International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-5, March 2020

Analysis of Concrete Made from Natural and Recycled Aggregate from Hardened Concrete

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***Abstract*: Detoriation of environment and depletion of natural resources is a major concern of the hour. Concrete not being an environmental pro material, a lot of work needs to be done on its sustainability parameters. Because of infrastructural growth to cater population needs, huge quantities of concrete are required. Since we all know that aggregates form around 75% of concrete volume, the quantities of aggregate required for the production of such huge quantities of concrete is immense. Hence a sustainable solution for the alternative of aggregate is urgently required to fulfill the shortage of aggregates.**

Keeping in mind the above problem the present work aims at finding a probable solution for utilizing the recycled aggregate obtained from destruction of hardened concrete. Since literature review suggested the poor performance of the concrete produced from recycled aggregate but did not give the best optimum situation in which it can be used. So the study was carried out on six different mixes containing natural aggregates and recycled aggregate for three different grades of concrete and both fresh and hardened properties of concrete was studied. No admixture was used for making concrete in any of the mixes. The comparative study showed that if recycled coarse aggregate is used with stone dust it gives better result and Total fines if used with natural coarse aggregate gives better result.

***Keywords*: Recycled; Aggregate; Construction; Concrete; Workability; Environment; Sustainability.**

I. INTRODUCTION

Detoriation of environment and depletion of natural resources is the concern of the hour. Concrete not being an environmental pro material, a lot of work needs to be done on its sustainability parameters. Because of infrastructural growth to cater population needs, huge quantities of concrete are required [1, 2]. Since we all know that aggregates form around 75% of concrete volume, the quantities of aggregate required for the production of such huge quantities of concrete is immense. Hence a sustainable solution for the alternative of aggregate is urgently required to fulfill the shortage of aggregates [3].

Revised Manuscript Received on March 30, 2020.
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The above problem needs to be addressed and alternative source of raw materials of concrete must be earmarked to find a sustainable solution [4-6]. Reducing the adverse impact on environment and reducing the Carbon footprints and embedded energy of concrete is extremely important due to the scarcity of resources. The use of recycled aggregate obtained from demolished concrete and use of pozzolanic materials or mineral admixtures like flyash, microsilica, and ground granulated blast furnace slag (GGBS) as partial replacement of cement [1]. These materials not only improve the durability of concrete but also reduce the carbon di oxide emission by reducing the consumption of cement. The usage of recycled aggregate is an example of recycling and conservation of raw materials and protection of environment [7-8].

Without any proper alternative, the way virgin aggregates are exploited and used for concrete production, it would soon pose a serious threat for environment and shortage of aggregate would hamper the infrastructural growth [3, 5-7]. In line with the above problem, there is need for the recycling of construction and demolition waste and to be used as recycled coarse and fine aggregates. There is huge scope of recycling of construction and demolition waste especially in large developing countries due to new bye-laws, change in the settlement patterns because of increased population, development of new highways to cater increase in traffic and industrial development in urban areas [3].

In Indian pretext generation of solid waste and a shortage of aggregates is of prime concern. The use of recycled aggregate can fill a part of this gap. Therefore, the recycling of waste paves a new road for the preservation of environmental and protecting the depleting natural resources. Hence new concrete made from recycled aggregates obtained from old/demolished concrete leads to an efficient and sustainable solution [9].

The shortcomings of recycled aggregate and been vastly studied and still has limited applications because of inferior properties posing a serious concern to the long term durability of structures [10, 11].

Lot of work has been done to enhance the properties of recycled aggregate such as

(1) removal of adhered cement mortars of RCA
(2) Application of various coatings on RCA to improve its surface texture
(3) Change in the concrete mixing approach
(4) Using different methods of crushing and many more

(5) Optimization using partial or entire replacement for virgin aggregate.

Recycled aggregates are still not conventionally used in the construction industry because the most of the processes and procedures are time consuming, cost intensive and inconvenient in practice and practically not feasible [10].

The present work deals with the strength properties of concrete made with recycled aggregate (both coarse and fine) with those of concrete made from natural aggregate.

It main objective is to provide a simple and best solution for the usage of recycled aggregate without any treatment for direct field applications by the engineers, contractors, developers and town planners.

Objective of this work is to study the effect of different combinations of recycled and natural aggregates with varying fines on the strength pattern of different concrete mixes and to evaluate, compare and model the use of recycled aggregate for appropriate dosage/percentage with fines under consideration for field applications.

II. METHODOLOGY

The methodology consists of defining the following steps for the proposed work. Three grades of concrete (**M20, M25, and M30)** have been selected for the research work**.** Concrete mix for production of concrete has been done as per IS: 10262-2009.

Selection & testing of ingredients of concrete mix are as follows:-

Cement- OPC (43 Grade) confirming to IS: 8112, 1989. Result shown in Table 1.

Fine aggregates- Natural River Sand (RS), Stone Dust (SD), Total Fines (TF) are conforming to IS: 383-1970. Result shown in Table 2.

Table 1: Test result of cement (OPC 43 grade).

