregates, which are in most areas abundant [7]. However, in most cases where there is a need for large supply of concrete, the natural environment ends up being sacrificed for economic reasons. Due to the rise in environmental awareness, there has been substantial amount of research in incorporating wastes, especially C&D wastes, into the making of concrete [3].

TABLE I
COMPOSITION OF CONSTRUCTION AND DEMOLITION WASTES [1]

MATERIALS	COMPOSITION (%)
STONY FRACTION	75
Bricks, wall tiles and other ceramic materials	54
Concrete	12
Stone	5
Sand, gravel and other aggregates	4
NON STONY FRACTION	25
Wood	4
Glass	0.5
Plastic	1.5
Metals	2.5
Asphalt	5
Plaster	0.2
Rubbish	7
Paper	0.3
Others	4

C. Other Waste Materials

Waste materials such as tyres, rice husk ash, glass, and other wastes have also been investigated on the potential of being incorporated in concrete production, as either partial or total substitute for aggregates or cement in concrete, and in some instances, to provide specialized mechanical or chemical characteristics to the concrete.

One research noteworthy mentioning was whereby polymeric wastes were used in concrete as a beneficial filler material for use in maintaining hydraulic dams used in power generation. Three waste materials were chosen: (i) Agglutinated low-density polyethylene (LDPE – from the production of garbage and plastic bags), (ii) crushed polyethylene terephthalate (PET – from liquid deodorant flasks), (iii) and used rubber tires. After initial trials, these were optimized to 2.5% of the control concrete. All three produced positive results when compared to the control concrete, with the LDPE producing the best results. Comparisons were done in compressive strength, tensile strength under diametrical compression, underwater erosion-abrasion resistance, microstructure, and field application. Thus the research not only focused on reusing waste for environmental sustenance, but also to reduce the cost of structure while improving the quality of concrete [8].

Recently other materials such as construction and demolition wastes (C&D wastes), organic wastes (e.g. rice husk) have been introduced in the making of concrete, for both reasons of environmental sustainability and improvement of concrete properties. However, ceramic wastes are not in common use in the making of concrete. Ceramic wastes have potential to be incorporated in concrete due to their pozzolanic properties. They are also known for resistance to abrasion, and lower density, properties, which actually can be expected to improve the quality of concrete.

III. The Ceramics Industry

The term ceramics is a general term used to refer to ceramic products. Common manufactured ceramics include wall tiles, floor tiles, sanitary ware, household ceramics and technical ceramics. In essence, ceramic is a term used to describe inorganic materials (with possibly some organic content), made up of non-metallic compounds and made permanent by a firing process [9].

Clay, which is the most abundant material in the making of most ceramics, is naturally not a pozzolanic material. This is because it does not have silicate properties, which can react with water to form calcium hydroxide in the production of concrete. Research conducted by on the possibility of waste clay materials being used as pozzolanic additions indicated that the activation of clay to become pozzolanic begins during dehydration process, which initiates when heating clay from around 500ºC, and the separation of amorphous and very active aluminum oxide. The temperature required to reach maximum concentrations of the aluminum oxide depends on the type of minerals in the clay [1]. During the making of ceramics, clay is heated at relatively high temperatures, the exact temperature depending on the type of ceramic being produced. For instance, the study at hand focuses on ceramic wall tile wastes, which are reject tiles, which went through the full firing process. The ceramic wall tiles are fired at around 1150ºC. Deducting from that, it is logical to say wastes from the ceramic industry (ceramic waste) possess characteristics suitable for use as pozzolanic materials and thus are suitable for use in the making of concrete.

IV. Recent Developments in Ceramic Waste Reuse

There has been some research worldwide regarding the possibility of using ceramic waste in the manufacturing of concrete, as a partial substitute for cement or aggregates. References [10]-[12] conducted researches on partial substitution of cement with *ceramic roofing* waste. Reference [10] substituted various weight ratios by percentage (25% up to 40%) of Portland cement by the waste tile, and optimized 25% up to 35% weight ratio substitution. Their main interest was on: (i) pozzolanic properties of waste tile, (ii) setting time, (iii) particle size, (iv) specific surface area, (v) volume stability, (vi) density, and (vii) strength of cement. Their findings indicated that waste roofing tiles have pozzolanic properties, while also showing chemical and physical properties similar to cement, thus conforming to cement standard. Reference [12] was more interested in the mineralogical composition, thus using mostly microscopy and X-ray tests (diffractometric and spectroscopic techniques). Their findings indicated that waste tiles have pozzolanic properties, and the compressive strength of the blend cement (up to 30% ratio by weight) produced developed similar to the compressive strength of Portland cement.

Reference [13] conducted extensive research on ceramic waste usage. Their focus was investigating the possibility of utilizing *general ceramic rubble (mostly clay bricks and tiles)* as an additive of cement and on the manufacturing of concrete-made roofing tiles, and particularly, the morphology of the blended cement. They not only checked on the pozzolanic properties of the ceramic wastes, but also compared their results with those of other known cement additives such as fly ash and silica fume. They discovered that temperatures used to produce ceramic material (which is about 900^{o}C for ceramic bricks, and higher on most tiles) is sufficient to activate clay minerals, and ultimately provide the rejects with pozzolanic properties. They also discovered that there are no morphological differences between cement pastes made with clay tile and those made with other pozzolanic materials.

