Mechanical Properties of Concrete with Admixed Recycled Aggregate

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***Abstract*— The concrete industry alone uses 20 billion tons of aggregates, 1.5 billion tons of cement and 800 million tons of water. The overexploitation of natural aggregate may reduce the resources to a crucial level, compromising the needs of future generation. Thus the necessity of conservation of natural aggregate leads to the use of recycled aggregate and this may provide sustainable development. But the use of recycled aggregate will cause reduction in strength and durability due to the adhered cement mortar. This strength can be improved by the addition of mineral admixture such as metakaolin. In this study, metakaolin is added as a partial replacement of recycled aggregate. The fresh and hardened properties of four mixes such as M20, M30, M40 and M50 mixes with admixed recycled aggregate is studied.**

***Keywords: Natural aggregate, Recycled aggregate, Sustainable development, Metakaolin*.**

I. INTRODUCTION

A. General

Concrete is a major construction material and plays a crucial role in the improvement of infrastructures such as highways, bridges, buildings etc. It is estimated that the total annual concrete production over the world is more than 10 billion tons[1]. The concrete industry alone uses 20 billion tons of aggregates, 1.5 billion tons of cement and 800 million tons of water. The idea of the conservation of natural aggregate (NA) has been largely ignored despite the fact that coarse aggregates make up 40–50% of a concrete mix by volume while cement makes up about 10%[2]. Volume of cement and concrete production probably will continue to increase. The overexploitation of NA may reduce the resources to a crucial level, compromising the needs of future generation. Thus the necessity of conservation of NA leads to the use of recycled aggregates (RA) and this may provide sustainable development. Sustainable development means development that satisfies the present needs without limiting the possibilities of fulfilling the needs in the future. The use of aggregate obtained from crushed concrete is an example of recycling and conservation of raw materials. It is estimated that about 450 million tons of construction waste is generated every year with only 28% recycled and 72% disposal, which has caused environmental pollution and hazard of human’s health. Hence, maximizing the use of RA in construction sites is becoming economically important and environmentally necessary[3].

B. Recycled Aggregate (RA)

RA mainly differs from NA as it is composed by two different materials: NA and residue old cement mortar attached. Old cement mortar is the origin of the worse properties of RA. Recycled coarse aggregate (RCA) tends to have decreased specific gravity, increased water absorption, and increased abrasion loss compared to NA, since they contain the mortar paste from the original concrete. Because of the increased water absorption, RCA also has greater water demand which can be resolved by increasing the amount of mix water, pre-soaking the aggregates or by using mineral admixtures. Generally, RAC has lower compressive strength, less stiffness, increased creep, and increased shrinkage as compared to NA concrete. At full aggregate replacement, the concrete losses its compressive strength from 10% to 20%. In comparison, the effect of RCA on the stiffness of concrete is greater with losses up to 33% at full replacement. There are various methods to manufacture RCA with better properties, such as removal of adhered mortar paste via microwave treatment, or acetic acid treatment, or treating with polymer emulsions[3,4].

C. Admixed Recycled Aggregate

Mineral admixtures can be successfully used as partial replacement of cement in order to mitigate the poor performance of the RCA, thus obtaining admixed recycled aggregate. Mineral admixtures such as fly ash (FA), silica fume (SF), metakaolin (MK) and ground granulated blast slag (GGBS) have been utilized for many years either as supplementary cementitious materials in Portland cement concrete or as a component in blended cement. Generally, due to their high pozzolanic activity, the mineral admixture improves the mechanical and durability properties of the concrete [5]. Here the mineral admixture metakaolin is added to the RCA and mixed well. Then the admixed coarse aggregate is put for two stage mixing (TSM). TSM divides the mixing process into two parts and proportionally splits the required water into two, which are added at different timing.

II. OBJECTIVE

The objective of this study is:

- To study the mechanical properties of concrete with admixed recycled aggregate

III. METHODOLOGY

A. General

In order to accomplish the objective of the study, the following methodologies are to be adopted.

a) Procurement of Materials
b) Testing of Materials
c) Mix Design
d) Determination of Fresh and hardened properties

B. Procurement of Materials

The following materials are procured

a) Portland Pozzolana Cement
b) Natural Aggregate
c) Super Plasticizer
d) Metakaolin
e) Recycled Coarse Aggregate

C. Testing of Materials

a) Cement

Specific gravity, fineness, initial and final setting time as per IS 4031(part 5) 1988, consistency and compressive strength tests were conducted as per IS 1489 (part 1) 1991.

