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Strength Characteristic of Recycled Aggregate with Silica Fume as Admixture

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***Abstract:** In this study, conventional concrete is developed using recycled aggregates with micro silica (silica fume) as admixture. The concrete mix is designed for target strength of 25 MPa. Coarse aggregate were partially with recycled aggregate at 15 %, 30 % and 45 %. The relative parameters influencing the strength of concrete were studied in terms of recycled aggregate and silica content respectively. Test results reveled concrete produced with 45% of recycled aggregate tend to reduce the strength by 12% whereas addition of silica fume (10%) enhances the strength comparable to control mix (M25). Addition of microsilica functions as microfilling action in unreacted core of concrete which enhances the physical and mechanical properties of concrete. The significant reduction in compressive strength is noticed, when the recycled aggregate is increased beyond 30%.*

***Keywords:** Conventional concrete; Coarse aggregate; Recycled aggregate; Silica Fume.*

I.INTRODUCTION

Concrete is widely used construction material in the world because of its large scale application over infrastructure development activities. Concrete is used more than any man made product in the world, and it is the second most consumed product next to water in the current world. Every year the concrete industry produces 12 billion tons of concrete and 1.6 million tons of Portland cement worldwide. Construction and demolition (C and D) waste is one of the largest waste flows in the world. In India, the central pollution board control has assessed that solid waste generated is about 48 million tonnes per annum of which 25% is from construction industry. Disposal of C&D waste is not only an environmental concern but also has a major influence on the conservation of natural resources by avoiding excavation of raw material. It is estimated that the global demand for aggregate will rise at an annual rate of about 5.2% and can reach 55 billion metric tons in 2020. Global demand for these resources has almost doubled since 2004, and the world becomes more populated and urbanized, the demand will continue to rise in future. Utilization of C&D waste as an alternative to natural aggregates resolves the environmental issues such as disposal to landfill and gradual drop in opening new stone quarries by addressing the sustainability issues (Etxeberria et al. 2007). Quality of recycled aggregate mainly depends on the type of aggregate used for construction and cement mortar adhered to aggregate surface (De Juan and Gutiérrez 2007).

Recycled aggregates are generally characterized by high water absorption and lower density of material due to unhydrated cement particles accumulated over surface of aggregate (Li et al. 2018). Several authors reported the mechanical properties of concrete produced recycled aggregates decreased with increase in percentage of recycled content (Silva et al. 2016). Prime reason for reduction in strength of recycled aggregate induced concrete is due to existence of dual interfacial transition zone, one existing between natural aggregate and old cement mortar another being new mortar and recycled content affecting the performance of concrete (Francesconi et al. 2016). Flexural strength and modulus of elasticity of RA (Recycled Aggregate) incorporated concrete mixes exhibits similar strength as those natural aggregates (Limbachiya et al. 2000). Concrete mixes developed with recycled aggregate exhibits lower durability property compared to conventional concrete (Sasanipour 2020, Kisku 2017). Cement particles adhered over aggregate surface plays a vital in resistance towards ingress of foreign material thereby influencing strength and durability aspects (Guo et al. 2018). However, the durability issues related to recycled aggregate concrete can be addressed by addition of pozzolanic material along with admixtures (Wang et al. 2016). The main aim of this paper is to develop the concrete with recycled aggregate and pozzolanic material along with admixture that enhances the performance of concrete. To study the feasibility of recycled aggregate for structural application.

II.MATERIAL AND METHODOLOGY

1.1 Cement

In this study, Ordinary Portland Cement (OPC) 43 grade conforming IS 8112-1989 obtained from local dealers. Physical properties of cement used in this study are given in Table-1.

Table-1 Physical properties of OPC-43 grade

Test	Results
Consistency	32%
Soundness	2mm
Intial setting time	43min
Final setting time	180min
Specific gravity	3.05
Fineness	2%
Compressive strength (28 days)	32.05N/mm2

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1.2 Coarse Aggregate

Crushed stone pieces of maximum nominal size of 20mm down were used as coarse aggregates confirming to IS 383-2004. Physical properties of coarse aggregate used in this study are given in Table-2.

Table-2 Physical properties of coarse aggregate

Test	Result
Specific gravity	2.75
Bulk density	1.70
Water absorbtion	1.1
Fineness modulus	6.8
Flakiness index %	17.5
Elongation index %	19.5

1.3 Recycle Coarse Aggregate

Recycled Aggregates obtained from crushed slab and crushed Beams at construction site confirming to IS 383-2004. Physical properties of recycled coarse aggregate used in this study are given in Table-3.

