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Concrete with ceramic waste aggregate

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Abstract

Use of hazardous industrial wastes in concrete-making will lead to greener environment. In ceramic industry about 30% production goes as waste, which is not recycled at present. In this study an attempt has been made to find the suitability of the ceramic industrial wastes as a possible substitute for conventional crushed stone coarse aggregate. Experiments were carried out to determine the compressive, splitting tensile and flexural strengths and the modulus of elasticity of concrete with ceramic waste coarse aggregate and to compare them with those of conventional concrete made with crushed stone coarse aggregate. The properties of the aggregates were also compared. Test results indicate that the workability of ceramic waste coarse aggregate concrete is good and the strength characteristics are comparable to those of the conventional concrete.

Keywords: Aggregate; Ceramic waste; Compressive strength; Tensile strength; Flexural strength

1. Introduction

It has been estimated that about 30% of the daily production in the ceramic industry goes to waste. This waste is not recycled in any form at present. However, the ceramic waste is durable, hard and highly resistant to biological, chemical and physical degradation forces. As the ceramic waste is piling up everyday, there is pressure on the ceramic industries to find a solution for its disposal. Meanwhile, conventional crushed stone aggregate reserves are depleting fast, particularly in some desert regions of the world [1]. Use of inorganic industrial residual products in making concrete will lead to sustainable concrete design and greener environment [2]. The need to develop concrete with non-conventional aggregates is urgent for environmental as well as economic reasons. A review of earlier research shows that industrial as well as other wastes were used in concrete-making to improve the properties of concrete and to reduce cost. Inclusion of recycled tyre rubber fibres in concrete was found to avoid the opening of cracks and increase energy absorption [3]. Structural light weight concrete has been produced using oil palm shells [4] and demolished masonry waste [5] as aggregates in concrete. An improvement in the modulus of elasticity of concrete was observed with partial replacement of crushed stone coarse aggregate by crushed vitrified soil aggregate [6]. Compressive strength was unchanged when ceramic waste was used to partially replace conventional crushed stone coarse aggregate [7]. The main objective of this investigation is to study the performance of concrete with ceramic waste coarse aggregate.

2. Experimental programme

The experimental programme comprises the following two stages:

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i. Characterization of ceramic waste aggregate and comparison with crushed stone coarse aggregate.
ii. Study the behaviour of fresh and hardened concrete with ceramic waste coarse aggregate and compare the respective properties with conventional concrete.

3. Materials

3.1. Ceramic waste as coarse aggregate

Ceramic electrical insulator industrial wastes (Fig. 1) are generally too big to be fed into a crushing machine. They are broken into small pieces of about 100–150 mm sizes by a hammer and the surface is deglazed manually by chisel and hammer. These small pieces are then fed into a jaw crusher to get the required 20 mm size (specific gravity 2.45 and fineness modulus 6.88) coarse aggregate (Fig. 1).

3.2. Other concrete mix components

Ordinary Portland Cement 53 Grade conforming to IS 12269-1987 [8], locally available river sand (specific gravity 2.67 and fineness modulus 2.62) conforming to IS 383-1970 [9] and natural crushed stone aggregate of maximum size 20 mm (specific gravity 2.68 and fineness modulus 6.95) conforming to IS 383-1970 were used in the conventional concrete.

3.3. Mix proportions

In the preliminary trials it was observed that the minimum operating water required was 186 litres per cubic meter of concrete for 20 mm maximum size of aggregate. Therefore, the water content was kept constant at 186 l/m^3 and the maximum size of coarse aggregate used was 20 mm for both ceramic waste coarse aggregate concrete and the conventional concrete. Six ceramic waste coarse aggregate concrete mixes were designed by the volumetric method with different water–cement ratios (0.35, 0.40, 0.45, 0.50, 0.55 and 0.60). Similarly, six more conventional concrete mixes were designed with crushed stone coarse aggregate. The volume of individual ingredients was the same in both the ceramic waste coarse aggregate concrete and the conventional concrete mixes. Ceramic waste coarse aggregate and crushed stone coarse aggregate were in a saturated and surface dry condition. The mix proportions are presented in Table 1.

