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Ceramic Dust as Construction Material in Rigid Pavement

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Abstract Ceramic dust is produced as waste from ceramic bricks, roof and floor tiles and stoneware waste industries. Concrete (M35) was made by replacing % (up to 30%) of cement (OPC 53) grade with ceramic dust (passing 75µm) shows good workability, compressive strength, split-tensile strength, flexural strength and elastic modulus. In this experimental investigation, concrete specimens were tested at different age for different mechanical properties. The results show that with water – cement ratio (0.46), core compressive strength increase by 3.9% to 5.6% by replacing 20% cement content with ceramic dust. It was observed that no significant change in flexural strength and split-tensile strength when compared to the conventional concrete.

Keywords: *ceramic dust, cement, rigid pavement, flexural test*

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1. Introduction

The Indian ceramics industry, which is comprised of wall and floor tiles, sanitary ware, bricks and roof tiles, refractory materials and ceramic materials for domestic and others use is producing approximately 15 to 30 MT per annum waste. Out of total waste, 30% goes as waste in India and dumped the powder in open space. Ceramic waste is of generally two types, waste earthenware and also cracked during the manufacturing process. Ceramic waste is considered as non-hazardous solid waste and possess pozzolanic properties. Therefore, after recycling can be reuse in different building construction application [1,2,3,4,5]. Industrial wastes coarser than cement particles generally use as fine and coarse aggregate in concrete mix up to 35% tile waste [6,7].

The use of waste as an alternative to aggregate in highway construction would produce two major benefits; firstly, the natural aggregate quarry life can be extended. Secondly, the consumption of industrial space or productive land for dumping such waste may be reduced. The Indian concrete pavement are essentially jointed plain cement concrete with dowel bar of mild steel. The pavement quality concrete (PQC) for road slab (thickness varies from 290 to 350 mm) is mainly M40 and M35. Dowel bars are provided across transverse joints for load transfer and longitudinal joints are to connects adjoining lanes to relieve warping stresses. The PQC slab is generally placed over a layer of low grade dry lean concrete (DLC) of 150 mm thickness. A 125 mm thick antifriction polythene layer is used in between PQC and DLC [8,9].

Researchers used ceramic waste to make green concrete by using minimum 20% replacement natural aggregate. It was found that ceramic waste based concrete shows good workability and achieve characteristics strength. The permeation characteristics of green concrete is also reported as similar to the conventional concrete durability [10,11,12,13]. Use of non-hazardous industrial waste is also gaining popularity in India to use in building construction work for developing building material components. The waste was used in cement concrete up to 20% of conventional coarse aggregate is due to high absorption coefficient (0.5%) and achieved compressive strength approximately 50Mpa with and without super plasticizers additives [14,15,16]. Ceramic waste as a replacement of natural aggregate in concrete slab shows good abrasion resistance and tensile strength with confirmation of relevant standard. Ceramic waste used in road sub-base layer as filler and in PQC reached strength 40-50 Mpa. Even ceramic waste was also used to replace fine aggregate and found good compressive strength and abrasion resistance, together with less penetration by chlorides which could provide greater protection for the reinforcement used in reinforced concrete. Researches suggested that more than 20% replacement of natural coarse and fine aggregate with ceramic waste will decrease the compressive strength of the concrete. The reuse of ceramic waste in concrete road is viable and economical option to achieve target strength M35 after 28 days curing. Apart from replacing natural aggregate in concrete, ceramic waste also used in replacing cement percentage in concrete as additive, in the light of pozzolanic properties. Result shows that concrete used ceramic powder, possesses satisfactory mechanical and durability [17,18].

However, such a use of ceramic waste powder should not compromise the quality and performance of the highway infrastructure nor create environmental problems. Therefore, the aim of this research is to assess the feasibility of using ceramic dust with a particle size less than 75µm for partial replacement of cement percentage in paving quality concrete (PQC) and dry lean concrete (DLC) by investigating their mechanical properties in laboratory.

