

# Mechanical Properties of Concrete with Ceramic Waste Aggregate

D.Gopinath and R.M.Senthamarai

Department of Civil and Structural Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, India

E-mail: dgnath008@gmail.com, d.g.nath008@gmail.com

(Received on 17 August 2012 and accepted on 25 October 2012)

**Abstract - Concrete prepared using ceramic waste as aggregate is comparable to conventional concrete prepared using HBG metal. Compressive strength, split tensile strength, flexural strength and modulus of elasticity of concrete with ceramic waste aggregate were studied. Compressive strength of the concrete with ceramic waste aggregate was compared to conventional concrete. Regression equations are proposed for predicting properties of concrete with ceramic waste aggregate.**

**Keywords: Concrete, Ceramic Waste, Mechanical Properties**

## I. INTRODUCTION

Concrete containing ceramic waste as coarse aggregate offers dual advantage of reasonable performance under various service conditions and helps to dispose unwanted waste material. The performance characteristics of concrete prepared using ceramic waste aggregate are comparable to those of concrete prepared using conventional stone aggregates.

The applicability of ceramic microspheres, known as cenospheres for light weight concrete was investigated by McBride *et al.* (2002). The investigation found that the interfacial bond between the ceramic aggregate and cement binder was inadequate and considered the addition of silica fume and a proprietary coupling agent. The addition of silica fume improved the compressive strength of the light weight concrete mixed with cenospheres by 80% and tensile strength by 35%.

Experimental investigations on the compressive strength, tensile strength, flexural strength and elasticity modulus of concrete prepared using ceramic waste aggregates revealed that the performance levels are comparable to those of conventional concrete prepared using crushed stone aggregates (Senthamarai, R.M. and Manoharan, P.D., 2005).

On the addition of ceramic powder as replacement for fine aggregate in concrete, performance under compressive loading was comparable to that of concrete prepared using river sand as fine aggregate (Lopez *et al.*, 2007).

Compressive strength and flexural strength of concrete prepared using ceramic waste aggregate as replacement for conventional stone aggregate was studied by Mashitah *et al.* (2008). The replacement of conventional aggregates by ceramic waste aggregate was in the range of 0% to 80% in steps of 20%. At 20% replacement of conventional aggregates by ceramic aggregate, compressive strength and flexural strength of concrete dropped by 19% and 13% respectively. At 80% replacement of conventional aggregates by ceramic waste aggregate, compressive strength dropped by only by 3% but tensile strength increased by 13%. The results indicated that mixing higher percentage of ceramic aggregate produces better concrete comparable to that prepared using conventional stone aggregates.

Experimental investigations on the suitability of ceramic waste aggregate for structural members concluded that concrete containing partial replacement of conventional stone aggregate by ceramic waste aggregate is suitable for structural applications (Mortinez *et al.*, 2009). Replacing conventional stone aggregates by ceramic waste aggregates did not adversely affect the compressive strength of concrete up to 20% (Reddy, V.M., 2010).

## II. EXPERIMENTAL PROGRAMME

Concrete was prepared in 3 different mix proportions, as shown in Table III. For each mix proportion, both conventional stone aggregate and ceramic waste aggregate were used. Test were carried out to find compressive strength, split tensile strength, flexural strength and modulus of elasticity for all the mix proportions.

### A. Material Properties

Fine aggregate used for preparation of concrete was a mix of sand (50%) and bottom ash (50%) obtained from powdered coal combustion residues from the thermal power plant of Neyveli Lignite Corporation. The combined fine aggregate was conforming to particle size distribution of grading zone II. The chemical properties of bottom ash are presented in Table I.

TABLE I CHEMICAL PROPERTIES OF BOTTOM ASH

Sl. No.	Chemical Property	Percentage
1	Loss on ignition	11.93
2	Silica (SiO <sub>2</sub> )	52.71
3	Iron Oxide (Fe <sub>2</sub> O <sub>3</sub> )	29.36
4	Titanium Oxide (TiO <sub>2</sub> )	0.00
5	Alumina (Al <sub>2</sub> O <sub>3</sub> )	1.53
6	Calcium Oxide (CaO)	0.00
7	Magnesia (MgO)	1.76
8	Sodium Oxide (Na <sub>2</sub> O)	0.23
9	Potassium Oxide (K <sub>2</sub> O)	0.41
10	Sulphur Trioxide (SO <sub>3</sub> )	2.07



Fig.1 Ceramic waste aggregates used in the experiment

Crushed ceramic aggregate was used as coarse aggregate for preparation of concrete. The crushed ceramic aggregates had maximum size of 20mm. Physical properties of the crushed ceramic aggregates are presented in Table II. For comparison with normal concrete, 20mm size stone aggregates were also used for preparation of mixes. Figs.1 and 2 show the ceramic aggregates and stone aggregates respectively.