3.4. Test details

The physical and mechanical properties of the ceramic waste coarse aggregate and conventional crushed stone coarse aggregate were determined as per IS 2386 (Part I–VIII)-1963 [10].

To understand the workability of ceramic waste coarse aggregate concrete and conventional concrete, slump test was conducted as per IS 7320-1974 [11].

For each mix, six cubes of size 100 mm, six cylinders of size 100 mm diameter and 200 mm long, six beams of size $100 \times 100 \times 500$ mm and six cylinders of size 150 mm diameter and 300 mm long were cast to determine compressive strength, splitting tensile strength, flexural strength and modulus of elasticity respectively at 28 days. The specimens were demoulded 24 h after casting and were cured under water at 27° ± 2 °C until the test age. To determine the above properties of ceramic waste coarse aggregate concrete and conventional concrete, all the tests were conducted as per IS 516-1959 [12].

Table 1
Mix proportions

Mix	w/c (by weight)	Cement kg/m^3	Proportions (by volume) C:FA:CA*
1	0.35	531	1:1.39:2.38
2	0.40	465	1:1.73:2.71
3	0.45	413	1:2.08:3.05
4	0.50	372	1:2.42:3.39
5	0.55	338	1:2.76:3.73
6	0.60	310	1:3.10:4.07

* Cement:fine aggregate:coarse aggregate.

Fig. 1. Ceramic waste and aggregate.

4. Discussion

4.1. Properties of ceramic waste coarse aggregate

The properties of ceramic waste coarse aggregate are presented in Table 2. The surface texture of the ceramic waste aggregate was found to be smoother than that of crushed stone aggregate. In the soundness test, after 30 cycles, the weight loss of ceramic waste aggregate was 51% less than that of conventional crushed stone aggregate, since ceramics have more resistance against all chemicals. In general, ceramic waste aggregate showed properties close to those of natural crushed stone aggregate.

4.2. Properties of ceramic waste coarse aggregate concrete

The properties of the ceramic waste coarse aggregate concrete are presented in Table 3. The results presented in the Table are the average of six tests. Fresh ceramic waste coarse aggregate concrete was more cohesive and workable than conventional concrete. This is due to the lower water absorption and smooth surface texture of the ceramic waste coarse aggregate.

The compressive strength varied from 51 to 30 MPa. As far as strengths are concerned, the basic trend in the behavior of ceramic waste coarse aggregate concrete is not significantly different from that of the conventional crushed stone aggregate concrete.

The splitting tensile strength varied from 4.5 to 3.2 MPa. The splitting tensile strength of ceramic waste coarse aggregate concrete was less than that of the conventional concrete, whereas the tensile to compressive strength ratio was lower for ceramic waste coarse aggregate concrete than that of the conventional concrete. The flexural strength varied from 6.9 to 4.7 MPa. The variations in flexural strength between ceramic waste

Table 2
Aggregate properties

Properties	Ceramic waste	Crushed stone
Specific gravity	2.45	2.68
Maximum size (mm)	20	20
Fineness modulus	6.88	6.95
Water absorption 24 h (%)	0.72	1.20
Bulk density (kg/m^3)		
Loose	1200	1350
Compacted	1325	1566
Voids—loose (%)	50	48
Voids—compacted (%)	45	44
Crushing value (%)	27	24
Impact value (%)	21	17
Abrasion value (%)	28	20
Soundness test:weight loss after 30 cycles (%)	3.3	6.8

Table 3
Properties of ceramic waste coarse aggregate concrete and conventional concrete mixes at 28 days