2. Material and Mix Proportion

In this research, mainly three materials were used namely ceramic waste, aggregate and cement to prepare required samples. Cement, aggregate and sand was used as per IS 456-2000 codal provision for construction of cement concrete road [19]. The ceramic waste was collected from Morbi Ceramic industrial area, Rajkot, Gujarat, India. The sample of the waste was collected manually and freshly at the beginning of the experimental work and stored as per standard specification. With the help of jaw crusher the ceramic wastes pieces wastes were broken into 20 mm maximum size coarse aggregate and same was made in dust form manually in Transportation Engineering Laboratory, CED, SVNIT, Surat. The physical and chemical property of ceramic waste was investigated for in SVNIT, Surat Laboratory. The specific gravity is estimated to be 2.717 and 98.5 % of ceramic dust passed through the sieve of 0.075mm. The chemical properties were given in Table 1 with the compliance of test method IS 3812 [20].

Figure 1. Ceramic waste in dust form

Table 1. Chemical properties of Ceramic dust

Sr. No.	Test Description	Result
1.	Aluminum Oxide, Al_2O_3	32.43%
2.	Calcium Oxide, CaO	2.16%
3.	Ferric oxide, Fe_2O_3	1.152%
4.	Magnesium Oxide, MgO	0.251%
5.	Potassium Oxide, K_2O	0.009%
6.	Silicon Oxide, SiO_2	60.21%
7.	Sodium Oxide, Na_2O	0.093%

The other ingredient OPC 53 Grade cement confirming to IS 12269-1987 and fine aggregate of Sp.gr. 2.66 and finesses modulus 2.65 confirming to IS 383-1970 was used along with coarse aggregate [21,22]. The physical properties of coarse aggregate such as aggregate impact test, Los Angeles Abrasion test, water absorption test etc. were performed in Transportation Engineering Laboratory, CED, SVNIT, Surat and presented in Table 2.

Table 2. Properties of Coarse Aggregate and Fine Aggregate observed in Laboratory Test

Sr. No.	Tests	Results	
		Fine Aggregate	Coarse Aggregate
1.	Aggregate Impact Test		20.24%
2.	Los Angeles Test	17.19%	
3.	Specific Gravity	2.73	2.87
4.	Water Absorption	1.29%	1.895%
5.	Bulk Density	1.657 gm/cc	1.420 gm/cc (10mm), 1.455 gm/cc (20 mm)
6.	Flakiness Index	9.41%	
7.	Elongation Index	12.80%	

3. Experimental Investigation

Based on physical strength requirements of DLC and PQC layers for concrete road, different experimental tests were conducted on the given samples. Potable water was used to mix with different ingredient to make concrete in ceramic as well as in conventional mix. The mix design methodology was developed based upon absolute volume method by conducting several trail mix and proportion of these mixes were used to find an optimum mix proportion. The different water content ratios (0.40, 0.42, 0.44, 0.46, 0.48 and 0.50) were used in different initial trails. For respective w-c ratio, volume of each concrete ingredient was same except cement, however, total volume was kept same in ceramic dust concrete mix and conventional concrete mix. With the control concrete environment, the cement was replaced in mix with 10%, 20% and 30% ceramics dust and mix content is given in Table 3.

Table 3. Proportion for Compressive Strength

Ingredients	% Ceramic waste dust			
	0	10	20	30
Cement (kg)	9.88	8.89	7.9	6.92
Ceramic Waste (kg)	0	0.90	1.58	2.08
Water (liter)	4.45	4.45	4.45	4.45
Sand (kg)	19.05	18.91	18.77	18.63
Coarse Aggregate (kg) (10mm)	8.89	8.82	8.76	8.69
Coarse Aggregate (kg) (20mm)	22.86	22.69	22.52	22.36
Admixtures (gms) (Sika LT10)	25	27	28	28
No. of Cubes	18	18	18	18

The concrete cube samples were cast in the mould of size 150x150x150 mm as shown in Figure 2 and placed on a level and rigid base. The filled moulds were kept in moist closet or moist room for 24 ± 1 hour after completion of vibration. The moulds were then removed and immediately submerged in clean fresh water and kept there until taken out just prior to breaking. The water was renewed every 7 days and was maintained at a temperature of 27 ± 2ºC. The slump of the fresh concrete was determined to ensure that it would be within the designing value and to study the effect of ceramic waste replacement on the workability of concrete and lies between 75 to 100 mm. The specimens were de-mould after 24 hours, cured in water and then tested at room temperature at the required age as shown in Figure 3.

