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Experimental Investigation on Durability Properties of Concrete Using Ceramic Waste Electric Insulator Powder As A Partial Replacement of Cement

Abhishek Verma . Jeevan Meena . Krishna murari . Ravindra Goliya

Jaypee University of Engineering and Technology, Department of Civil Engineering, Guna-MP, India.

ABSTRACT

The population of our country is increasing with a faster rate due to the rapid growth in the economy. Construction industry is playing a vital role in the development of country. Due to which, the consumption of construction materials is increasing day by day which may cause scarcity of construction materials in future. Many of waste materials are generated in tile industry in the form of sanitary fittings, electric insulator, and glazed tile. But around 30% of ceramic materials changes into wastage during processing, transporting and fixing due to its brittle nature which is not recycled at present. These ceramic wastes have better mechanical behavior and shows pozzolanic nature. Therefore by using these wastes in to the concrete can be improved the properties of concrete. In this research work ceramic waste electric insulator is collected from juet campus and its pozzolanic reactivity was evaluated and its suitability as a partial replacement of cement using ordinary Portland cement 43 grade was analyzed. Hence, the ceramic waste insulator powdered passing from 90micron sieve were used in concrete as a partial replacement of cement with 10%, 20%, 30%, 40% by weight of cement. Concrete mixtures were produced, tested and compared in terms of durability properties to the conventional concrete. These tests were carried out to evaluate the water absorption, effect of magnesium sulphate on compressive strength, sorptivity, rapid chloride permeability test.

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Introduction

Aggregate and Cement, which are the most important constituents used in concrete production, are the essential materials needed for the construction industry. This certainly led to a continuous and increasing demand of natural materials used for their production.

The global production of ceramic tiles during 2011-12 in the world is about 11,166 million square meters. China is the largest ceramic tiles producer (5,200 million square meters) which is 46.6% of world production as well as consumer (4,250 million square meters) which is 38.9% of world consumption.

Compared to China, India ranks third; accounting for just 691 million square meters tiles production which is 6.2% of world production and also ranks third in terms of consumption accounting for just 681 million square meters which is 6.2% of world consumption.

In present situation the cost of construction materials like cement, sand and aggregate is increasing day by day because of high demand result in Scarcity of raw materials, and high price of energy. From the standpoint of energy saving and conservation of natural resources, the use of alternative constituents in construction materials is now a global concern [2]. Research Conducted 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 [3]. Ceramic wastes can be used safely with no need for dramatic change in production and application process. On one hand, the cost of deposition of ceramic waste in landfill will be saved and, on the other, raw materials and natural resources will be replaced, thus saving energy and protecting the environment. Production of cement requires high energy input (850 kcal per kg of clinker) and the production of one tonne of cement generates 0.55 tonnes of chemical CO_2 and an additional 0.39 tonnes of CO_2 in fuel emissions, accounting for a total of 0.94 tonnes of CO_2. Therefore, the replacement of cement in concrete by ceramic wastes represents a tremendous saving of energy and has important environmental benefits [4].

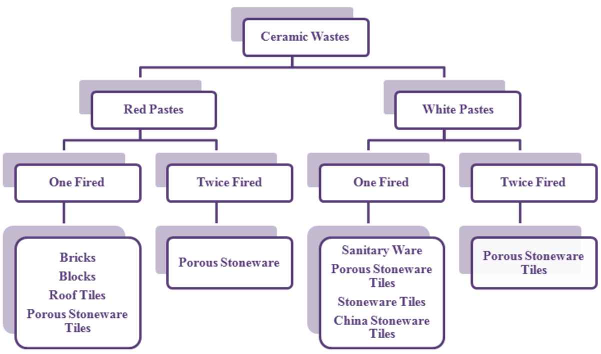

Figure.1 Classification of ceramic wastes by type and production process [1]

Figure 1 shows the classification of ceramic waste which is classified under two category white paste and red paste. Both white and red paste ceramic wastes further classified in to once fired and twice fired. There is a good reason why most people use two firings. It will have more loss with

Corresponding Author: Abhishek Verma, Tel: +91-9165363530
Email: verma.abhishek000@gmail.com

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single firing. In addition to pieces cracking, it tends to get more glaze problems like crawling and pinholing. For these reasons, most people believe that in the long run, single firing is not any more efficient.