S.No.	Physical Properties of OPC Cement 43 grade	Test Results	Requirements as Per IS:8112
1	Specific Gravity	3.15	3.10-3.15
2	Standard Consistency (%)	32	30-35
3	Initial Setting Time (min.)	125	30 min.
4	Final Setting Time (min.)	211	600 min.
5	Compressive Strength (at 28 days in N/mm^2)	51	43 N/mm^2 minimum

Table 2: Final result on tests of fine aggregates.

S. No	Particulars	River Sand	Stone Dust	Total Fines
1	Source	Ganga Sand	Crusher Dust	Crushed Concrete Fine
2	Zone	Zone II	Zone II	Zone II
3	Specific Gravity	2.54	2.58	2.35
4	Fineness Modulus	2.77	2.715	2.63
5	Density	1752 Kg/m³	1689 Kg/m³	1734 Kg/m³
6	Water Absorption (%)	0.92	1.15	11.06

SD- Crusher dust obtained as waste from crusher site.

TF- Fine aggregate obtained during formation of Recycled coarse aggregate.

Coarse Aggregate- Crushed Natural Coarse Aggregate passing 20mm IS sieve and retained on 4.75mm IS sieve (NCA) and Recycled Coarse Aggregate passing 20mm IS sieve and retained on 4.75mm IS sieve (RCA). Crushing to be done using pulverizes for obtaining RCA is conforming to IS: 383-1970. Result shown in Table 3 and Table 4.

Water - Potable water to be used for mixing and curing of concrete. (IS: 456- 2000).

Hardened concrete cubes obtained from nearby RMC plant has been used as recycled aggregate which were generated using Pulverizer and impact crusher. The various mixes for all the three grades of concrete were prepared using natural and recycled coarse aggregate (Table 5). Properties of fresh concrete i.e. workability of different mixes was determined in terms of slump then cubes, cylinders and beams from the different combinations were prepared. From each combination of mix the specimens were cast and tested at 7, 28 and 56 days. Three Cubes for each grade were used for determining the characteristic compressive strength, three Cylinders for each grade for the determination of split tensile strength and three Beams for each grade were used for determining the flexural strength.

From the results obtained comparative study was done regarding the characteristics/properties of concrete made from recycled aggregates as well as concrete made from natural aggregates.

Table 3: Final result on tests of coarse aggregate.

S. No.	Particulars	Natural Aggregate	Recycled Aggregate
1	Source	Crusher	Crushed Concrete
2	Max. Aggregate Size	20mm	20mm
3	Specific Gravity	2.64	2.54
4	Fineness Modulus	7.086	7.476
5	Density	1805.62 Kg/m³	1660.44 Kg/m³
6	Water Absorption (%)	0.905	8.19

Table 4: Result of Crushing and Impact Value of coarse aggregate.

Description	2.36mm Passing (gm)	Total Wt. (gm)	Impact Value (%)	Crushing Value (%)
Natural Coarse Aggregate	26 gm	326gm	27.1	19.31
Recycled Coarse Aggregate	38 gm	294gm	27.6	28.28

Table 5: Combination of various mixes

S.No.	Type of Concrete Mix for one grade	Ingredients
1	M_A	OPC + RS + NCA
2	M_B	OPC + SD + NCA
3	M_C	OPC + TF + NCA
4	M_D	OPC+ RS + RCA
5	M_E	OPC + SD + RCA
6	M_F	OPC + TF + RCA

Retrieval Number: E1970039520/2020©BEIESP
DOI: 10.35940/ijitee.E1970.039520
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

III. RESULT AND ANALYSIS

Various tests conducted on the ingredients of concrete as shown in table 1-3 to design the concrete mix and to study their physical properties. The proportions of mix design for M20, M25 and M30 for all the six mixes (M_A to M_F) as shown in Table 6-14 and were used for casting the concrete specimens (cubes, beams and cylinders).

162: cubes (150mm), beams (100mm x100mm x500mm) and cylinders (150 mm dia and 300mm height) were casted to determine the compressive strength, Flexural strength and split tensile strength respectively of various mixes of concrete at the end of 7, 28 and 56 days (Table 6-8).

The average result of the compressive, flexure and split tensile strength shows that the test results are quite satisfactory and reasonable.

Table 6: Mix design proportions of various mixes for M20 grade of concrete

MIX	W/C RATIO	CEMENT	WATER	FA	CA
		Kg	Kg	Kg	Kg
M_A	0.55	348	191.6	655.8	1160.6
M_B	0.55	348	191.6	666.2	1160.6
M_C	0.55	348	191.6	606.8	1160.6
M_D	0.55	348	191.6	655.8	1116.7
M_E	0.55	348	191.6	666.2	1116.7
M_F	0.55	348	191.6	606.8	1116.7

Table 7: Mix design proportions of various mixes for M25 grade of concrete

MIX	W/C RATIO	CEMENT	WATER	FA	CA
		Kg	Kg	Kg	Kg
M_A	0.5	383	191.6	662.9	1124.1
M_B	0.5	383	191.6	673.3	1124.1
M_C	0.5	383	191.6	613.3	1124.1
M_D	0.5	383	191.6	662.9	1081.5
M_E	0.5	383	191.6	673.3	1081.5
M_F	0.5	383	191.6	613.3	1081.5