The workability of mix proportion in this work was determined by slump cone test. Flow table was used to filled the mould and mixed was tampered. Slum test shows that maximum slum was observed in between 70 to 100 mm. If ceramic waste mixes increase up to 20% ceramic waste, results shows no detrimental effect on slump value. The physical and chemical properties of ceramic wastes resembles with the cement. So, it can replace the cement in concrete. In this study, ceramic waste was added in the ratios of 10%, 20% and 30%. All the cubes were tested on digital compression testing machine of capacity 2000 kN compressive load. The load was applied without shock and increased continuously at rate of approximately 140 kg/cm^2/min until the resistance of the specimen to the increasing load broke down and no greater load could be sustained.

Figure 2. Sample prepared for test

Figure 3. Cube compression test

Table 4. Proportion for Split Tensile Strength and Modulus of Strength

Ingredients	% Ceramic waste dust			
	0	10	20	30
Cement (kg)	6.65	5.99	5.33	4.66
Ceramic Waste (kg)	0	0.60	1.10	1.42
Water (liter)	2.99	2.99	2.99	2.99
Sand (kg)	12.82	12.73	12.64	12.54
Coarse Aggregate (kg) (10mm)	5.98	5.94	5.89	5.85
Coarse Aggregate (kg) (20mm)	15.38	15.27	15.2	15.05
Admixtures (gms) (sika LT10)	16.5	18	18	18.5

To determine the split tensile strength, cylinder moulds of diameter 150mm and length 300mm were casted. Totally, 18 cylindrical specimens were casted with different proportions of ceramic dust and mix content as shown in Table 4.

The crude black oil was applied as seen earlier along the inner surfaces of the mould for the easy removal of casted cylinder from the mould. To determine the flexural strength concrete was poured throughout its length of mould of size 1000 x150 x150mm and compacted well. The size of beam specimens is 1000 x150 x150mm. The beam specimens were cast and tested with and without ceramic waste for normal conditions.

Figure 4. Flexural testing on samples

Load cell was placed on the beam top and corrected to its centre by using plumb bob. Load cell was connected by the load indicator; three deflectometers were placed on the bottom side of the beam. Two point loading system was adopted for the test. Finally for the flexural strength 06 samples were prepared with the mix content as shown in the Table 5.

Table 5. Proportion for Flexural Strength

Ingredients	% Ceramic waste dust			
	0	10	20	30
Cement (kg)	20.9	18.81	16.72	14.63
Ceramic Waste (kg)	0	1.90	3.35	4.40
Water (liter)	9.41	9.41	9.41	9.41
Sand (kg)	40.3	40	39.71	39.41
Coarse Aggregate (kg) (10 mm)	18.81	18.67	18.53	18.4
Coarse Aggregate (kg) (20mm)	34.85	48	47.65	47.29
Admixtures (gms) (sika LT10)	52.5	56.5	58.5	58.5

4. Results and Discussion

The experimental investigation was done to determine Compressive strength, Flexural strength, Split Tensile strength and Modulus of Elasticity of concrete mixed with different ratios of 10%, 20% and 30% ceramic dust for DLC and PQC concrete.

4.1. Effect of Ceramic Dust on Compressive Strength of Concrete

The compressive strength was obtained at 7-days and 28 days of different samples of concrete. The results show that differences were wider in early age than after 28 days strength. The mechanical strength decreases considerably after ceramic dust percentage increases beyond 20%. Since, concrete pavement is become operational after 28 days, so this will not pose any problem in DLC and PQC quality.