It can be seen that using waste ceramic tiles in concrete production causes no remarkable negative effect in the properties of concrete. The optimal case of using waste ceramic tiles as coarse aggregates is found to be 10 to 30 percent. In these measures, not only an increase happens in compressive strength, but also a decrease in unit weight is reported [5].Utilization of ceramic waste or marble dust and its application for the sustainable development of the construction industry is the most effective solution and also speak the high value application of such waste. It is the possible alternative solution of safe disposal of the Ceramic waste powder and Marble dust powder thus stepping into a realm of solving the environmental pollution by cement production; being one of the primary objectives of Civil Engineers[6]. As compared to conventional concrete, on addition of ceramic waste powder its characteristic strength is decreased. So the ceramic waste powder has been replaced by up to 30% by weight of cement without affecting the characteristic strength of M20 grade concrete. On further replacement of cement with ceramic waste powder decreases the compressive strength [7]. CC 60% specimens were significantly more resistant to chloride penetration than those of other specimens. An increase in the percentage of both crushed ceramic and crushed basaltic pumice (CC and CBP) additives also affected the chloride penetration depths sharply [8]. Concrete on 30% replacement of Cement with Ceramic Powder, Compressive Strength obtained is 22.98 N/mm^2 and vice-versa the cost of the cement is reduced up to 12.67% in M20 grade and hence it becomes more Economical without compromising concrete strength than the standard concrete. It becomes technically and economically feasible and viable [9].

Experimental

Experimental Investigation on durability properties of concrete using Ceramic Waste Electric Insulator Powder as a Partial Replacement of Cement begins with concrete testing. The specimen shown A0, A1, A2, A3, A4 denoted the replacement level i.e. 10%, 20%, 30%, 40%, of the cement is replaced with ceramic waste powder. The data of concrete made with ceramic waste is compared with data from a standard concrete without ceramic waste. Three cube samples were cast on the mould of size 150 x 150 x 150 mm for each 1:1.58:2.48 concrete mixes with partial replacement of cement with a w/c ratio as 0.45. After about 24 hrs the specimens were de-molded and water curing was continued till the respective specimens were tested after 7, and 28 days.

Material Used

Cement- Cement is a fine grey powder. Properties of the cement are listed in Table 1. It is mixed with water and materials such as sand gravel and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous material clay predominates and in calcareous materials calcium carbonate predominates.

Fine Aggregate- In this research work natural river sand has been used which is conforming to IS: 383 -1970 it lies in Zone II. Natural river sand is passing through from 4.75 mm sieve is used [11].

Coarse Aggregate- The fractions from 20 mm to 10 mm sieve are used as coarse aggregate. The Coarse Aggregates from crushed Basalt rock, conforming to IS: 383-1970. Table 2 gives the properties of aggregates. Specific gravity, water absorption and gradation of sand (FM) test, bulk density were carried out as per IS 2386 (part I -Part IV) – 1963 [12]. Properties of fine and coarse aggregate are listed in Table 2.

Water – Generally water that is suitable for drinking is satisfactory for used in concrete. Water from lakes and streams that contain marine life also usually is suitable Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Since it helps to from the strength giving cement gel, the quantity and quality of water are required to be looked into very carefully.

Table 1: Cement properties [10]

Physical property	Result obtained	IS: 8112 - 1989
Specific gravity	3.12	3.15
Fineness	2.90 m^2/kg	-
Soundness	2 mm	-
Normal consistency	27.5%	-
Initial setting time	110 minutes	30 minutes
Final setting time	180 minutes	600 minutes

Table 2: Properties of fine and coarse aggregate [12]

Aggregate	Specific gravity	Fineness modulus	Bulk density kg/m^3	Water absorption
Fine aggregate	2.7	2.8	1670	0.85%
Coarse aggregate	2.8	6.85	1690	1.3%

Experimental Programme

Ceramic waste electric insulator material collected from juet campus is break in to small pieces using compression testing machine. The collected output from the compression testing machine is put in to the loss Angeles machine to produced powdered ceramic. This waste is collected in the form of paste and after drying and hand crushing it passing through 90 microns and replaced by cement in concrete.

