Physical and Mechanical Experimental Investigation of Concrete incorporated with Ceramic and Porcelain Clay Tile Powders as Partial Cement Substitutes

Morris Oleng
Post Graduate Student
Department of Civil Engineering
PAN AFRICAN UNIVERSITY Institute for Basic Sciences, Technology and Innovation (PAUSTI)
Nairobi, Kenya

Christopher Kanali
Professor
Dept. of Agricultural and Biosystems Engineering
Jomo Kenyatta University of Agriculture and Technology
Nairobi, Kenya

Zachary C. Abiero Gariy
Professor
Department of Civil Engineering
Jomo Kenyatta University of Agriculture and Technology
Nairobi, Kenya

Erick Ronoh
Doctor
Dept. of Agricultural and Biosystems Engineering
Jomo Kenyatta University of Agriculture and Technology
Nairobi, Kenya

***Abstract*— The increased demand of construction over the past two decades has led to drastic increase in the cost of concrete production. The increasing cost and scarcity of portland cement has impacted negatively on the delivery of affordable housing and infrastructural development in developing countries like Uganda. For this reason, there is urgent need for finding suitable alternatives which can replace cement partially or at a high proportion. This study focussed on establishing the feasibility of using crushed ceramic and porcelain clay tiles powder as partial replacement of cement in production of eco-friendly concrete. Concrete cubes measuring 150 mm × 150 mm × 150 mm and 100 mm × 200 mm cylinder specimens were made from seven different concrete mixes prepared by using crushed ceramic and porcelain clay tile powder to replace 0%, 5%, 10%, 15%, 20%, 25% and 30% of ordinary portland cement by mass. The workabilities of the fresh concrete mixes were evaluated using the slump while compressive and splitting tensile strengths of hardened concrete were evaluated at different curing periods of 7, 14, and 28 days. The results of slump test showed that increase in ceramic and porcelain powder replacement decreased the workability of concrete. Replacement of cement with ceramic and porcelain powder significantly increased the compressive strength of concrete. Conclusively, the target compressive and tensile splitting strengths were achieved up to 20% replacement of cement with ceramic and porcelain powder beyond which the strength reduced.**

Keywords*— *Cement; Ceramic And Porcelain Clay Tile Powder; Concrete; Workability; Compressive Strength; Splitting Tensile Strength

I. INTRODUCTION

The construction industry constitutes one of the main contributors to the economy of any country (about 10% of the gross domestic product). It plays a huge role in not only economic development but also improving the welfare of the citizens. Recently, the growth rate in construction has increased drastically by over 1.8% globally with the largest contributors to the construction market being Europe, America, Asia and Japan as they control more than 70% of the industry [22]. Concrete is the world most utilized construction material and due to this, statistics have shown that worldwide cement production, by major producing countries from 2011 to 2016 has drastically increased and so has its cost [23]. Additionally, the growing concern of depletion of resources necessitates the search for alternatives sources [1]. For these reasons, there is need for increased initiatives to modify ordinary concrete to make it more sustainable and affordable so as to cater for the increasing construction boom [18].

Different studies have been done with interest driven much towards wastes and recycled materials as they are economical and more environmental friendly. Such studies reported include replacing cement with animal blood, partial replacement with waste glass powder, replacing cement with rice husks, replacement with saw dust, replacement by steel shot dust, using kiln saw dust and many others [21]. Particularly, ceramic materials which include brick walls, ceramic tiles and all the ceramic products contribute the highest proportion of wastes in the construction and demolition waste [17]. Ceramic tile is a product that stands out for its low water absorption and high mechanical strength. The properties of the product result from its low porosity due to the processing conditions (high degree milling of raw materials, high force compaction and sintering temperature), and the potential of the raw materials to form liquid phases during sintering (high desiccation). Porcelain tile on the other hand has high vitreous characteristics [20].

This study, therefore, seeks to assess the suitability of utilizing old waste tiles from demolished structures in order to reduce waste around cities such as Kampala. The properties of crushed ceramic and porcelain clay tile powder were determined. Cement was partially replaced 0%, 5%, 10%, 15%, 20%, 25%, and 30% of crushed ceramic and porcelain clay tile powder in M25 concrete.