As shown in Figure 5, The average 28 days compressive strength for different proportions of concrete result show that strength of concrete is increased, as ceramic waste quantity increases up to 20 %. Beyond, 20 % mix, it was reduces mainly. The 7-days compressive strength mix decreases by 28% and 17% with respect to conventional concrete mix. However, 28 days strength was having no significant change. The compressive strength significantly decreases due to excessive free water content in the mixes with ceramic waste content causes the bleeding and segregation in concrete. Therefore, it leads reduction in the concrete strength. For dry lean concrete, 7-day compressive strength required in between 6.5 Mpa to 10 Mpa. Less strength concrete is preferred in DLC as high strength concrete tends to develop crack. Therefore, less early age strength in ceramic waste concrete is beneficial in constriction of DLC. Regarding PQC the characteristic strength, 35 N/mm^2 is required after 28 days and traffic also get open after 28 days curing of PQC. This will also increase the debate as Indian specification makes it mandatory to achieve quantity of cement and quality of strength. As contractors are of the opinion that only required strength should be made mandatory and quantity of cement should be made optional. Required strength was achieved by using 280 Kg/m^3 for the given 20% ceramic waste in place of 350 Kg/m^3. Extra cement than required, only gives rise to increased CO_2 emission and leads to shrinkage cracks. Even minimum, 260 Kg/m^3 cement is also recommended for flyash mix concrete. Therefore, using 280 Kg/m^3 for ceramic waste mix concrete to achieve characteristic strength of M35 is may be useful saving.

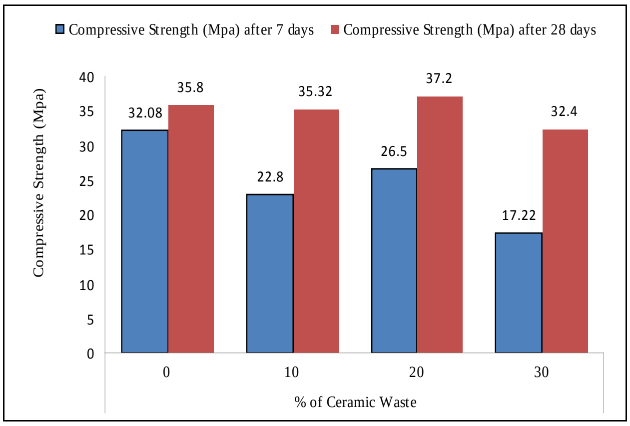
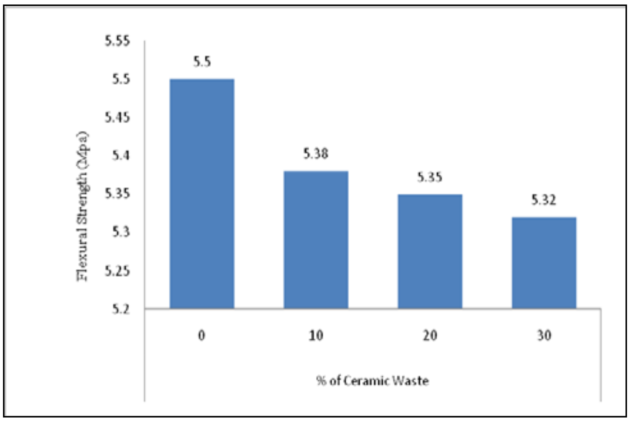


Figure 5. Test Result of Compressive Strength

4.2. Effect of Ceramic Dust on Flexural Strength of Concrete

Flexural strength of the concrete mix decreases as the percentage of ceramic waste in concrete increases. It is also noted that reduction in flexural strength decreases after every 10% addition of ceramic waste. It decreases by 0.12 Mpa on 10% addition of ceramic waste in concrete. The flexural strength decreases by 0.15 Mpa on further 10% addition of ceramic waste and by 0.18 Mpa on even further 10% addition of ceramic waste as shown in Figure 6. The decrease in flexural strength is not as significant as it satisfy the minimum flexural strength for PQC i.e. 4.5 Mpa. This criterion is also passed to use ceramic based concrete to construct rigid pavement.

In concrete road construction, flexural strengths are considered one of the important strength parameters. The results shows that cermic waste proportion uo to 20% is feable to use in DLC and PQC.



Figuer 6. Flexural Strenght (Mpa) after 28 days

4.3. Effect of Ceramic Dust on Split Tensile Strength of Concrete

The splitting tensile strength value varies from 0.89 Mpa to 1.28 Mpa at 7 days. It is observed that split tensile strength of the PQC decreases as the percentage of ceramic waste in concrete is increased up to 20 %. It decreases by approximately 0.037 Mpa on every 10% addition of ceramic waste. The loose bond of the matrix might have led to the decreasing values of split tensile strength as shown in Figure 7. However, results shows that splitting tensile strength will also have under limits and can be use in DLC and PQC.