Table-3 Physical properties of recycled coarse aggregate

Properties	Result
Specific gravity	2.95
Bulk density	1.70
Water absorbtion	4.1
Fineness modulus	6.26
Flakiness index %	17.5
Elongation index %	19.5

1.4 Fine Aggregate

Locally available river sand used as fine aggregate. Sand used in this belongs to zone-II as per IS 383-2004. Physical properties of fine aggregate used in this study are given in Table-4.

Table-4 Physical properties of fine aggregate

Test	Result
Specific gravity	2.57
Bulk density kg/m^3	1534
Water absorbtion	0.9
Fineness modulus	2.7

1.5 Silica Fume

Silica fume (micro silica) used in this study was procured from local chemical dealers confirming to IS 15388-2013.Physical and chemical properties of silica fume are given in Table-5 and Table-6 respectively.

Table-5 Physical properties of silica fume

Test	Result
Specific Gravity	2.42
Fineness (%)	--
Specific Surface Area (kg/m^2)	496
Standard Consistency (%)	31
Initial Setting Time	120
Final Setting Time	300

Table-6 Chemical properties of silica fume

Test	Result
Silica (SiO_2)	2.42
Alumina Oxide (Al_2O_3)	--
Ferric Oxide (Fe_2O_3)	496
Calcium Oxide (CaO)	31
Magnesium Oxide (MgO)	120
Loss on Ignition	300

1.6 Mix Design

Mix design for M25 grade of concrete was carried as per IS 456-2000. All the materials were proportioned by volume batching method. The conventional concrete and concrete with recycled aggregate content of 15%, 30 % and 45 % were cast with appropriate dosage of silica fume. The resulting homogenous mix of concrete was subjected to workability test with slump cone. Then the cube specimens were cast using 100 mm x 100 mm x 100 mm moulds for determining the compressive strength and water absorption test. Cylindrical specimens, 150 mm diameter x 300 mm height, were casted for young's modulus test and split tensile strength test. Similarly prism specimens, 500 mm x 100 mm x 100 mm moulds for determining the flexural strength. All the specimen were de-moulded after 24hrs and then subjected to water curing under room temperature. Sufficient numbers of specimen were cast for facilitating compressive strength test at the age of 3-days, 7-days and 28-days.

Table-7 Constituents of mixes (kg/m^3)

Mix ID	Cement (kgs)	Coarse aggregate(kgs)	Fine aggregate(kgs)	Recycled coarse aggregate(kgs)	Silica fume(kgs)	Water (kgs)
M1	392	1141	682	0	0	210
M2	392	970	682	171	0	215.28
M3	392	799	682	342	0	220.15
M4	392	628	682	513	0	225
M5	353	624	676	510	39	224.78

Note: Water content is adjusted considering water absorption of coarse aggregate , Recycled concrete aggregate & Fine aggregate

1.7 Results and Discussions

1.7.1 Workability

Workability of Recycled Aggregate (RA) induced concrete mixes were conducted as per IS 1199-2004 and the test results are depicted in Fig. 1. High porosity of recycled aggregate has greater influence on water to cement (w/c) ratio. Therefore, required w/c ratio fixed based on initial trials by considering the size, shape and texture of recycled aggregate.

1.7.2 Compressive strength

Compressive strength test was conducted as per IS 516:2004 and test results are depicted in Fig. 2. Addition of silica fume to the sole binder increased the compressive strength; likewise, increased aggregate (recycled) content also contributes to the strength development. Gradual drop in the compressive strength was observed with increase in recycled aggregate content (15%, 30% and 45%). Meanwhile, addition of silica fume as an admixture improves the strength properties by filling the voids through micro filling action hence increase in strength is achieved for the mixes with silica content. This phenomenon is observed for the mixes with 45% recycled aggregate and 10% silica fume showing comparable results with control mix.

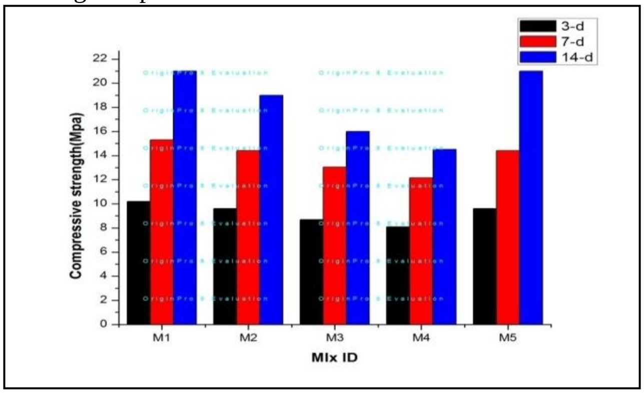

Figure.1 Compressive strength of RA induced concrete mixes

1.7.3 Split tensile strength

Split tensile strength tests were performed according to IS 5816-2004 and the results are as shown in Figure-2 for the various mixes, at 28-days curing period. In the concrete mixes with the presence of high calcium compound, it was observed that voids in silicate matrix were filled with Calcium silicate hydrate (CSH) products resulting in increased strength (Hanjitsuwan et al.2014).