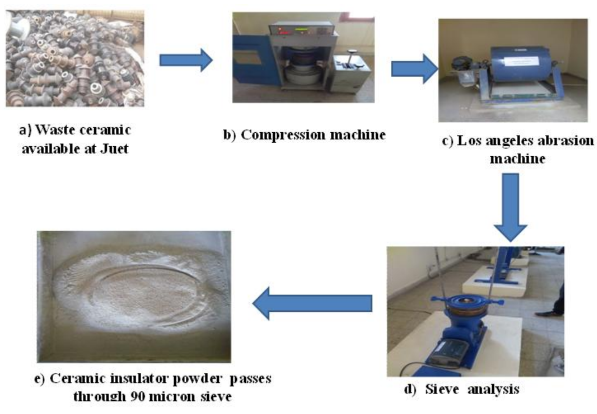


Figure 2: Processing of ceramic waste insulator [13]

Figure 2 Show the processing of ceramic waste electric insulator in which bigger waste pieces were converted into the small size pieces using compression testing machine. The small size pieces (50mm-80mm) collected from CTM machine, converted in to powdered ceramic using Los Angeles abrasion machine given 600 rotations. In ball mills it contains the powdered ceramic and 20mm- 40 mm size rounded shape ceramic waste aggregate. Again separation of the powdered ceramic formed in ball mills is carried out by sieving through 90 micron sieve before using it in concrete. Physical properties of the ceramic waste insulator powder are shown in Table 3.

Table 3: Physical and chemical properties of ceramic waste insulator powder

Property	Ceramic powder %
SiO_2	55.24
CaO	28.70
$Al2O_3$	13.25
MgO	0.82
SO_3	0.10
Na_2O	0.75
Fe_2O_3	4.28

Processes of Test: - Figure 3 The preparation of lime reactivity test above materials put in steel bowl and fit in planetary mixture machine add approximate water about 360 ml. Mix for two minutes immediately place the mortar in flow table mould and flow should cone 70.5 % with 10 drops in 6 seconds take another weight material as above make mortar from a same procedure and fill it in 6 no's 50 mm cube mould, keep it is moist chamber 65.5% relative humidity and 27+2C temp For 48 hours. After 48 hours removes the specimens from the mould and keep it for curing in humidity control oven for 8 day. Humidity and temperature should be maintained 90% minimum and 50+2C respectively. Compressive strength of ceramic powder with lime at 7 and 28 days are shown in Table 4.

Figure 3: Lime reactivity test on ceramic waste insulator powder [13]

Table 4: Compressive strength of ceramic powder with lime at 7 and 28 days

Compressive strength in N/mm2	7 days	28 days
	2.94	3.98

Concrete Mix design- A mix of M25 grade was designed as per Indian Standard method (IS 10262-2009) and the same was used to prepare the test samples (Table 5). The design mix proportion is 1:1.58:2.48 and water cement ratio used as 0.45 and sample is prepared with replacement of cement with ceramic powder at 0% 10% 20% 30% and 40% in concrete [14].

Table 5: Concrete Mix Design as per IS 10262-2009

S. No	% Replac-ement	Cement Kg/m3	F. A (Kg/m³)	C A (Kg/m³)	Water	Ceramic powder
1	0%	437 kg	682 kg	1177 kg	197 lit	0 kg
2	10%	393 kg	618 kg	1177 kg	197 lit	44 kg
3	20%	349 kg	602 kg	1177 kg	197 lit	88 kg
4	30%	306 kg	586 kg	1177 kg	197 lit	131 kg
5	40%	262 kg	570 kg	1177 kg	197 lit	175 kg