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II. MATERIALS AND METHODS

A. Cement, Ceramic and Porcelain clay tile powders

Cement is a hydraulic binder, finely ground inorganic material that, when mixed with water, forms concrete which is a composite material consisting of a binder, typical cement, and rough and fine aggregates, which are usually stone and sand, and water. The cement used was Ordinary Portland Cement (OPC) which is the most common type of cement used in Uganda, particularly Tororo cement brand of OPC conforming to BS EN 197-1:2000 [15], of strength class 32.5. Samples of ceramic and porcelain clay tiles were taken from of the five demolition sites within Kampala metropolitan area in accordance to BS 1881-101: 2011 [6], which gives methods of sampling. The chemical composition of the ceramic and porcelain clay tile powder was determined using X-Ray Fluorescence Spectrometer method while the physical properties were determined as specified in ASTM C 187 [2] and ASTM C 188 [3]. A comparison between the properties of ceramic and porcelain powders with cement properties was made to verify if their composition warrants it as a pozzolan. The physical properties of cement, ceramic and porcelain powders are presented in Table I.

TABLE I. PHYSICAL PROPERTIES OF CEMENT, CERAMIC AND PORCELAIN CLAY TILE POWDERS

Property	Ordinary Portland Cement	Ceramic Powder	Porcelain Powder
Specific Gravity	3.15	2.95	3.11
Consistency	30	32.5	35.0
Initial Setting Time	30 minimum	70	45
Final Setting Time	540 maximum	475	320

The major compounds of ordinary portland cement, ceramic and porcelain powders are given in Table II. About 95% of portland cement clinker is made of combinations of four oxides. These are; lime (CaO), silica (SiO2), alumina (Al2O3), and iron oxide (Fe203). Other, so-called minor constituents or impurities include, among others, magnesia; sodium, and potassium oxides. Since the primary constituents of portland cement are calcium silicates, we can define Portland cement as a material that combines CaO and SiO2 in such a proportion that the resulting calcium silicate will react with water at room temperature and normal pressure.

TABLE II. CHEMICAL COMPOSITION OF CEMENT, CERAMIC AND PORCELAIN CLAY TILE POWDER

Component	Percentage by mass		
	Ordinary Portland Cement	*Ceramic Powder*	*Porcelain Powder*
SiO_2	21.03	66.39	73.04
CaO	64.67	3.64	1.43
Al_2O_3	6.16	18.14	19.39
Fe_2O_3	2.58	3.79	1.42
MgO	2.62	3.60	1.58
K_2O	0.61	3.39	2.56

From the Table II it can be seen that the combined percentage of SiO_2, Fe_2O_3 and Al_2O_3 for both crushed ceramic and porcelain clay tile powder was 88.32% and 93.85% respectively, thus meeting the 70% minimum requirement of ASTM C 618 [4] for a good pozzolan.

B. Fine Aggregates

From the sieve analysis of the fine aggregates, all the sand passed the 37.5 mm and 28 mm sieves; a moderate amount was retained on 10 – 0.6 mm sieves while 1.7% was silt. These showed that the aggregates were uniformly graded since they are relatively evenly retained on each sieve, hence they were suitable aggregates for concrete requirements BS 882:1992 [13]. The physical properties of the fine aggregates are presented in Table III.

TABLE III. PHYSICAL PROPERTIES OF FINE AGGREGATES

BS 882:1992	Sieve Analysis (% passing given sieve)							
Sieve (mm)	20.0	10.0	5.0	2.0	1.18	0.60	0.30	0.15
Limits	100	100	100-89	100-60	100-30	100-15	70-5	15-0
% Passing	100	99.2	91.0	73.9	58.1	20.3	6.4	1.7
Moisture Content 4.4 %			Specific Gravity 2.6 Mg/m^3			Silt Content 1.5 %		

A plot of cumulative percentage passing against the sieve sizes done on a graph containing the sieve envelope as shown in Fig. 1. Uniformly graded aggregates enhance the workability of concrete by minimizing the voids in the mix as the voids will be filled by smaller particles of the aggregates and no bleeding.