Table 8: Mix design proportions of various mixes for M30 grade of concrete

MIX	W/C RATIO	CEMENT	WATER	FA	CA
		Kg	Kg	Kg	Kg
M_A	0.45	426	191.6	632.7	1119.8
M_B	0.45	426	191.6	642.7	1119.8
M_C	0.45	426	191.6	585.4	1119.8
M_D	0.45	426	191.6	632.7	1077.4
M_E	0.45	426	191.6	642.7	1077.4
M_F	0.45	426	191.6	585.4	1077.4

A. Analysis and Comparative study of various mixes (M_A to M_F) for M20 grades of concrete

The Strength results are given in Table 9. The compressive test done on concrete cubes for all the six mixes for 7, 28 and 56 days are depicted in Fig. 1. From the figure it is very clear that the concrete made from recycled coarse aggregate (RCA) gives reduced strength as compared to concrete made from natural coarse aggregate (NCA). The same has been investigated by [12, 13]. Concrete made from RCA falls short of the minimum strength requirement i.e. 20 MPa. The strength of Mix$_A$ is seen to be the best of all the mixes. The Mix having total fines (TF) as fine aggregates is giving the poorest results both with NCA and RCA, with latter being the worst. Luis R.Evangelista and Jorge C.de Brito also predicted the same and suggested that it is feasible to use recycled fine aggregate upto 30% with the same grading curve [13-17]. The rate of gain in strength in case of Concrete Mix made with RCA (M_D to M_F) almost ceases after 28 days with very slight gain in strength at the end of 56 days. The result of Mix M_A is more as compared to Mix M_B; Thus Mix M_A is showing the best results. The use of TF drastically reduces the strength of concrete made with NCA, as compared to Mix M_A and M_B having river sand and Stone dust as fine aggregate respectively.

Table: 9: Comparative Strength test results of various mixes for M20 grade of concrete

Mix	Avg. Compressive Strength (N/mm^2)			Avg. Flexural Strength (N/mm^2)			Avg. Split tensile Strength (N/mm^2)		
	7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
M_A	16.12	24.14	25.76	2.41	3.61	3.83	3.54	5.33	5.65
M_B	15.61	23.31	24.24	2.34	3.49	3.61	3.43	5.10	5.31
M_C	10.73	16.11	18.32	1.60	2.41	2.59	2.35	3.54	3.86
M_D	11.52	17.24	20.61	1.72	2.58	2.62	2.53	3.78	3.83
M_E	11.73	17.52	19.82	1.76	2.62	2.68	2.52	3.85	3.94
M_F	10.11	15.16	17.43	1.52	2.26	2.38	2.20	3.32	3.43

The Flexural test done on concrete beams for all the six mixes for 7, 28 and 56 days are depicted in Fig. 2. From the figure it is clear that the concrete beam made from RCA shows a lesser flexural strength as compared to concrete made from NCA. Concrete made from RCA falls short of the minimum Flexural strength requirement as per codal provisions for M20 grade of concrete [18, 19]. The strength of Mix A is seen to be the best of all the mixes. The Mix having TF as fine aggregates is giving the poorest results both with NCA and RCA, with latter being the worst. The rate of gain in strength in case of Mix made with RCA almost ceases after 28 days with very slight gain in strength at the end of 56 days. The Split Tensile Strength test done on concrete cylinders for all the six mixes for 7, 28 and 56 days are depicted in Fig. 3. Result clearly shows that the concrete made from RCA shows a lesser Split tensile strength as compared to concrete made from NCA. Concrete made from RCA falls short of the minimum Split tensile strength requirement as per codal provisions for M20 grade of concrete. The strength of Mix M_A is seen to be the best of all the mixes. The Mix having TF as fine aggregates i.e. M_C and M_F is giving the poorest results both with NCA and RCA, with latter being the worst. Mix M_E shows a better result as compared to mix M_D.

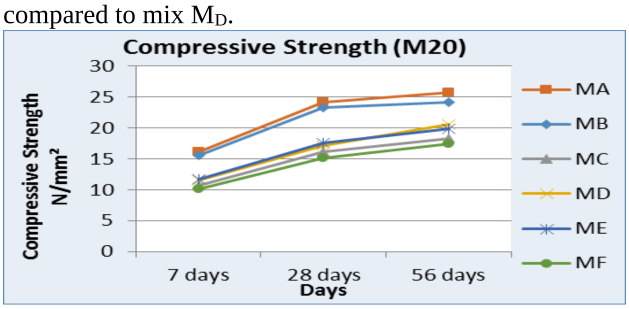

Fig. 1: Compressive Strength of M20 grade concrete for various mixes.

