# Mechanical Properties of Concrete with Ceramic Waste Aggregate

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*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 McBridge *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 ($SiO_2$) | 52.71 |
| 3 | Iron Oxide ($Fe_2O_3$) | 29.36 |
| 4 | Titanium Oxide ($TiO_2$) | 0.00 |
| 5 | Alumina ($Al_2O_3$) | 1.53 |
| 6 | Calcium Oxide (CaO) | 0.00 |
| 7 | Magnesia (MgO) | 1.76 |
| 8 | Sodium Oxide ($Na_2O$) | 0.23 |
| 9 | Potassium Oxide ($K_2O$) | 0.41 |
| 10 | Sulphur Trioxide ($SO_3$) | 2.07 |

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 $kg/m^3$ |
| 6 | Bulk density (Compacted) | 1523 $kg/m^3$ |
| 7 | Voids (Loose) | 48.00% |
| 8 | Voids (Compacted) | 44.32% |
| 9 | Crushing strength | 17 $kg/mm^2$ |
| 10 | Impact strength | 8 $J/m^2$ |

Fig.1 Ceramic waste aggregates used in the experiment

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/ $m^3$) | Water content (litre/$m^3$) |
|---|---|---|---|---|---|
| 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.

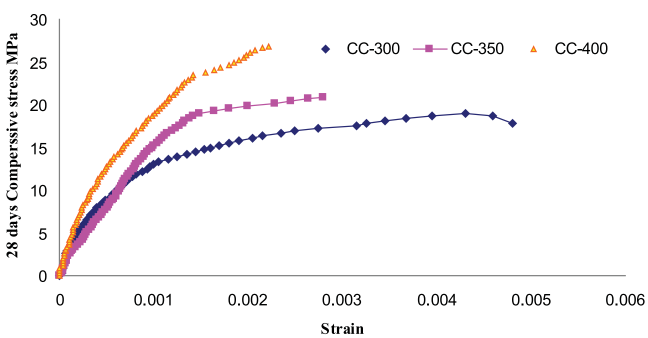


Fig.3 Stress-strain behaviour of stone aggregate concrete after 28 days of curing

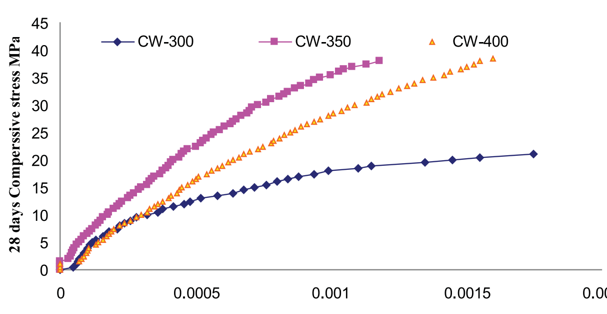


Fig.4 Stress-strain behaviour of ceramic waste aggregate concrete after 28 days of curing

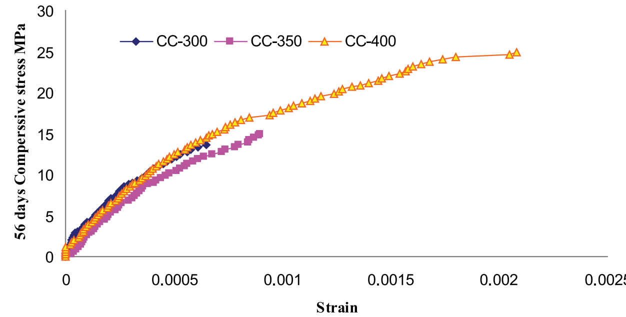


Fig..5 Stress-strain behaviour of stone aggregate concrete after 56 days of curing

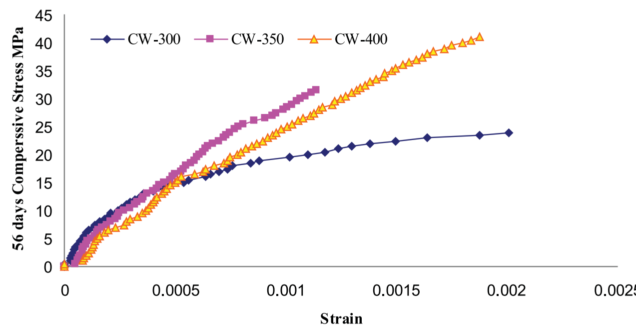


Fig. 6 Stress-strain behaviour of ceramic waste aggregate concrete after 56 days of curing

Table IV Compressive Strength of Conventional and Ceramic Waste Aggregate Concretes

| Sl. No. | Mix Designation | Compressive strength at 28 days (MPa) | Compressive strength 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 | |

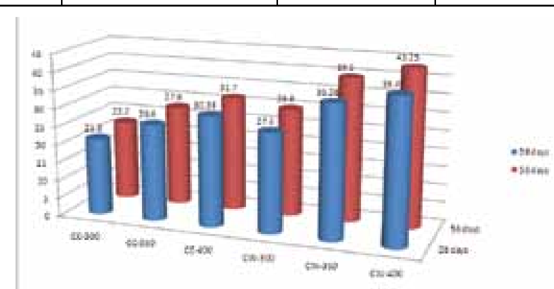

Fig. 7 Stress-strain behaviour of ceramic waste aggregate concrete after 56 days of curing

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,

$f_c$ - *ompressive 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*

$R_{we}$ - *Water c*ement 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.

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