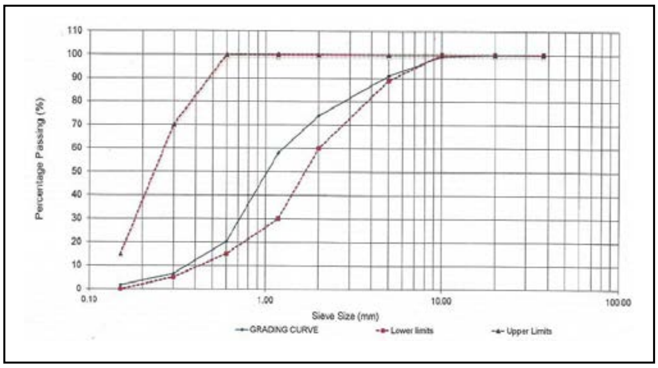

Fig. 1: Particle Size Distribution of Fine aggregates

C. Coarse Aggregates

The fractions from 20 mm to 4.75 mm are used as coarse aggregate. Machine crushed angular granite metal of 20 mm nominal size from the local source was used as coarse aggregate. It was free from impurities such as dust, clay particles and organic matter etc. The coarse aggregate chosen for concrete was typically angular in shape, dense graded, and smaller than maximum size suited for conventional concrete. The physical properties were investigated in accordance with BS 882:1992 [13]. Table IV shows the physical properties of the coarse aggregates and the particle size distribution is shown in Fig. 2.

TABLE IV. PHYSICAL PROPERTIES OF COARSE AGGREGATES

Property	Value
Specific Gravity	2.7 Mg/m^3
Water Absorption	1.1 %
Bulk Density	1.5 g/m^3

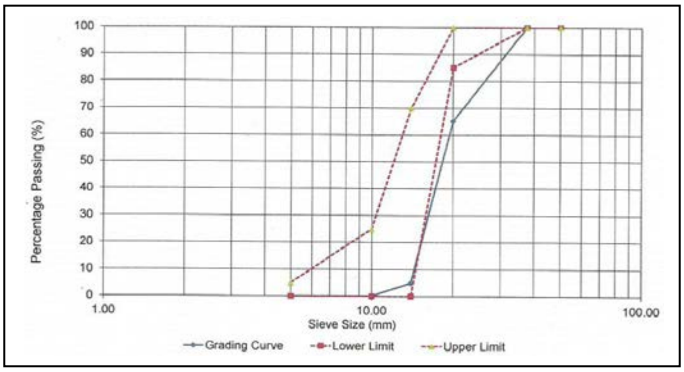

Fig. 2: Particle Size Distribution of Coarse aggregatesWater for mixing concrete

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Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Since it gives the strength to cement concrete, the quantity and quality of water were required to be looked into very carefully. Potable tap water free from any injurious amounts of oils, acids, alkalis, sugar, salts and organic materials available in the laboratory with pH value of 7.0 ± 1.0 and conforming to the requirements of BS EN 1008:2002:1980 [14] was used for mixing concrete and curing the specimens. The water source was tap stand of National Water and Sewerage Corporation (NW&SC) Kampala branch.

D. Concrete Mix Design

A control mix of ratio 1:2:3 batched by mass using a water-cement ratio of 0.50 was used. The control mix was produced using OPC only as binder while in other mixes, crushed ceramic and porcelain clay tile powder was used to partially replace 5%, 10%, 15%, 20%, 25% and 30% by mass of ordinary portland cement in the control mix. The details of mix proportions are shown in Table V.

TABLE V. CONCRETE MIX PROPORTIONS

Percentage Cement Replacement (%)	Mass of constituents (kg)			
	Cement	Ceramic & Porcelain Powder	Fine Aggregates	Coarse aggregates
0	1.33	0	2.38	3.71
5	1.26	0.07	2.38	3.71
10	1.20	0.13	2.38	3.71
15	1.13	0.20	2.38	3.71
20	1.06	0.27	2.38	3.71
25	1.00	0.33	2.38	3.71
30	0.93	0.40	2.38	3.71

Mixing method was done manually with a control mechanism to prevent the loss of water quantified for the mixing purpose. Concrete mix was made using a binder, sand and coarse aggregates [21]. The specimens were casted in moulds generally 150 mm cubes. The mould surface was cleaned and oiled on their inside surfaces in order to prevent development of bond between the moulds and the concrete. Curing may be defined as the procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. Sample of cubes were taken from the moulds after 24 hours of casting and then cured for 7, 14, and 28 days prior to testing. Testing equipment was the Universal Testing Machine (UTM) as specified in BS 1881-115:2011. The compressive strength of each cube was calculated by dividing the maximum load applied to it by the cross-sectional area according to BS 1881-116:2011 [9]. The splitting tensile strength test was conducted in accordance to BS 1881-117:2011 [5].