TABLE II PHYSICAL PROPERTIES OF CRUSHED CERAMIC AGGREGATE

Sl. No.	Property	Value
1	Specific gravity	2.73
2	Maximum size	20 mm
3	Fineness Modulus	6.05
4	Surface texture	Smooth
5	Bulk density (Loose)	1410 kg/m <sup>3</sup>
6	Bulk density (Compacted)	1523 kg/m <sup>3</sup>
7	Voids (Loose)	48.00%
8	Voids (Compacted)	44.32%
9	Crushing strength	17 kg/mm <sup>2</sup>
10	Impact strength	8 J/m <sup>2</sup>



Fig.2 Stone aggregates used in the experiment

Ordinary Portland Cement (OPC) was used for mixing concrete. Different water cement ratios were adopted for preparation of concrete.

### B. Mix Proportions

In addition to the concrete mixes with ceramic waste aggregate, normal concrete with stone aggregates having identical ratio was also prepared. The fine aggregate for stone aggregate concrete was made up of 50% sand and 50% bottom

TABLE III CONCRETE MIXES ADOPTED FOR THE INVESTIGATION

Sl. No.	Mix Designation	Mix Ratio	Water Cement Ratio	Cement content (kg/ m <sup>3</sup> )	Water content (litre/m <sup>3</sup> )
1	CC-300 1	:2.41:3.73 0	.58	300	175
2	CC-350 1	:1.93:3.19 0	.50	350	175
3	CC-400 1	:1.56:2.79 0	.44	400	175
4	CW-300 1	:2.41:3.73 0	.58	300	175
5	CW-350 1	:1.93:3.19 0	.50	350	175
6	CW-400 1	:1.56:2.79 0	.44	400	175

ash obtained from Neyveli Lignite Corporation. For ceramic waste aggregate concrete, the fine aggregate was made up of 42.5% of sand, 42.5% of bottom ash from Neyveli Lignite Corporation and 15% of silica fume.

Table III shows the mixes of concrete used in this experimental investigation. The mix designations CC-300, CC-350 and CC-400 refer to the three mixes of concrete prepared using traditional 20mm size stone aggregate. The mix ratios CW-300, CW-350 and CW-400 were prepared using ceramic waste aggregate to replace the stone aggregate.

**III. EXPERIMENTAL PROGRAMME**

Twelve cylindrical specimens having 150mm diameter and 300mm length were prepared for testing in the compression testing machine having 2000kN capacity. For each mix designation, two specimens were prepared and tested after 28 days and 56 days curing. The compressive load was applied in small steps and the corresponding compressive strains were recorded.

**IV. RESULTS AND DISCUSSION**

The relationship between compressive stress and strain is shown in Figs.3 to 6. The compressive strength values for the concrete specimens are shown in Table IV.

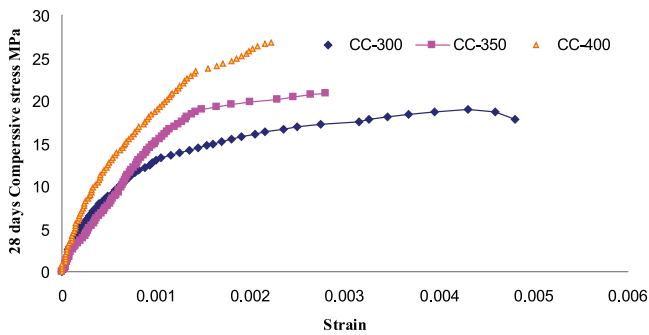


Fig.3 Stress-strain behaviour of stone aggregate concrete after 28 days of curing