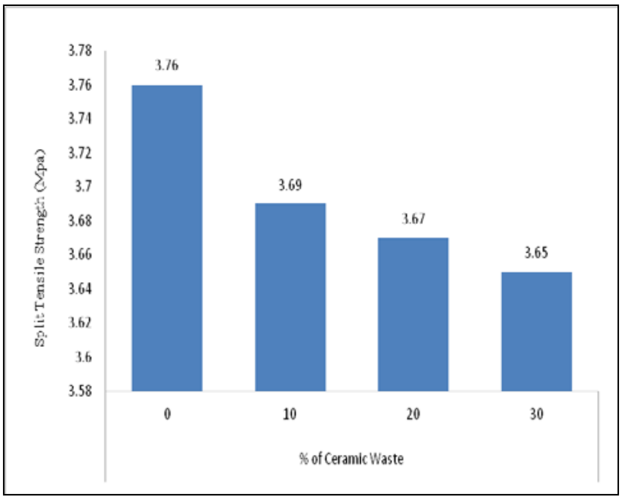


Figure 7. Spit Tensile Strength

4.4. Effect of Ceramic Dust on Modulus of Elasticity of Concrete

Recently, changes are made in Indian concrete road construction specification, IRC-58-2012, that strength based design should be followed rather than empirical methods. The results reveal that modulus of elasticity of the sample strength decreases as the percentage of ceramic waste in concrete is increased. It decreases by 2.2 % on 10% addition of ceramic waste in concrete. It decreases by 0.85 GPa as compared to control specimen on 20% addition of ceramic waste in mix as shown in Figure 8.

All of the beams tested failed in flexure with crushing of concrete in the compression zone at the failure stage after the development of flexural cracks. The first visible cracks formed between the locations of the two point loads in the region of maximum bending moment. Thereafter, as the load was increased more cracks started to form over the shear span on both sides of the beam. Flexural beams replaced with copper slag gives more flexural strength compared to the control specimens. Hence, it is concluded that 20% replacement of ceramic waste may be for PQC and DLC may be used with proper quality control and assurance.

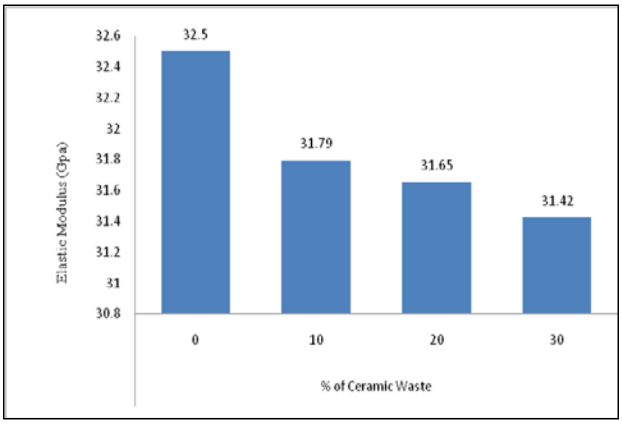


Figure 8. Elastic Modulus of ceramic based concrete

5. Conclusion

This paper aims at finding out the different strength characteristics of concrete mix of M35 grade using ceramic waste. Concrete mix with water – cement ratio of 0.45 were prepared. For each mix four different ceramic waste contents ranging from 0 to 30 percent at an interval of 10 percent are tried. A low level workability of 0 to 50 mm slump has been used in all mixes. Different tests such as Cube Compressive strength, Modulus of Elasticity, Split Tensile strength and Flexural strength were performed.

When comparison is made with control mix, the following conclusion is drawn.

1. The addition of ceramic waste has improved the compressive strength, split tensile strength and flexural strength of PQC and DLC.
2. The slump value of ceramic waste concrete lies between 75 to 100 mm.
3. There is an increase in the cube strength to the extent of 3.9% at w/c ratio of 0.46 with replacement of 20% ceramic wastes.
4. It was also found that split tensile strength and flexural strength results are insignificantly decreased at all water cement ratio at 2 to 3 % in comparison of conventional concrete. Hence, it is observed that waste ceramic ware can be used as an alternative constructional material (PQC and DLC) in road construction.
5. 20% replacement of ceramic waste contents slightly decreases at all w/c ratios but within the limits.
6. A field study may be undertaken at different climatic/ traffic conditions on NH or SH road.

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