E. Experimental Setup

A mix ratio of 1:2:3 batched by mass using a water-cement ratio of 0.50 was used. The control mix was produced using OPC only as binder while in other mixes, crushed ceramic and porcelain clay tile powder was used to partially replace 5, 10, 15, 20, 25 and 30% by mass of ordinary portland cement in the control mix. Laboratory tests were carried out on fresh and hardened concrete. As a measure of workability, Slump test was carried out on the fresh concrete for all concrete mixes. For the hardened concrete, the compressive strength and split tensile strength tests were carried out in accordance to the appropriate standards. Test cubes and cylinders were taken from the moulds after 24 hours of casting and then cured for 7, 14, and 28 days prior to testing. The performance of concrete with various treatments at different ages was monitored to establish the optimal mix.

The flow chart for evaluating the performance of concrete with ceramic and porcelain clay tile powders as partial cement replacements is shown in Fig. 3. The study was operated by varying amounts of tile powder in concrete production by either weight and volume or the percentage of concrete.

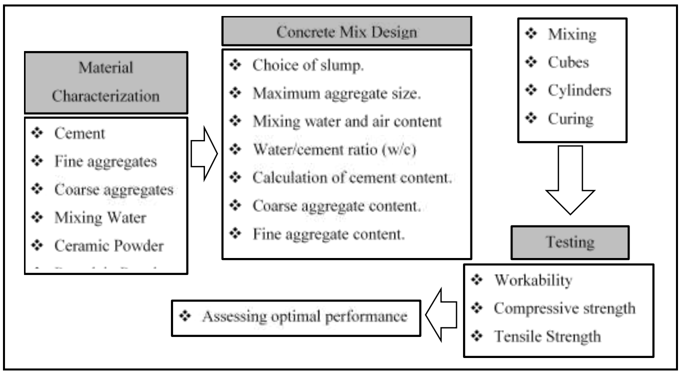

Fig. II. Flow chart for evaluating the performance of concrete mix obtained from ceramic and porcelain clay tile powders as partial cement substitutes

III. Results and Discussion

A. Workability of Fresh Concrete

The results of the slump test for various replacement levels is presented in Fig. 4.

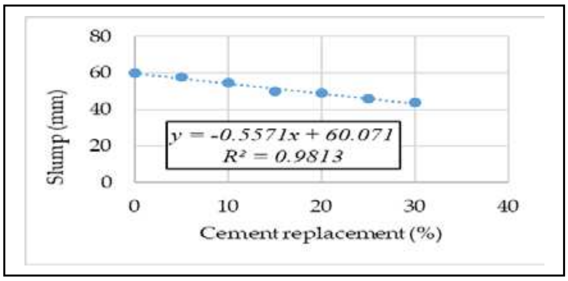

Fig. 4. Workability against percentage replacement

From the results in Fig. 4, it can be seen that as the percentage replacement of OPC with crushed ceramic and porcelain clay tile powder increases, the workability of concrete decreases. There was a reduction in the workability levels as reported by a reduction in the slump values from 60 mm for normal concrete at percentage reductions of 3.33%, 8.33%, 16.67%, 18.33%, 23.33% and 26.67% for 5%, 10%, 15%, 20%, 25% and 30% crushed ceramic and porcelain clay tile powder partial replacement of cement respectively as compared to the control. Replacing cement by an equal mass of crushed ceramic and porcelain clay tile powder causes an increase in volume since the density of cement is higher than that of crushed ceramic and porcelain clay tile powder. This therefore increases the water demand and as the crushed ceramic and porcelain clay tile powder content increases the workability reduces since the quantity of water remains the same for all mixes. Also a reduction in the workability of fresh concrete may be caused by an adhesion within the concrete and

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holding the other ingredients of concrete together impeding easy flow of water as was reported by Nibudey [19].

B. Compressive Strength

The results of compressive strength test are presented in Fig. 5. Concrete derives its strength from the pozzolanic reaction between silica in pozzolan and the calcium hydroxide liberated during the hydration of OPC. In the very first period after the adsorption of water on the surface of the dry powder, the dissolution of part of the inorganic phases starts to occur. Very soon, however, new silicate and aluminate hydrated phases begin to precipitate from the solution on the existing grains, thus favouring the further dissolution of the anhydrous phases through an incongruent process. The hydrated phase responsible for the binding characteristics of the cement is an amorphous calcium silicate hydrate, called C-S-H, having the properties of a rigid gel. A secondary product of the hydration process is crystalline $Ca(OH)_2$, portlandite. The reaction of the silicate and aluminate phases with water is an exothermic process. The C-S-H gel is not only the most abundant reaction product, occupying about 50% of the paste volume, but it is also responsible for most of the engineering properties of cement paste. This is because it forms a continuous layer that binds together the original cement particles into a cohesive whole. The ability of the C-S-H gel to act as a binding phase arises from its nanometer-level structure.