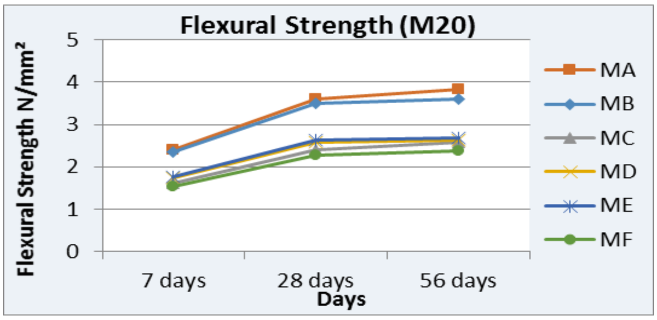

Fig. 2: Flexural Strength of M20 grade concrete for various Mixes

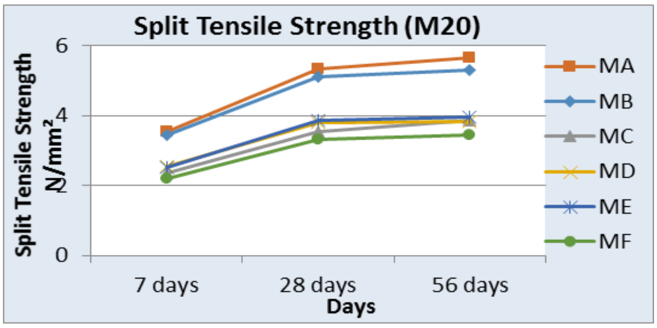

Fig. 3: Split Tensile Strength of M20 grade concrete for various mixes.

B. Analysis and Comparative study of various mixes for M25 grades of concrete

The Strength results are given in Table 10. The compressive test done on concrete cubes for all the six mixes for 7, 28 and 56 days are depicted in Fig. 4. The pattern above clearly depicts that the concrete made from RCA shows a lesser strength as compared to concrete made from NCA. The minimum strength requirement i.e. 25 MPa is not achieved for concrete made from recycled coarse aggregate. The strength of Mix M_A is seen to be the best of all the mixes. The Mix having total fines as fine aggregates, M_C and M_F is giving the poorest results both with NCA and RCA both, with latter being the worst. The rate of gain in strength in case of Mix made with RCA almost negligible after 28 days with very slight gain in strength at the end of 56 days. The result of Mix M_A is more as compared to Mix M_B; Concrete made from natural coarse aggregate and river sand as fine aggregate i.e. Mix M_A is showing the best results because of good bond strength, lower water absorption and because of lesser deleterious impurities. The use of TF drastically reduces the strength of concrete made with NCA, as compared to Mix M_A and M_B having river sand and Stone dust as fine aggregate respectively.

Table: 10: Comparative Strength test results of various mixesfor M20 grade of concrete

Mix	Avg. Compressive Strength (N/mm^2)			Avg. Flexural Strength (N/mm^2)			Avg. Split tensile Strength (N/mm^2)		
	7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
M_A	19.91	28.32	29.94	2.83	4.24	4.33	4.15	6.22	6.36
M_B	18.52	27.76	28.16	2.77	3.87	4.21	4.10	6.09	6.14
M_C	15.48	20.11	22.73	2.10	2.81	3.25	2.94	4.55	4.77
M_D	15.25	20.86	21.61	1.98	2.91	3.02	2.77	4.53	4.63
M_E	14.42	21.62	22.14	2.16	2.81	3.09	3.02	4.64	4.69
M_F	13.93	19.31	21.12	1.93	2.51	2.74	2.70	4.43	4.51

The Flexural test done on concrete beams for all the six mixes for 7, 28 and 56 days are depicted in Fig. 5. The pattern above clearly depicts that the concrete beam made from RCA shows a lesser flexural strength as compared to concrete made from NCA. The flexural strength of recycled concrete is poorer as compared to natural aggregates moreover because of the poorer bond strength. The strength of Mix M_A is seen to be the best of all the mixes. The Mix having TF as fine aggregates is showing poor results both with NCA and RCA. The rate of gain in strength in case of Mix made with RCA is slow and doesn't show much improvement with the increase in curing age much because of the adhered mortar.

The Split Tensile Strength test done on concrete cylinders for all the six mixes for 7, 28 and 56 days are depicted in Fig. 6. It clearly shows that the concrete made from RCA shows a lesser Split tensile strength as compared to concrete made from NCA. The strength of Mix A is seen to be the best of all the mixes. The Mix having TF as fine aggregates i.e. M_C and M_F having the least strength both with both NCA and RCA. Mix M_E shows a better result as compared to mix M_D. The split tensile strength of Mix M_C, M_D, M_E and M_F remain more or less equal at all curing ages.

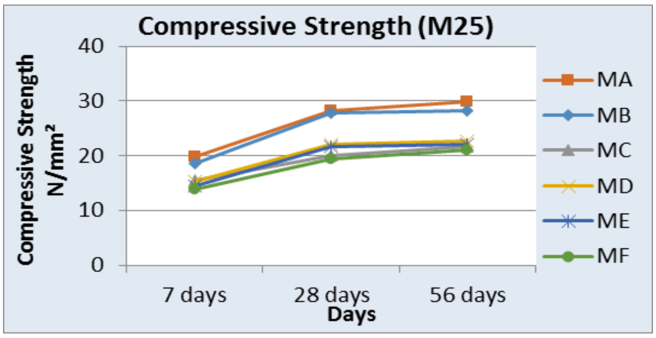

Fig. 4: Compressive Strength of M25 grade concrete for various mixes.