Results and Discussion

Water Absorption Test-Water absorption test was conducted on 100 mm cube specimen. Cube specimens were cast in triplicate for each mix and demoulded after 24 hours of casting. Specimens cured for 28 days in water were removed from curing tank and kept in laboratory conditions for eight weeks. Then these were dried in oven for 3 days at 55°C and then cooled in desiccators. The initial weight (W_1) was taken before immersing them in water for 24 hours. The final weight (W_2) was taken after wiping off all the excess water from the surface. Water absorption in percentage was calculated as follow:

$$\text{Water absorption} = (W_2-W_1) \times 100 / W_1 \qquad (1)$$

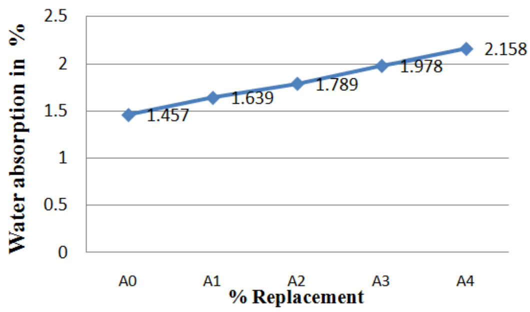


Figure 4: Percentage Replacement v/s water absorption in percentage after 28 days

Figure 4 shows the water absorption with various percentage replacement of ceramic waste after 28 days of curing. From the results of lime reactivity test the ceramic powder shows pozzolanic property due to which, by increasing the percentage of powdered ceramic in concrete, the water absorption of control concrete mix is as comparable to the concrete with ceramic waste.

Effect on Sulphate attack test [15]

Magnesium sulfate attacks calcium silicate hydrate as well as calcium hydroxide and calcium aluminates hydrate. The consequences of sulfate attack include not only disruptive expansion and cracking, but also loss of strength of concrete due to the loss of cohesion in the hydrated cement paste and of adhesion between it and the aggregate particles. Sulfates combines with the C-S-H, or concrete paste, and begins destroying the paste that holds the concrete together. As sulphate dries, new compounds are formed, often called ettringite. These new crystals occupy empty space, and as they continue to form, they cause the paste to crack further damaging the concrete. Physically sulfate attack, often evidenced by bloom (the presence of sodium sulphates Na2SO4 and/or Na2SO4.10H2O) at exposed concrete surfaces. Concrete attacked by sulfates has a characteristic whitish appearance. The damage usually starts at edges and corners and is followed by progressive cracking and spalling which reduce the concrete to a firable or even soft state. Compressive strength after 28 days with 5% $MgSO_4$ and without $MgSO_4$ is shown in Table 6.

Table 6: Compressive strength after 28 days with 5% $MgSO_4$ and without $MgSO_4$ [16]

Specimen designation	Compressive strength without sulphate after 28 day in N/mm²	Compressive strength with sulphate after 28 day in N/mm²
A0	32.55	30.6
A1	29.85	28.4
A2	27.05	25.52
A3	21.32	20.85
A4	18.73	17.93

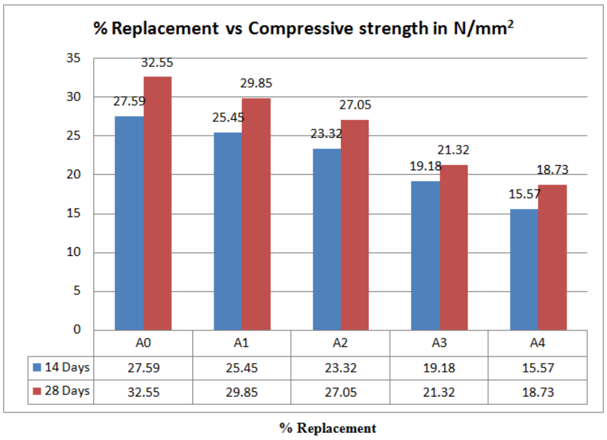


Figure 5: Percentage Replacement V/S Compressive Strength of Concrete At 5% of $MgSo_4$

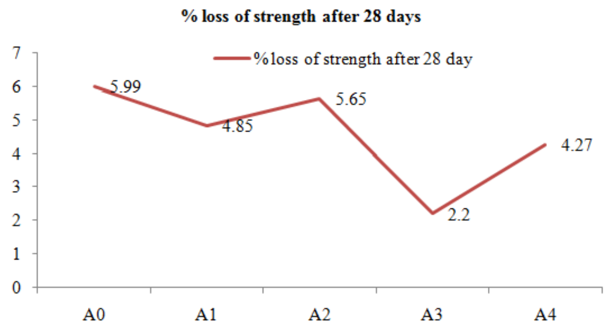


Figure 6: Percentage Replacement **v/s** Compressive Strength of Concrete At 5% Of $MgSO_4$