b) Aggregate

Bulk density, water absorption, fineness modulus, sieve analysis as per IS 383-1970 and specific gravity tests were conducted as per IS 2386 (part III)-1963

D. Mix Design

In this study, M20, M30, M40 and M50 grades of concrete are used. The mix was designed using IS 10262:2009. Slump is fixed as 90mm. The fresh properties of the mix were evaluated by measuring the slump according to IS 1199-1959 and the hardened properties were evaluated according to IS 516-1959

E. Determination of Fresh and Hardened properties

The strength and behaviour of concrete containing admixed recycled aggregate were studied in M20, M30, M40 and M50 mixes. These mixes were prepared using normal coarse aggregate. The coarse aggregate is then replaced with recycled coarse aggregate, and obviously the strength goes down. Mineral admixture, metakaolin, is used as partial replacement of recycled aggregate. The fresh properties were evaluated by measuring slump according to IS 1199-1959. Super plasticizer was added for keeping the workability constant. The hardened properties were evaluated according to IS 516-1959 and IS 5816-1999 and the optimum dosage of mineral admixture was found from the hardened properties.

IV. EXPERIMENTAL INVESTIGATION

A. Material Properties

The materials used for the study were cement, manufactured sand as fine aggregate, coarse aggregate, recycled coarse aggregate, metakaolin, water and superplasticizer. The first step in the experimental investigation is the analysis of the properties of the above ingredients, and was carried out based on Indian standards and foreign standards. Their properties and specifications are given in the following section

a) Cement

Cement paste is the binder that holds the aggregate together and reacts with mineral materials in hardened mass. Portland Pozzolana Cement is used for the entire experimental work.

TABLE I.PROPERTIES OF CEMENT

Test		Test Results	IS code specification
Fineness		4	< 10
Specific gravity		3	3.15
Standard consistency		34%	
Setting time	Initial	180 min	>30 min
	Final	250 min	<600 min
	28 days	54	Not less than 53 MPa

b) Fine Aggregate

Manufactured sand passing through IS sieve 4.75 conforming to zone II is used. The different results were tabulated in table II

TABLE II. PROPERTIES OF FINE AGGREGATE

Properties	Values
Bulk density (gm/cc)	1.958
Specific gravity	2.75
Sieve analysis	Confirming to Zone II
Water absorption	6.01%

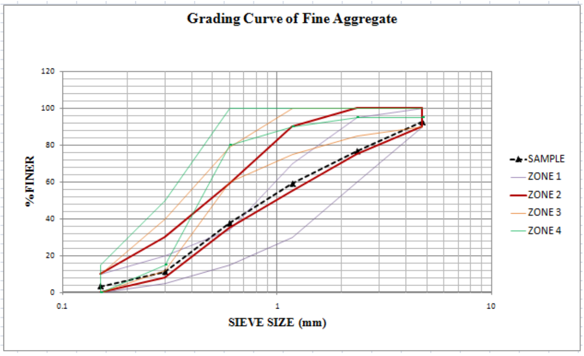

Fig 1.Grading curve of fine aggregate

c) Coarse Aggregate

Various tests were conducted as per IS specifications and results are provided in Table III.

TABLE III. PROPERTIES OF COARSE AGGREGATE

Properties	Values
Bulk density (gm/cc)	1.65
Specific gravity	2.87
Sieve Analysis	Confirms to IS specification of IS 383-1970
Water Absorption (%)	0.63

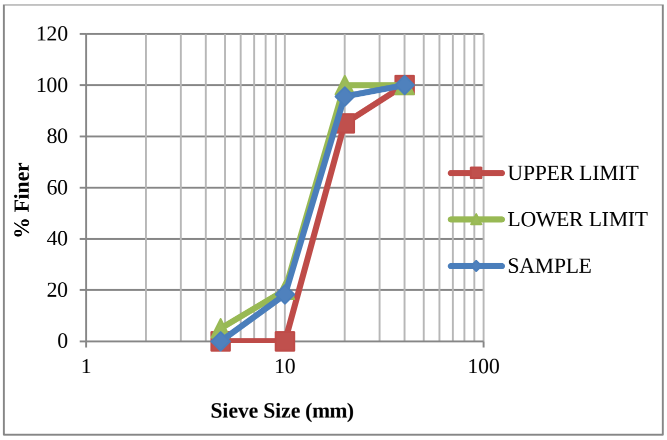

Fig 2.Grading curve of coarse aggregate

d) Recycled Aggregate

The properties of recycled aggregate is shown in table IV

TABLE IV.PROPERTIES OF RECYCLED AGGREGATE

Properties	**Values**
Bulk density (gm/cc)	1.53
Specific gravity	2.69
Water absorption (%)	2.1
Fineness modulus	8.166
Sieve analysis	Conforms to IS specification 383:1970