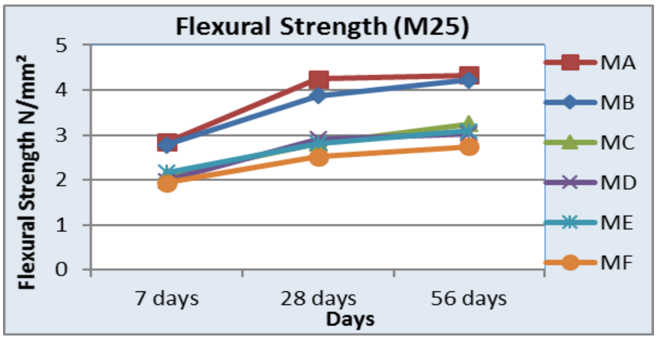

Fig. 5: Flexural Strength of M25 grade concrete for various mixes

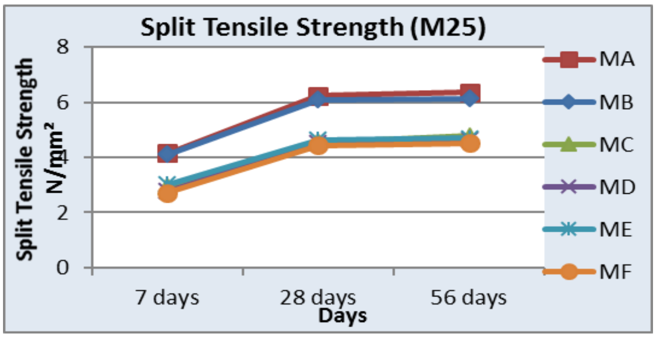

Fig. 6: Split Tensile Strength of M25 grade concrete for various mixes.

C. Analysis and Comparative study of various mixes for M30 grades of concrete

The Strength results are given in Table 11. The compressive test done on concrete cubes for all the six mixes for 7, 28 and 56 days are depicted in Fig. 7. The result are quite consistent and follows in line with the previous two grades i.e. M20 and M25, and it clearly depicts that the concrete made from RCA has lesser strength as compared to concrete made from NCA. Concrete made from RCA does not fulfill the minimum strength requirement i.e. 30 MPa. The strength of Mix M_A is seen to be the best of all the mixes. The Mix having TF as fine aggregates is giving the least strength both with NCA and RCA. The rate of gain in strength in case of Mix made with RCA is very slow with increase in curing ages. The result of Mix M_A is more as compared to Mix M_B; Thus Mix M_A is showing the best results. The use of TF drastically reduces the strength of concrete made with NCA, as compared to Mix M_A and M_B having river sand and Stone dust as fine aggregate respectively.

Table: 11: Comparative Strength test results of various mixes for M30 grade of concrete

Mix	Avg. Compressive Strength (N/mm^2)			Avg. Flexural Strength (N/mm^2)			Avg. Split tensile Strength (N/mm^2)		
	7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
M_A	22.45	33.53	35.36	3.37	5.30	5.61	5.16	6.87	6.89
M_B	21.40	32.07	33.84	3.22	5.01	5.40	4.92	6.62	6.70
M_C	13.18	22.13	23.69	1.98	3.31	3.54	2.90	4.81	4.97
M_D	15.21	24.21	24.96	2.28	3.63	3.74	3.35	4.95	4.99
M_E	15.95	23.81	24.98	2.39	3.57	3.75	3.51	4.91	4.93
M_F	13.13	21.24	21.78	1.96	3.18	3.26	2.89	4.50	4.61

The Flexural test done on concrete beams for all the six mixes i.e. Mix M_A to M_F for 7, 28 and 56 days is depicted in Fig. 8. The pattern above clearly depicts that the concrete beam made from RCA shows a lesser flexural strength as compared to concrete made from NCA. The minimum strength requirement is not achieved for the concrete made from recycled aggregate both coarse and fine. The strength of Mix M_A is seen to be the best of all the mixes. The Mix having TF as fine aggregates is giving the poorest results both with NCA and RCA, with latter being the worst. The rate of gain in strength in case of Mix made with RCA almost ceases after 28 days with very slight gain in strength at the end of 56 days. Mix M_D and M_E attain almost the same flexural strength at the end of 56 days.

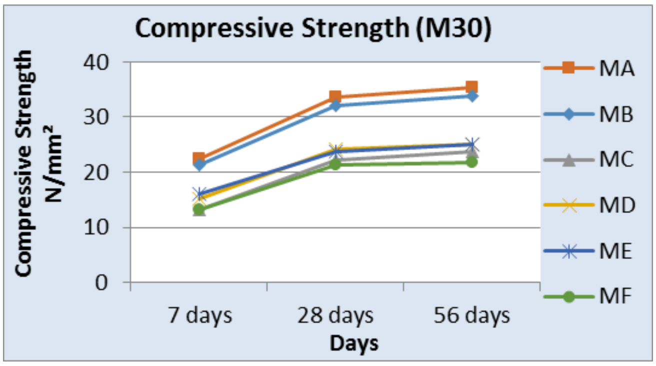

Fig. 7: Compressive Strength of M30 grade concrete for various mixes.