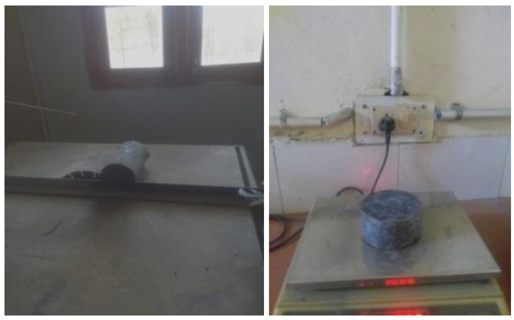
Figure 5 shows the 14 and 28 days of compressive strength at various level of percentage replacement of ceramic waste with 5% solution of $MgSO_4$ in concrete. The compressive strength is decreasing continuously by increasing the percentage of powdered ceramic. Solution of the sulfates of various bases including sodium, potassium, magnesium and calcium react with hydrated cement paste forming gypsum or a compound called ettringite (sulphoaluminate) which leads to the expansion and disruption of the concrete and mortar. Figure 6 shows the percentage loss of compressive strength at various level of replacement of ceramic powder. The trend of graph shows the variation in strength is very little but after 30 % of replacement again the loss of strength is increasing.

Sorptivity Test

Sorptivity test was conducted on a prism of 100mm x 100 mm x 70 mm at the age of 28 days. It was obtained by cutting and removing top 30 mm slice from a 100 mm cube specimen. Sides of the prism were coated with epoxy resin so that flow takes place unidirectional only from the bottom. Test specimens were kept in a pan as shown in before putting the specimens in the pan; they were dried in oven for 3 days at 55°C and then allowed to cool in desiccators. The water level in the pan was maintained at about 5 mm above the base of the specimens during the experiment. The specimens were removed from water, then excess water from surface was removed by absorbent cloth and the mass of the specimens was measured using a balance at the time intervals of 4, 9, 16, 25, 36, 49, 64, 81, 121, 144, 169, 196 and 225 minutes. The sorptivity co-efficient was calculated by the slope of line fitted to the plot of cumulative absorbed volume of water per unit area of inflow surface versus square root of time.

$$f_{sc} = i / \sqrt{t} \qquad (2)$$

Where, f_{sc} = sorptivity coefficient, mm/√min., i = cumulative absorbed volume of water per unit area of inflow surface, mm and t = elapsed time, min. For each test, measurements were obtained from three specimens and the average values were reported. Initial readings (up to 16 min.) were ignored to find the slope of best fitted curve. Figure 7 shows the core cutter machine used to prepare the samples to perform sorptivity test.



(a) (b)

Figure 7: (a) Cylinder Cutter Machine, (b) Cylinder Weight

Figure 8 shows the graph between sorptivity at different level of percentage replacement of ceramic powder with cement and square root of time t. In this graph the slope of the line is increases as we are increasing the percentage of ceramic powder in concrete. The line with lower slope shows the sorptivity at 0% ceramic and highest slope line with 40% ceramic. Basically sorptivity is the absorption of water due to capillary voids present in concrete.

Figure 9 shows the sorptivity coefficient with various % replacement of ceramic powder. The value of sorptivity coefficient is increasing as we are increasing the % replacement of ceramic powder. The slope of the best fitted curve is not too steep, it means the variation occurs is in very small values.

RCPT Test [17]

Testing Process- The Rapid Chloride Permeability Test is performed by monitoring the amount of electrical current that passes through a sample 50 mm thick by 100 mm in diameter in 6 hours (see schematic). This sample is typically cut as a slice of a core or cylinder. A voltage of 60V DC is maintained across the ends of the sample throughout the test. One lead is immersed in a 3.0% salt (NaCl) solution and the other in a 0.3 M sodium hydroxide (NaOH) solution. Figure 10 (a) shows the concrete sample used for RCPT and (b) shows the rcpt test instrument conducted for different percentage of replacement. Rating of chloride permeability of concrete according to ASTM C1202 [17] is listed in Table 7 and RCPT rating is listed in Table 8.