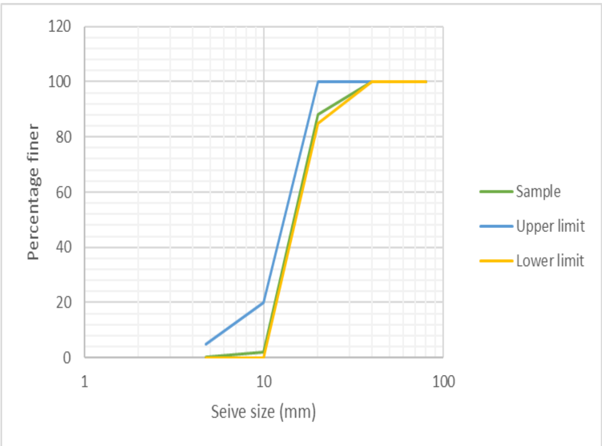

Fig 3. Grading curve of recycled aggregate

e) Metakaolin

Physical properties of metakaolin is shown in table V

TABLE V. PHYSICAL PROPERTIES OF METAKAOLIN

Property	**Test result of metakaolin**
Blaine value (cm^2/g)	22000-25000
Specific gravity	2.6

f) Superplasticizer

TABLE VI. PROPERTIES OF SUPERPLASTICIZER

Properties	**Values**
Specific gravity	1.06 to 1.12 at 300°C
Chloride content	Nil
Appearance	Liquid
Colour	Beige
Chemical Composition	Poly carboxylate ether
pH	6 to 8

B. Mix Design

The mix design of M20, M30, M40 and M50 are shown in table VII

TABLE VII. MIX DESIGN

Trial mix	**Cement content (kg/m^3)**	**Mix proportion**	**Water cement ratio**	**Compressive strength (N/mm^2)**
M20	340	1: 1.97: 3.81	0.45	28.10
M30	360	1: 1.93: 3.58	0.45	38.89
M40	390	1: 1.81: 3.36	0.4	48.65
M50	420	1:1.71:3.29	0.35	58.10

C. Hardened Properties

a) Cube Compressive strength

The cube strength was evaluated according to IS 516-1959 (Reaffirmed 2004). The test was conducted on a 2000 kN compression testing machine.

b) Cylinder Compressive Strength

The cylinder strength was evaluated according to IS 516-1959 (Reaffirmed 2004). The test was conducted on a 1000 kN universal testing machine.

c) Modulus of Elasticity

The modulus of elasticity was evaluated according to IS 516-1959 (Reaffirmed 2004). The test was conducted on a 1000 kN universal testing machine.

d) Splitting Tensile Strength

The splitting tensile strength was evaluated according to IS 5816-1999 (Reaffirmed 2004). The test was conducted in a 2000 kN compression testing machine. The splitting tensile strength is calculated using Eqn.1

$$f_{ct} = \frac{2P}{\pi dl} \quad (1)$$

where,

f_{ct} = splitting tensile strength in N/mm
P = maximum load in N
d = diameter of the specimen in mm
l = length of specimen in mm

e) Modulus of Rupture

The modulus of rupture was evaluated according to IS 516-1959 (Reaffirmed 2004). The test is conducted in a 100 kN flexure testing machine. Modulus of rupture is calculated by Eqn.2

$$f_b = \frac{Pl}{bd^2} \quad (2)$$

Where,

f_b= modulus of rupture
P = maximum load
l = length of specimen between supports
b = width of the specimen
d = depth of the specimen

V. RESULTS AND DISCUSSIONS

A. Fresh Properties

The fresh properties were evaluated by measuring slump according to IS 1199-1959 (Reaffirmed 2004). Since the slump was observed to be low, superplasticizer was added to maintain the slump between 80-90mm.

B. Hardened Properties

By using recycled aggregate by 100%, the strength of mix reduces. To overcome this, mineral admixture such as metakaolin is added to it. The optimum percentage of metakaolin was found out from cube compressive strength and then the hardened properties of control mix, mix with 100% recycled aggregate and mix with 100% aggregate & optimum percentage of metakaolin was found out.

a) M20 Mix

The optimum percentage of metakaolin in M20 mix is shown in table VIII.