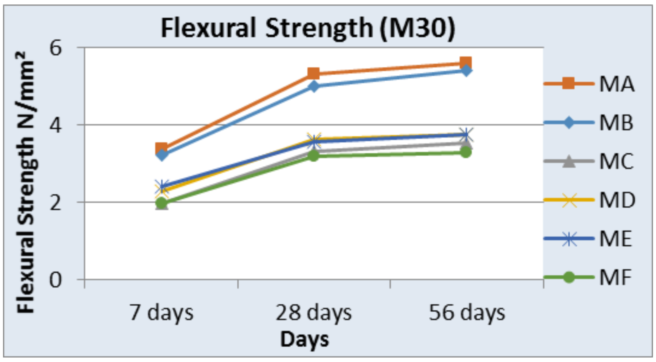

Fig. 8: Flexural Strength of M30 grade concrete for various mixes.

The Split Tensile Strength test done on concrete cylinders for all the six mixes i.e. Mix M_A to M_F for 7, 28 and 56 days are depicted in Fig. 9. Concrete made from RCA falls short of the minimum Split tensile strength requirement as per codal provisions for M30 grade of concrete which is evident from the figure. The strength of Mix M_A is seen to be the best of all the mixes. The Mix having TF as fine aggregates along with RCA i.e. Mix M_F is having the least strength. The split tensile strength of Mix M_C, M_D and M_E becomes almost equal at the end of 56 days of curing. There is no variation in strength of Mix M_D at the end of 28 and 56 days and the results obtained are same, whereas rest of the mixes shows increase in strength with age. The split tensile strength of mix having TF as fine aggregate both with NCA and RCA shows almost the same result at the end of 7 days but with age the result of Mix C increased which is evident from Fig. 9.

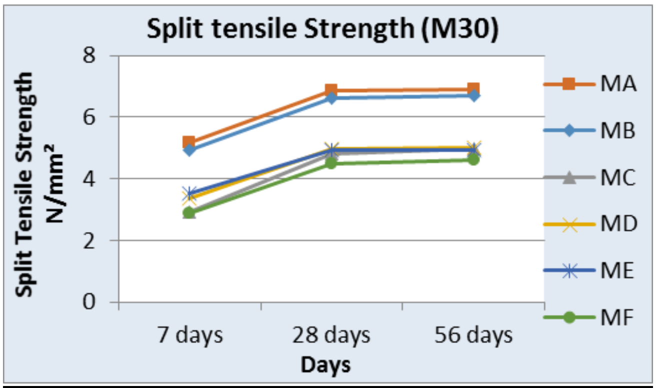

Fig. 9: Split Tensile Strength of M30 grade concrete for various mixes.

D. Workability test on fresh concrete for various mixes.

Workability of fresh concrete was measured by slump test and compacting factor test. The test results for workability of all the mixes of concrete for various grades is given in Table 12, 13, 14 for M20, 25 and 30 grade of concrete respectively. From the test result it is observed that with the usage of recycled aggregate there is a significant decrease in workability for all grades of concrete. This is reflected in both slump test as well as compaction factor test. Considerable reduction in workability of recycled aggregate concrete was investigated [20].

Table 12: Slump and Compacting Factor Values of M20 grade concrete for various mixes

Mix for M20 grade	Slump (mm)	Compacting Factor
Mix M_A	65	0.87
Mix M_B	61	0.85
Mix M_C	45	0.84
Mix M_D	35	0.83
Mix M_E	28	0.80
Mix M_F	25	0.80

Slump and compacting factor for various mixes for all the grade of concrete is shown above. Mixes containing recycled aggregate both coarse and fine show a lower slump as well as compacting factor values. The rough surface texture of the recycled aggregate and higher water absorption is responsible for lower workability and hence lower strength as evident from the strength tests. Recycled coarse aggregate production process and quality affects the workability and hence the Recycled coarse concrete have lower workability than concrete made from natural coarse aggregate [13, 21-26].

Table 13: Slump and Compacting Factor Values of M25 grade concrete for various mixes

Mix for M25 grade	Slump(mm)	Compacting Factor
Mix M_A	50	0.85
Mix M_B	45	0.84
Mix M_C	30	0.82
Mix M_D	26	0.80
Mix M_E	25	0.80
Mix M_F	25	0.80

Table 14: Slump and Compacting Factor Values of M30 grade concrete for various mixes

Mix for M30 grade	Slump(mm)	Compacting Factor
Mix M_A	45	0.84
Mix M_B	42	0.83
Mix M_C	30	0.82
Mix M_D	33	0.82
Mix M_E	30	0.81
Mix M_F	25	0.80