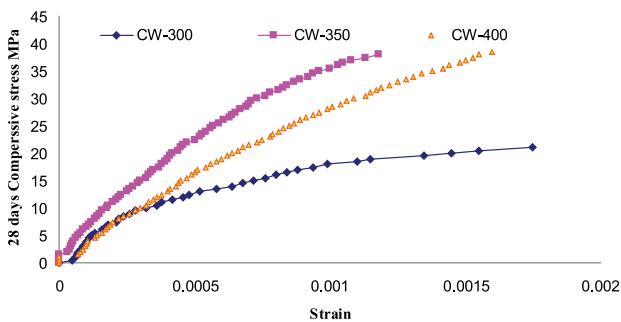


Fig.4 Stress-strain behaviour of ceramic waste aggregate concrete after 28 days of curing

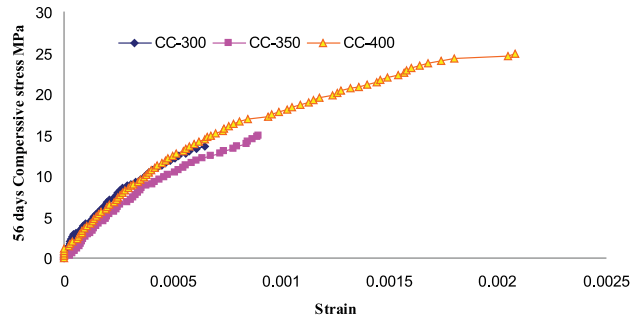


Fig.5 Stress-strain behaviour of stone aggregate concrete after 56 days of curing

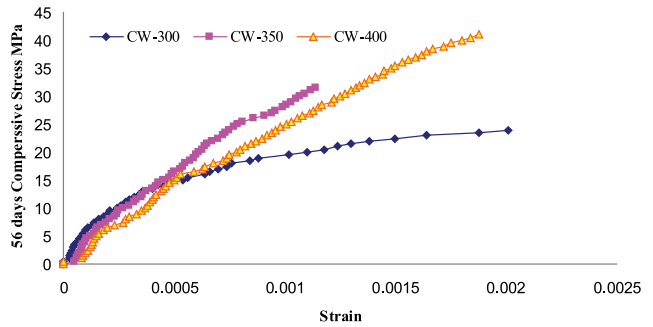


Fig. 6 Stress-strain behaviour of ceramic waste aggregate concrete after 56 days of curing

TABLE IV COMPRESSIVE STRENGTH OF CONVENTIONAL AND CERAMIC WASTE AGGREGATE CONCRETES

Sl. No.	Mix Designation	Compressive strength	
		at 28 days (MPa)	at 56 days (MPa)
1	CC-300	21.30	22.20
2	CC-350	26.60	27.80
3	CC-400	30.33	31.70
4	CW-300	27.40	29.80
5	CW-350	36.28	39.60
6	CW-400	39.45	

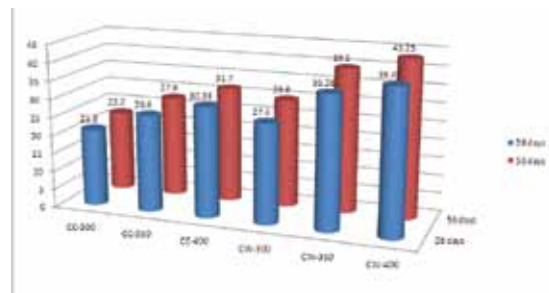


Fig. 7 Stress-strain behaviour of ceramic waste aggregate concrete after 56 days of curing

The results indicate that the concrete prepared using ceramic waste aggregates resulted in marginally higher compressive strength compared to the concrete prepared using traditional stone aggregates. The increase in compressive strength of ceramic waste aggregate concrete over traditional stone aggregate concrete was in the range of 29% to 36% at 28 days and in the range of 34% to 42% at 56 days.

The reduction in water cement ratio in stone aggregate concrete resulted in 25% and 42% increase in compressive strength at 28 days for water cement ratios of 0.50 and 0.44 over the reference level of 0.58. Reduction in water cement ratio from 0.58 to 0.50 and 0.44 resulted in 70% and 85% increase in compressive strength of ceramic waste aggregate concrete respectively.

At 56 days, the increase in compressive strength of stone aggregate concrete due to reduction in water cement ratio from 0.58 to 0.50 and 0.44 is 25% and 43% respectively. For ceramic waste aggregate concrete, the increase in compressive strength due to same level of reduction in water cement ratio was 78% and 95% respectively.