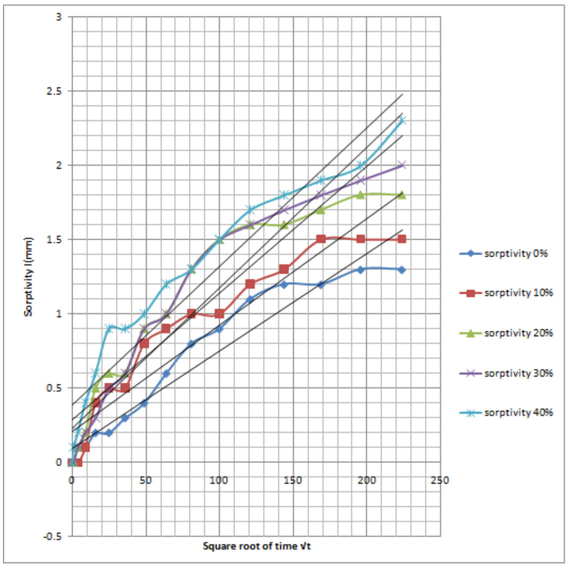


Figure 8: Graph between square root of time VS Sorptivity I (mm)

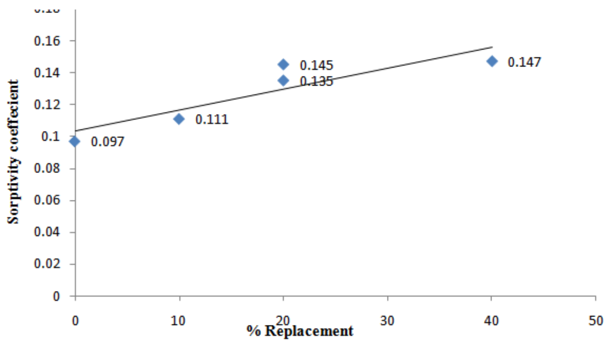


Figure 9: Sorptivity coefficient vs % Replacement

(a) (b)

Figure 10: Test sample and RCPT instrument (a) Test sample (b) RCPT Instrument

Table 7: Rating of chloride permeability of concrete according to ASTM C1202 [17]

Chloride permeability	Charge passing	Typical concrete type
High	>4000	High w/c ratio >0.6 conventional PC concrete
moderate	2000 to 4000	Moderate w/c ratio 0.40 to 0.50 conventional PC concrete
Low	1000 to 2000	Low w/c ratio <0.40 conventional concrete
Very low	100 to 1000	Latex modified concrete internally sealed concrete
Negligible	< 100	Polymer impregnated concrete. Polymer concrete

Table 8: RCPT Rating

Design specimen	Charge passed	Chloride ion permeability
A0	1205	Low
A1	1222	Low
A2	1849	Low
A3	1486	Low
A4	1180	low

Conclusions

The process of substituting 0 to 40 percent ceramic insulator waste powder as a partial replacement of cement was studied and then parameters of concrete like durability properties of concrete were observed. Finally, the following conclusions can be derived based on the present work and can be summarized as follows

1. Ceramic insulator waste can be used as partially replacement of cement in concrete.
2. Lime reactivity test show that it is a low reactive pozzolana. But it can be used up to 20-30% replacement level with cement gives satisfactory results.
3. As increases in percentage of ceramic waste the compressive strength after 28 days decreases at 5% $MgSO_4$, but up to 20% replacement it is higher than characteristics compressive strength design of M25 grade of concrete.
4. In water absorption test on increasing the percentage replacement of powdered ceramic the water absorption is also increasing but at a slower rate. This is due to low percentage of silica present in ceramic results less dense and compacted concrete.
5. In sorptivity test sorptivity coefficient is decreases with increase in percentage replacement of powdered ceramic. Capillary voids are formed due to hydration of unreacted particles in ceramic and cement.
6. In rapid chloride permeability test the charge passes through at various percentage replacement level shows low chloride permeability. From this study 20-30% replacement gives satisfactory results.
7. The ceramic waste can be innovative supplementary cementetious Construction Material but judicious decisions are to be taken by engineer.
8. When defective construction material is thrown away, or when a building is demolished, much incorporated energy is wasted. Using these wastes in to the concrete can reduce the production cost of concrete.

9. Concrete made using ceramic power as a partial replacement of cement will be durable when replacement level lies within 20-30 %.

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