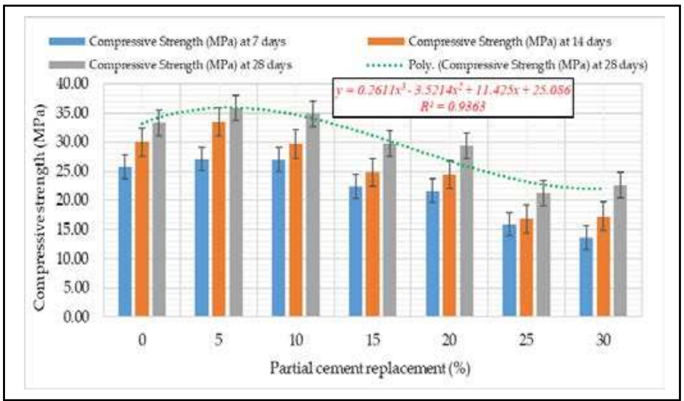

Fig. 5. Compressive strengths for various cement replacement levels at different ages.

At low percentages of replacement, the quantity of silica is low, therefore, only a limited quantity of C-S-H can be formed despite the large quantity of calcium hydroxide liberated due to the relatively large quantity of portland cement. However, at high percentage replacement, the quantity of pozzolan in the mix increases. C-S-H formed reduces due to liberation of a small quantity of calcium hydroxide from the hydration of the relatively small quantity of portland cement available. The strength of concrete at both low and high percentage replacement is therefore low. An optimum level of replacement exists at which compressive strength is the highest. It can also be concluded that the strength of concrete depends on the relative proportions of silica in crushed ceramic and porcelain powder and ordinary portland cement available.

The optimum reaction take place at 5% replacement of OPC hence the rate of strength gain with respect to time is highest for concrete with 5% replacement of OPC by crushed ceramic and porcelain powder. The variation of compressive strength of concrete is presented in Figure 4. The target compressive strength at 28 days was achieved up to 20% replacement of cement with crushed ceramic and porcelain clay tile powder beyond which the addition reduces the strength. This trend is similar at all ages of testing. It is also seen that the strength of concrete increases with age.

C. Splitting Tensile Strength

Knowledge of tensile strength of concrete is of great importance. Tensile strength was determined using Universal Testing Machine (UTM). The split tensile strength of concrete was tested using 100 mm × 200 mm cylinder specimens and carried out by placing specimen between the loading surfaces of a UTM and the load was applied until the failure of the specimen. Three test specimens were cast for each proportion and used to measure the tensile strength for each test conditions and average value was considered. The average values of 3 specimens for each category at the ages of 7 days, 14 days and 28 days are shown in the Fig. 6.

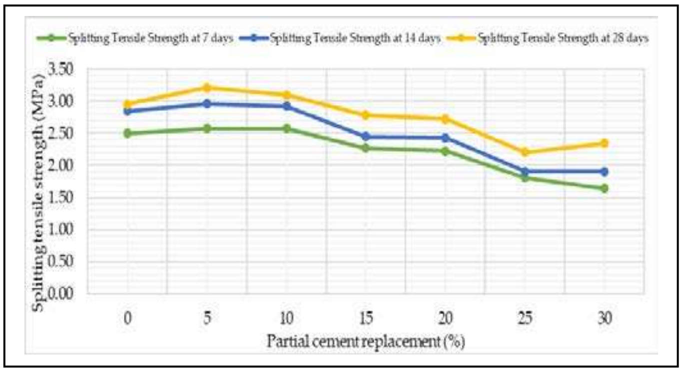

Fig. 6: Splitting tensile strengths for various cement replacement levels at different ages.

Fig. 6 shows that there was an improvement in the tensile splitting values up to 10 % cement replacement with ceramic and porcelain powder at 7 days, 14 days and 28 days curing times. The target tensile strength was achieved up to 20 % cement replacement with ceramic and porcelain powder.