Mix	w/c	Cement content (kg/m^3)	Ceramic waste coarse aggregate concrete							Conventional concrete						
			Slump (mm)	Compressive strength		Splitting tensile strength		Flexural strength		Modulus of elasticity	Slump (mm)	Compressive strength		Splitting tensile strength		Flexural strength		Modulus of elasticity
				Mean (MPa)	C.V	Mean (MPa)	C.V	Mean (MPa)	C.V	Mean (GPa)		Mean (MPa)	C.V	Mean (MPa)	C.V	Mean (MPa)	C.V	Mean (GPa)
1	0.35	531	13	51.0	3.28	4.5	6.00	6.9	4.35	22.2	10	53.0	2.79	5.5	4.36	7.0	4.57	25.1
2	0.40	465	24	45.8	4.17	4.3	6.51	6.1	3.93	20.3	18	46.0	2.35	5.0	4.00	6.4	3.44	23.5
3	0.45	413	45	40.0	4.05	3.8	6.87	5.6	2.86	19.0	35	40.0	3.18	4.5	4.06	5.8	3.10	21.3
4	0.50	372	64	37.0	2.46	3.6	4.72	5.3	2.45	17.9	48	38.0.	2.29	4.4	3.18	5.5	2.91	20.5
5	0.55	338	99	34.0	2.44	3.5	3.71	5.0	3.00	17.5	80	35.0	2.03	4.1	3.42	5.3	2.64	18.3
6	0.60	310	155	30.0	2.73	3.2	5.63	4.7	2.55	16.1	148	31.0	1.77	3.9	3.59	5.0	3.40	16.5

Note: C.V is Coefficient of variation.

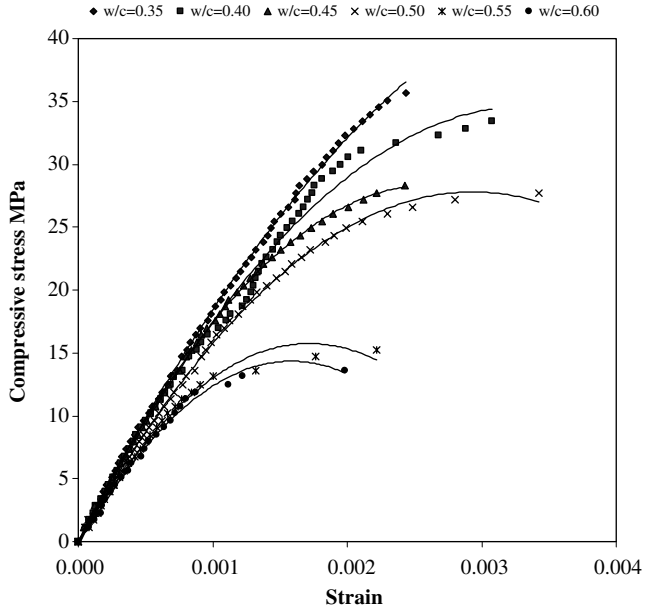

Fig. 2. Relationship between stress and strain for ceramic waste coarse aggregate concrete.

coarse aggregate concrete and conventional concrete are very small.

Fig. 2 shows the stress–strain behavior of ceramic waste coarse aggregate concrete. The modulus of elasticity of ceramic waste coarse aggregate concrete varied from 22.2 to 16.1 GPa. This is 13.6% to 2.4% lower compared to conventional concrete.

5. Conclusion

The following conclusions are drawn from the study on ceramic waste coarse aggregate concrete and they are applicable for the range of parameters and materials used in this study.

Ceramic waste can be transformed into useful coarse aggregate. The properties of ceramic waste coarse aggregate are well within the range of the values of concrete-making aggregates. The compressive, splitting tensile and flexural strengths of ceramic waste coarse aggregate concrete are lower by 3.8, 18.2 and 6% respectively when compared to conventional concrete, but ceramic waste coarse aggregate concrete possesses lower tensile to compressive strength ratio. The properties of ceramic waste coarse aggregate concrete are not significantly different from those of conventional concrete. This research work is the basis for further experiments on reinforced concrete members with the use of ceramic waste coarse aggregate concrete.

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