TABLE VIII.OPTIMUM PERCENTAGE OF METAKAOLIN IN M20 MIX

Mix	Percentage of metakaolin	Compressive strength (N/mm^2)
M20	-	28.10
M20R100	-	23.43
M20R100-2.5	2.5	24.63
M20R100-5	5	25.13
M20R100-7.5	7.5	26.46
M20R100-10	**10**	**32.33**
M20R100-12.5	12.5	30.51

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From Table VIII, it is clear that the optimum percentage of metakaolin in M20 mix was found out to be 10% by weight of recycled aggregate. The hardened property of other mixes is shown in table IX.

TABLE IX. HARDENED PROPERTIES OF M20 MIX

Mix	Cylinder compressive strength (N/mm^2)	Split tensile strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)
M20	23.65	3.11	2.32×10^4	4.05
M20R100	19.3	2.46	1.9×10^4	3.24
M20R100-10	28.92	3.89	2.86×10^4	5.15

b) M30 mix

The optimum percentage of metakaolin in M30 mix is shown in table X

TABLE X. OPTIMUM PERCENTAGE OF METAKAOLIN IN M30 MIX

Mix	Percentage of metakaolin	Compressive strength (N/mm^2)
M30	-	38.89
M30R100	-	32.52
M30R100-2.5	2.5	33.98
M30R100-5	5	34.54
M30R100-7.5	7.5	37.20
M30R100-10	**10**	**43.17**
M30R100-12.5	12.5	38.25

The optimum percentage of metakaolin was found out to be 10% by weight of recycled aggregate. The hardened properties of M30 mix is shown in table XI

TABLE XI.HARDENED PROPERTIES OF M30

Mix	Cylinder compressive strength (N/mm^2)	Split tensile strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)
M30	31.50	3.26	2.73×10^4	4.3
M30R100	25.88	2.62	2.29×10^4	3.57
M30R100-10	39.08	4.16	3.38×10^4	5.21

c) M40 Mix

The optimum percentage of metakaolin in M40 mix is shown in table XII.

TABLE XII. OPTIMUM PERCENTAGE OF METAKAOLIN IN M40

Mix	Percentage of metakaolin	Compressive strength (N/mm^2)
M40	-	48.65
M40R100	-	40.09
M40R100-2.5	2.5	43.86
M40R100-5	5	45.23
M40R100-7.5	7.5	47.98
M40R100-10	**10**	**51.05**
M40R100-12.5	12.5	48.53

The optimum percentage of metakaolin in M40 mix was found out to be 10% by weight of recycled aggregate. The hardened properties of M40 mix is shown in table XIII

TABLE XIII.HARDENED PROPERTIES OF M40

Mix	Cylinder compressive strength (N/mm^2)	Split tensile strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)
M40	39.83	3.76	3.16×10^4	5.26
M40R100	32.95	3.04	2.59×10^4	4.23
M40R100-10	48.28	4.66	3.98×10^4	6.52

d) M50 Mix

The optimum percentage of metakaolin in M50 mix is shown in table XIV.

TABLE XIV.OPTIMUM PERCENTAGE OF METAKAOLIN IN M50 MIX

Mix	Percentage of metakaolin	Compressive strength (N/mm^2)
M50	-	58.10
M50R100	-	50.55
M50R100-2.5	2.5	53.48
M50R100-5	5	55.48
M50R100-7.5	**7.5**	**63.28**
M50R100-10	10	57.23
M50R100-12.5	12.5	54.89

The optimum percentage of metakaolin in M50 mix was found out to be 7.5% by weight of recycled aggregate. The hardened properties of M0 mix is shown in table XV

TABLE XV. HARDENED PROPERTIES OF M50 MIX

Mix	Cylinder compressive strength (N/mm^2)	Split tensile strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)
M50	47.06	5.21	3.57×10^4	6.2
M50R100	38.82	4.16	3.02×10^4	5.05
M50R100-7.5	55.76	6.72	4.32×10^4	7.87

VI. CONCLUSIONS

The following are the conclusions obtained from this study.

- By replacing coarse aggregate by 100% recycled coarse aggregate, the hardened properties were reduced by about 15-20% in every mix.
- By the addition of metakaolin, the hardened properties were increased by 20-30% in each mix.
- The optimum percentage of metakaolin was found to be 10% in M20,M30 and M40 & 7.5% by weight of recycled aggregate in M50 mix on the basis of compressive strength

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