IV. CONCLUSION

- Increase in crushed ceramic and porcelain clay tile powder replacement decreased the workability of concrete (Fig. 4).
- Replacement of cement with crushed ceramic and porcelain clay tile powder significantly increased the compressive strength of concrete.
- Replacement of 5% of the mass of cement with crushed ceramic and porcelain clay tile powder achieved the maximum compressive strength (Fig. 5). The 7-day, 14-day, and 28-day compressive strengths at 5% replacement respectively showed increases of 5%, 12% and 8% over the compressive strength of the control concrete at those ages.
- The 28-day compressive strengths at 20% replacement showed increases of 18% compared to the target compressive strength of M25. Hence the replacement of cement using 20% crushed ceramic and porcelain clay tile powder in concrete gives the required strength and can be considered as optimum percentage (Fig. 5). Further increase in the percentage addition of ceramic waste, reduces the compressive strength of concrete by 56% at 28 days.

- The 28-day splitting tensile strengths was achieved up to 20% replacement and it showed increases of 8.2% compared to the target tensile strength of M25 (Fig. 6).

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REFERENCES

[1] Agbede, O. I., & Monash, J., (2009). Suitability of Periwinkle Shell as Partial Replacement for Gravel in Concrete. Leonardo Electronic Journal of Practice and Technologies, (15), 56-66.
[2] ASTM C 187 – 16, Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste. ASTM International, Pennsylvania.
[3] ASTM C 188 – 17, Standard Test Method for Density of Hydraulic Cement. ASTM International, Pennsylvania.
[4] ASTM C 618, (2005), Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. USA: ASTM International. www.astm.org/standards/C618.htm: pp. 1 – 623.
[5] BS 1881 Part 117 (2011). Testing concrete. Method for determination of tensile splitting strength. British Standards Institution, London, UK.
[6] BS 1881-101:2011. Testing concrete. Method of sampling fresh concrete on site, British Standard Institution, London, UK.
[7] BS 1881-102:2011. Testing concrete. Method for determination of slump, British Standard Institution, London, UK.
[8] BS 1881-111:2011. Testing concrete. Method of normal curing of test specimens, British Standard Institution, London, UK.
[9] BS 1881-115:2011. Testing concrete. Specification for compression testing machines for concrete, British Standard Institution, London, UK.
[10] BS 1881-116:2011. Testing concrete. Method for determination of compressive strength of concrete cubes. British Standards Institution, London, UK.
[11] BS 812-1:1975, Methods for determination of particle size and shape, British Standard Institution, London, UK.
[12] BS 812-2:1995, Methods of determination of density, British Standard Institution, London, UK.
[13] BS 882 (1992), Specification for aggregates from natural sources for concrete. British Standards Institution, London, UK.
[14] BS EN 1008:2002. Mixing water for concrete — Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete, British Standards Institution, London, UK.
[15] BS EN 197-1:2000, Cement - Part 1: Composition, specifications and conformity criteria for common cements, British Standard Institution, London, UK.
[16] BS EN 933-2:1996. Tests for geometrical properties of aggregates — Determination of particle size distribution — Test sieves, nominal size of apertures, British Standard Institution, London, UK.
[17] Meena, A. V. J., (2017). Experimental Study of Ceramic Waste Electric Insulator Powder Used as a Partial Replacement of Cement in Concrete. Journal of Materials Science & Surface Engineering, 5(4): 606-611
[18] Naik, T. R., Kraus, R., & Siddique, R. N., (2003). Controlled low-strength materials containing mixtures of coal ash and new pozzolanic material. Materials Journal.
[19] Nibudey, R. N., Nagarnaik, P. B., Parbat, D. K., Pande, A. M., & Polytechnic, G. (2014). Compressive Strength and Sorptivity Properties of PET Fiber Reinforced Concrete, 7(4), 1206–1216.
[20] Pérez, J. M., Rincón, J. M., & Romero, M., (2012). Effect of moulding pressure on microstructure and technological properties of porcelain stoneware. Ceramics International, 38(1), 317-325.
[21] Prabagar, S., Kalya, S., & Kerthi, W. R. F., (2015). Wood ash as an effective raw material for concrete blocks. International journal of research in engineering and technology, Environmental Technology Section, Industrial Technology Institute,363, Bauddhaloka Mawathe.
[22] Wadel, G., (2009). Sustainability in industrialized architecture: Modular lightweight construction applied to housing. Doctoral Thesis, Polytechnic University of Catalonia-Department of Architectural Constructions.
[23] Xi, F., Davis, S. J., Ciais, P., Crawford-Brown, D., Guan, D., Pade, C., & Bing, L., (2016). Substantial global carbon uptake by cement carbonation. Nature Geoscience, 9(12), 880-883.