IV. DISCUSSIONS

A. Physical properties of recycled coarse aggregate and fine aggregate

It has been found that the physical properties of recycled coarse aggregate and fine aggregate are suitable according to the codal provision as per IS: 383-1970 (Table 2, 3, 4). Only the water absorption of both the recycled coarse as well as fine aggregate is found to be much higher than the required value. Higher water absorption value is due to the old mortar covering the coarse aggregate and the same mortar present in the fine aggregate. The same has been investigated by [27] regarding the substitution of natural coarse aggregate with crushed old concrete as recycled coarse aggregate. Water absorption of recycled coarse aggregate was much higher than the natural coarse aggregate. Recycled aggregate concrete has higher water absorption than natural aggregate concrete due to the adhered old mortar leading to high porosity. Due to higher water absorption value the workability of concrete made from recycled coarse and fine aggregate is very poor which is thus affecting its properties both in fresh and hardened state.

Recycled Coarse Aggregate (RCA) because of the old mortar attached to its surface has a high water absorption which is evident from the results obtained. It is having higher porosity and thus higher water absorption as compared to Natural Coarse Aggregate (NCA). [28] Stated that the performance of recycled aggregate concrete in terms of strength and workability is lower than the conventional concrete due to the adhered old mortar on the surfaces of the recycled aggregate.

As evident from the results obtained the impact value of Recycled Coarse Aggregate (RCA) and Natural Coarse Aggregate (NCA) is more or less the same and is also well below the codal provisions (i.e. not more than 30% for wearing surfaces in roads and not more than 45% in case of concrete works). The crushing value of RCA is higher than that of NCA but is well within the codal provisions. Hence we can say that the RCA satisfies the strength test.

B. Aggregate surface properties

For environmental concerns, we are bound to use increasing amounts of recycled concrete aggregate. For this to happen we have to establish a reliable method of assessing the particle properties with respect to their influence on workability. Of course, the same applies to ordinary crushed aggregate. The crushed recycled concrete aggregate needs to be graded and recombined with appropriate particle sizes. But particle size is not the only criterion for achieving suitable aggregate for the mix. Specifically, the shape of the crushed particles, and their rougher texture, may not be optimal. Water absorption is often high as seen from the test results because the pores in the old concrete are now additional pores in the aggregate. The same has been reported [29] that the water absorption of recycled aggregate was about 6-12 times higher than the natural aggregate due to the adherence of residue mortar to original aggregate.

C. Effect of using recycled aggregate on concrete properties both fresh and hardened state

As seen from Fig. 10-12 regarding the workability of concrete in terms of slump and compacting factor, the workability of the mix D to F shows a continuous drop in the workability of concrete both in terms of slump and compacting factor. This drop in workability is due to the usage of recycled coarse as well as fine aggregate. But still having low workability the concrete can be used at places where vibrators are being used for compaction. .The properties of concrete made from recycled aggregate (both coarse and fine) in hardened state in terms of compressive strength, split tensile strength and flexural strength is found to be lower than that of concrete made from natural aggregate.

The decrease in strength is mainly due to the bond failure as the old mortar covering the coarse aggregate does not allow the creation of a good bond leading to lowering of strength which is visible from the results for all the grades of concrete. The same has been reported by [10, 30-32].