References [14]-[17] researched and confirmed the possibility of usage of *general recycled ceramic waste aggregates* in the production of non-structural concrete. Furthermore, they obtained positive results, with increase in abrasion resistance and tensile strength, suitable for usage in the making of paving slabs.

Reference [18] conducted research on viability of using waste from *clay blocks* as partial substitution of cement in the production of mortars. Their research revealed that partial substitution improved the mechanical properties and durability of the mortar. On the other hand, research was conducted on using wastes in the form of *ceramic bricks and mortar, and recycled concrete* and a mixture of the two as partial substitution for coarse aggregates [19]. It was discovered that the use of ceramic aggregates resulted in satisfactory durability. However, the ceramic bricks aggregates proved to be having high water absorption, the modified concrete mix thereof, proved to be satisfactory. In addition, negative results were obtained when totally substituting the fraction of 4.32mm of natural aggregates with ceramic aggregates [19].

Reference [20] conducted research on the use of wastes from *sanitary ware* as partial substitute for coarse aggregates in concrete (15 to 25%), and produced positive results. The increase in partial substitution resulted in lower density in concrete, and higher compressive and tensile strength. The concrete produced was suitable for structural use. Reference [21] conducted investigation on the possibility of utilizing *sanitary ware wastes* as partial substitution for both coarse and fine aggregates. The study comprised of investigating physical properties of concretes in which conventional coarse aggregate had been partially substituted by coarse ceramic aggregate obtained by crushing ceramic sanitary ware, and natural fine aggregate had been substituted by powdered ceramic material. Satisfactory results were obtained in both cases.

Ceramic wastes from the manufacturing of *electrical insulation porcelain* have been researched on to determine their potential for substitution into concrete [22]. Despite positive results on the possible use in the making of concrete, the use of sulphate resistant cements proves to be the best option, to avoid negative effects, which generate alkali – aggregate reaction with the use of Portland cement [22].

Reference [23] conducted research on the compressive strength and chloride penetration of mortars using ceramic waste as fine aggregates. In their research, they incorporated ceramic wastes of *electrical insulators.* They discovered that mortars with ceramic wastes as fine aggregates gained higher compressive strength than the control mortar made from river sand. Furthermore, they made partial substitution of Portland cement with ceramic waste powder smaller than 0.075mm, and observed improved compressive strength for substitution up to 20%. Chloride penetration of mortar specimen made of ceramic wastes was reduced considerably. Furthermore, they discovered that the pore volume and pore diameter on hardened specimen made from ceramic wastes were considerably less than of the control concrete. Reduced chloride diffusion, higher compressive strength and reduced pore volume will contribute to higher durability of the mortars made using ceramic wastes.

High performance concrete (HPC) mostly suffer from early cracking due to very low water: cement (w/c) ratio, unless precautions are taken. One of the precautions investigated is possibility of internal curing of concrete. One research noteworthy is whereby recycled waste porous ceramic coarse aggregates (PCCA) are used instead of conventional coarse aggregates to reduce shrinkage. This concept blossom from the idea of replacing normal aggregate with pre-saturated lightweight aggregate (LWA), as indicated by many authors.

The research produced positive results, with slight decrease in tensile strength with increase in PCCA content, and increase in compressive strength. When optimized, PCCA can work attractively at reducing or eliminating shrinkage on high performance concrete [24].

Reference [25] did an interesting research on clinkers and cements obtained from raw mix containing ceramic waste as a raw material. The hydration, physical-chemical properties and leaching behavior in different acid media were investigated and found to be morphologically and compositionally similar in hydration behavior, when compared to conventional cement. The concentration levels of Zinc and Bromide, although higher than on conventional cement, were not on toxic levels. The investigation was conducted using *red ceramic wall tiles*, *white ceramic wall tiles*, and a combination of red and white ceramic wall tiles, and optimized at 11-14% substitution of raw materials for making cement. Positive results were obtained whereby the new cement provided all the technical conditions to be prepared and used as Portland cement. This regarded the attempt feasible.

V. Research Challenges

Not much research has been done on incorporating normal *ceramic wall tiles* waste as partial substitute of fine aggregates or cement, in the production of structural concrete. The current research is exploring the possibility of incorporating wastes from ceramic wall tiles as partial substitute of fine aggregates or cement in the making of concrete. The research is pertinent to South African situation whereby majority of tiles produced are ceramic wall and floor tiles. From economic point of view, cement and fine aggregates contribute a bigger portion of costs in the production of concrete, thus to have them replaced by waste material of similar characteristics is a major economic gain, while sustaining the environment.

VI. Conclusion

Sustainable development is a key towards improving living conditions of the future generations. Thus recycling wastes is only rational and logical step towards conservation of natural resources. The economic aspect of recycling is motivation to proceed in this direction.

From the researches discussed, it is clear that ceramic wastes are suitable to be used in the construction industry, and more significantly on the making of concrete. Ceramic wastes are found to be suitable for usage as substitution for fine and coarse aggregates and partial substitution in cement production. Researchers have indicated their potential for usage in both structural and non-structural concrete and even for mortars. They were found to be performing better than normal concrete, in properties such as density, durability, permeability and compressive strength. Thus to continue with further research in this area is necessary to make available the information, which will inevitably come handy in the near future.

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