The results indicate that concrete prepared using ceramic waste aggregates presented compression performance which comparable to the traditional concrete prepared using stone aggregates.

#### A. Regression Equation

Multivariate regression analysis was performed to formulate a relationship between compressive strength, type of aggregate, number of days of curing before testing and water cement ratio of concrete.

The fitness value was 0.97 and the root mean square error was 3.69%. The regression equation is presented as follows:

$$f_c = 54.314 + 9.308A_t + 0.077D - 79.372R_{wc}$$

Where,

$f_c$  - compressive strength, MPa

$A_t$  - Type of aggregate, 1 for stone aggregate, 2 for ceramic waste aggregate

$D$  - Number of days of curing, 28 or 56 days

$R_{wc}$  - Water cement ratio

The equation shown above may be used to calculate the compressive strength of stone aggregate or ceramic waste aggregate concrete, at 28 or 56 days of curing and water cement ratio in the range of 0.44 to 0.58.

#### V. CONCLUSIONS

Compressive strength of ceramic waste aggregate was investigated, using twelve specimens tested at 28 or 56 days of curing. Fine aggregate for the concrete was made up of sand conforming to grading zone-II (50%) and bottom ash obtained from powdered coal furnace of Neyveli Lignite Corporation (NLC) power plant (50%). Following deductions are made from the experimental results:

- i. Compressive strength achieved by ceramic waste aggregate concrete was marginally higher than that achieved by stone aggregate concrete.
- ii. Reduction in water cement ratio resulted in increase of compressive strength for the ceramic waste aggregate concrete. This behaviour conforms to that of stone aggregate concrete.
- iii. Reduction in water cement ratio led to increase in compressive strength upto 85% at 28 days and 95% at 56 days for ceramic waste aggregate concrete.

The regression equation proposed using the results of this study may be used for calculating the compressive strength of concrete prepared using tradition stone aggregates or ceramic waste aggregates after 28 days or 56 days of curing for water cement ratio in the range of 0.44 to 0.58.

#### REFERENCES

- [1] S. P. McBride, A. Shukla and A. Bose, "Processing and characterization of a lightweight concrete using cenospheres," *Journal of Materials Science*, Vol. 37, pp. 4217 – 4225, 1988.
- [2] R. M. Senthamarai and D. P. Manoharan, "Concrete with Ceramic Waste Aggregate," *Elsevier Jnl. of Cement and Concrete Composites*, Vol. 27, No. 9 & 10, pp. 913, 2005.
- [3] M. S. Mashitah, C. C. Kin and A. H. Badorul, "Recycling of Homogenous Ceramic Tiles for the Production of Concrete Block," *Proc. International Symposium on Environmental Management: Hazardous-Environmental Management Toward Sustainability*, pp. 22-23, Thailand, pp. 54-62, September 2005.
- [4] V. L. Lopez, B. Llamas, A. Juan, J. M. Moran and I. Guerra, "Eco-efficient Concretes: Impact of the Use of White Ceramic Powder on the Mechanical Properties of Concrete," *Jl. of Biosystems Engineering*, Vol. 96, No. 4, pp. 559–564, 2007.
- [5] C. M. Martínez, M. I. G. Romero, J. Pozo, and A. J. Valdés "Use of Ceramic Wastes In Structural Concretes," *Proc. 1st Spanish National Conference on Advances in Materials Recycling and Eco – Energy Madrid*, pp. 137-139, November 2009.
- [6] V. M. Reddy, "Investigations on stone dust and ceramic scrap as aggregate replacement in concrete," *Intl. Jl. of Civil and Structural Engg.*, Vol. 1, No. 3, pp. 661-666, 2010.
- [7] T. Sekar, N. Ganesan and N. V. M. Nampoothiri, "Studies on Strength Characteristics on Utilization of Waste Materials as Coarse Aggregate in Concrete," *Intl. Jl. of Engineering and Technology*, Vol. 3, No. 7, pp. 5436-5440, 2011.
- [8] G. Murali, R. Saravanakumar, C. Balaji, R. Muthuraman, V. SreeKavitha and S. Archana, "Experimental Investigation on Concrete with Different Waste Stone as a Aggregate," *Intl. Jl. of Engineering and Technology*, Vol. 2, No.3, pp. 253-256.