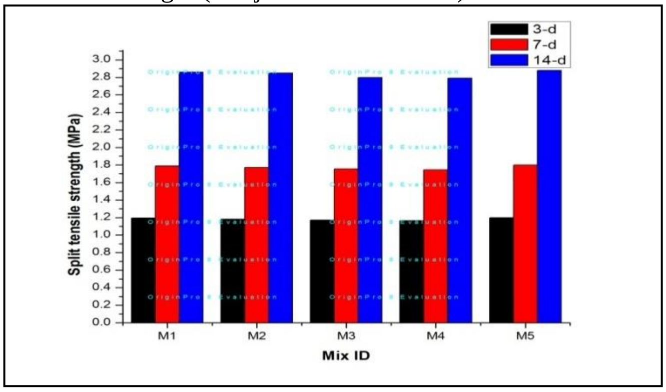

Figure.2 Split tensile strength of RA induced concrete mixes

Recycled aggregate concrete mixes were tested for modulus of elasticity according to IS 516:1959 after 28-days curing period and the results are shown in Table-7. There is variation in the relationship of tensile strength and elastic modulus due to formation of microstructure at varying hydration reaction, binder type and rate of strength development with 28-days strength.

Table-8 Modulus of Elasticity of various Recycled aggregate concrete mixes

Mix ID	Modulus of Elasticity (MPa)
M1	31780
M2	25780
M3	26500
M4	27560
M5	30950

2.7.4 Flexural strength

Flexural strength was determined as per IS 516:2004 for all the concrete mixes. The static flexural strength tests were conducted at 28-days of curing and the results are shown in Fig. 3. It is observed that the higher percentage of recycled aggregate decreases the flexural strength at 28-days curing, resulting due to existence of dual interfacial transition zone between aggregate and cement matrix which hinders the hydration reaction resulting in lower strength of concrete which was observed in case of compressive strength.

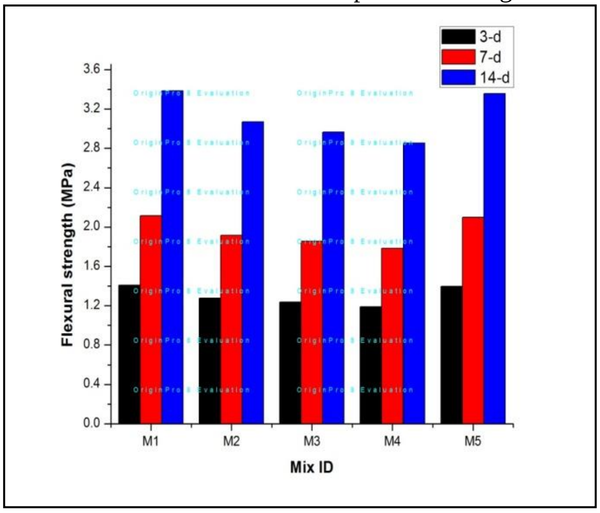

Figure.3 Flexural strength of RA induced concrete mixes

III.CONCLUSIONS

This paper has provided extensive experimental results and analysis on the workability, compressive, split tensile and flexural strength of concrete mixes developed using recycled aggregate. Based on the experimental findings, the following conclusions can be drawn.

- Workability of concrete containing recycled aggregate is significantly decreased because of high porosity and low density of recycled aggregate requires a large amount of water to achieve the required slump.

- Irrespective of the curing period of recycled aggregate concrete, an increase in the percentage of recycled aggregate diminishes compressive, tensile and flexural strength. However, addition of silica fume enhances the performance of recycled aggregate concrete.
- Concrete mixes produced with recycled aggregate produced have shown similar mechanical properties to control mix produced with natural coarse aggregate, even when the natural aggregates replacement percentage reaches upto 45%.
- Recycled aggregate with 45 % replacement for natural aggregate with 10% silica fume shows comparable results with control mix.

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