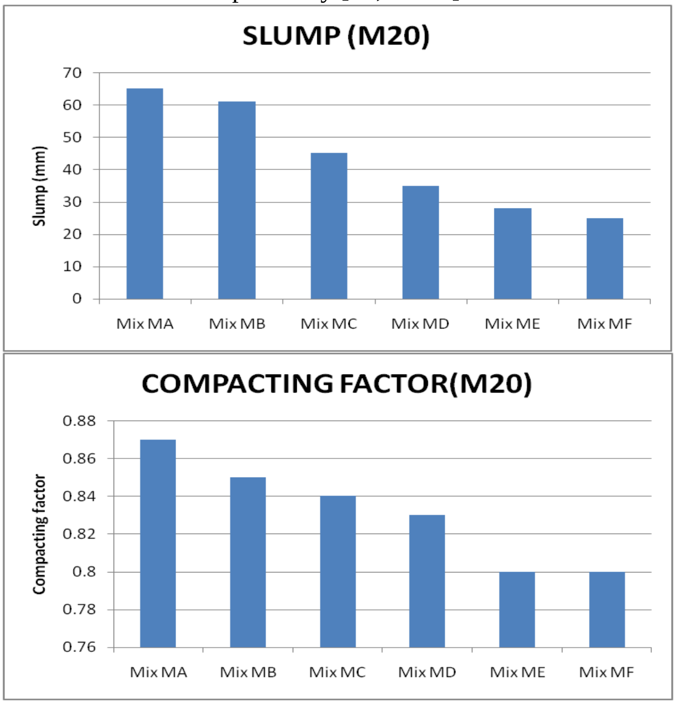

Fig. 10: Slump and Compacting Factor of M20 grade concrete for various mixes

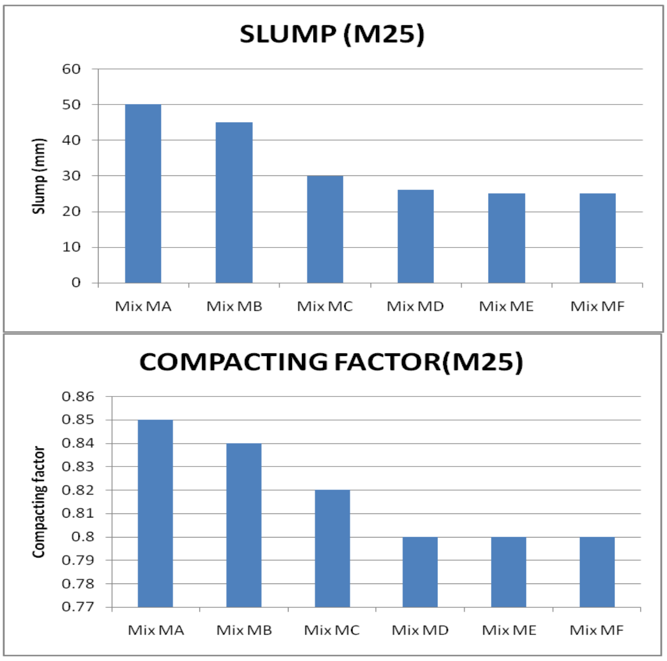

Fig. 11: Slump and Compacting Factor of M25 grade concrete for various mixes.

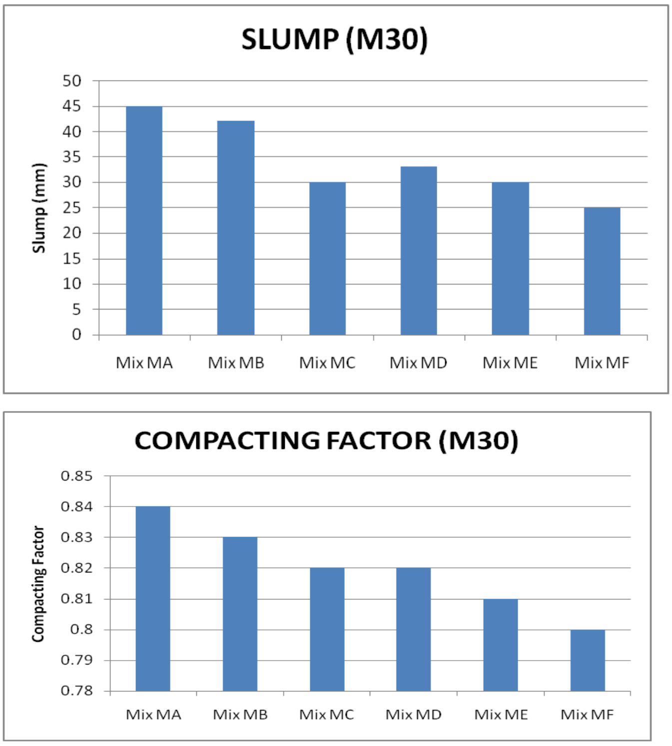

Fig. 12: Slump and Compacting Factor of M30 grade concrete for various mixes

D. Effect of use of recycled Total Fines on the properties of concrete

Total Fines being crushed mortar has a very high water absorption makes the concrete very harsh having poor workability and also poor strength of hardened concrete.

The result clearly shows that all the strength i.e. compressive, split tensile and flexural strength decreases with the usage of recycled aggregates (both coarse and fine). Lower strength is generally attributed to the weaker bond development which has been also seconded by [27, 29]. The workability of concrete is still coming within the design range.

V. CONCLUSION

There has been lot of studies on the usage of recycled aggregates but still its implications on field in India are not seen. Still the usage of recycled aggregate remains at large and usage still discouraged. The present study does not go into complication of usage of recycled aggregate but to provide an easy solution for the usage of recycled aggregate directly for field applications. The strength of concrete with natural coarse aggregate in general shows higher result as compared to recycled coarse aggregate. Uses of River sand give higher compressive and flexural strength as compared to Stone Dust as well as Total Fines. Higher mortar content and higher water absorption can be the reason behind the poor strength test of concrete using Total Fines (Recycled fine aggregate). The higher silt content in stone dust could be the possible reason behind lower strength as compared to river sand. From the comparative study of various mixes for various grades it can be concluded that recycled coarse aggregate (RCA) can be used with stone dust (SD) to give comparatively higher strength.

Retrieval Number: E1970039520/2020©BEIESP
DOI: 10.35940/ijitee.E1970.039520
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Hence RCA can be mixed with SD to get the best result as far as recycled aggregate is concerned. Recycled Fine aggregate that is Total Fines (TF) can be used with Natural Coarse aggregate (NCA) to get the optimum result. This is evident from the results that the Total fines are giving best results when used with Natural coarse aggregate.

Hence the study provides a simple and ready to use combination for field application wherein we can get the desired result with the given combination and the desired strength can be enhanced using mineral and chemical admixture.

ACKNOWLEDGMENT

The author would like to sincerely thanks NITTTR Chandigarh and KIET Group of Institutions, Ghaziabad for their help and support regarding the project and submitting it to this journal.

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