Optimization of Aggregate Gradation and its Effects on Properties of Medium Strength Concrete (M50)

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Abstract— By optimizing the packing of the combined aggregate gradations, the cement paste content needed to make concrete can be reduced, improving sustainability, cost, performance, durability, and workability. Optimization can be achieved using theoretical and empirical techniques, or waste concrete material as an intermediate size fraction. However, the potential for improvement is currently limited by prescriptive grading specifications that require meeting individual requirements for fine and coarse aggregates.

Key words: Coarseness Factor, Power Curve Fineness Modulus, Workability Factor

I. Introduction

Aggregate is the main constituent of concrete. Aggregates provide about 65%-75% of the body of concrete and hence its influence is extremely important they should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregate must be proper shape, clean, hard, strong and well graded. It should posses chemical stability and in many cases, exhibits abrasion resistance and resistance t freezing and thawing.

Normally from production of the concrete cement is the most expensive material about 55%-60% of the total cost of the production of concrete materials. The cement content only 25%-35% of the total volume of the concrete.

Properties of concrete can be improved by having well graded aggregates. Thus, the importance of optimization of aggregate is arises. The most suitable of aggregate gradation for concrete mix, however, will depends upon actual grading, particle shape and surface texture.

The optimization of aggregate grading is the most advantageous technique for economical and technical reasons. By using of this optimizing combined gradation of aggregate mixing cement content is reduced up to10%-15% of the volume of the concrete and concrete will be improve sustainability, durability by decreasing the permeability, potential when drying, shrinkage and cracking of the concrete, workability by decreasing the segregation of concrete and structural performance by decreasing the porosity and voids by increasing the total volume of the aggregate in concrete. The shape and texture of the aggregate of the aggregates have significant effect on the packing ability of individual aggregate and therefore potential for optimizing blended aggregate.

Typical concrete mixtures have a binary blend of fine aggregate and coarse aggregate, each meeting gradation envelopes, which are often defined as a “Gap-Graded” mixture because of lack of intermediately aggregate size particles ranging from 2.36 mm to 12.5 mm as shown in Figure 1. A well graded aggregate mixture has good distribution of aggregates its including the intermediate aggregate sized particles.

A well graded mixture of combined aggregate blend can achieved by using optimization techniques both theoretical and empirical. A significant quarried aggregate is wasted per year from sieving to meet gradation specifications; therefore using ternary aggregate aggregate blending is very cost-effective as well as environmentally sustainable. The potential for optimization is limited by specification as they separate grading envelopes for fine aggregate and coarse aggregate materials for concrete making.

The cement concrete is mixture of cement, fine aggregate and coarse aggregate with required amount of water and addition to admixtures like mineral and chemical admixture. Normally aggregates are the important constituents in concrete. It gives the structure of concrete. The aggregates effects on properties of the fresh and hardened concrete.

In cement concrete the aggregates are occupy nearly 70%-80% of the volume of cement concrete. The aggregates reduce the shrinkage and economy of the concrete. By use of aggregates their influence on cement concrete properties like strength, durability workability etc. For the achievement of high economy, the aggregates should be made clean, strong, bond strength, shape and texture, specific gravity, bulk density, voids, moisture content, fineness modulus and porosity.

The aggregates are generally divided into two different sizes they are coarse aggregate and fine aggregate. In cement concrete the coarse aggregate used for the main matrix and the fine aggregate used for fill the gaps or voids in between coarse aggregate. The aggregates also used for increasing the bulk density of the concrete.

Generally from making of the cement concrete cement is the high expensive material about 55%-65% of the total cost of the production of the cement concrete when compare to the other materials but uses of the cement content in concrete only 25%-35% of total volume of the concrete due to this reason the concrete cost is high. Reduce the cost of the concrete by using most advantageous technique of optimization of combined aggregate gradation techniques.

By using the optimization of aggregate gradation techniques cement content can be reduced upto 12%-15% of the total volume of the concrete and also the aggregates used in this techniques by combined well graded aggregates are used its improves the properties of the concrete like durability, workability, compressive strength, cohesiveness and economy.

This optimization of combined aggregate gradation provides the densest arrangement allowing the volume of the aggregate to maximize by minimizing the volume of the cement paste needed to provide sufficient workability.

The results is improve the workability, finishability and pumpability and reduced segregation when compare to concrete poorly graded aggregate gradation and reduced the shrinkage by directly reducing the cement paste in cement concrete with possible of increasing the aggregate content in concrete and reduced the shrinkage translates into reduced concrete.

A. Power Curve

The Fuller and Thompson groundbreaking work on optimization gradation to the concrete on greatest strength and workability. They concluded that aggregate should be well graded in sizes and combined with cement paste give the high density. They developed an ideal maximum density curve. It was shown that the Fuller curve may not always give the maximum strength or maximum density (Wig et al. 1916).

Further research Talbot and Richart developed the equation for maximum density line in 1923. The equation shown below

$$P = [\frac{d}{D}]^{n}$$

Where
P= Combined percentage passing of aggregates,
d= Size of the particular or sieve size,
D= Largest particle or Maximum sieve size,
n= Grading type factor or Power factor (0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6).

B. Fineness Modulus

Abrams in 1918 study his own- famous work on concrete mix design. He found drawbacks with previous methods of proportioning for maximum strength because they neglected importance of the water. His primary concerned on strength, while workability was of interest only insofar as the concrete was workable enough to be used. However, he did state that there was a relationship between aggregate grading and the quantity of water required to produce workable concrete. To aid in the selection of aggregate gradations that would prevent the use of excessive water, he developed a method of representing aggregate gradation known as the Fineness modulus (FM). The fineness modulus equation given below

$$\text{Fineness modulus} = \frac{Cumulative\ Retained}{100}$$

In the ideal situation, a greater FM should be representing a coarser gradation. He developed charts that gave maximum fineness modulus that should be used with a given quality of water and cement-aggregate ratio. He suggested that any sieve analysis giving the same FM will require the same amount of water to produce a mix with the same plasticity and strength. He study that the surface area of the aggregate varied widely within a given FM but did not seem to affect strength. He did not comment on workability. Examination of the experimental work by Abrams reveals that as FM decreased, the amount of water per sack of cement increased (Abrams 1918).

C. Shilstone Coarseness Factor Chart

The Shilstne in 1970 found several factors on concrete properties is depends on the aggregate gradation. He creates the methodology of well graded aggregates it includes the fine aggregate, intermediate aggregate and coarse aggregate sizes particles. They develop the coarseness factor chart in 1990. He also promoted the use a method of gradation an individual percent retained chart it gives easy identification of which size of the aggregates excessive or deficient.

$$\text{Coarseness Factor} = \frac{\%\ of\ Cumulative\ Retained\ 10\ mm}{\%\ of\ Cumulative\ Retained\ 2.36\ mm}$$

Workability Factor = % of Cumulative Passing 2.36 mm

II. Materials

A. Cement

Cement is a good substance which acts as a binding agent for materials like sand, coarse aggregate and water. Normally cement is manufacture in industries with raw materials of clay, lime and other required amount of chemicals for manufacturing of cement. The manufacturing process either may be dry process or wet process now days only we manufacture the cement by dry process.

In this experimental investigation using of the cement taking from Ultra Tech cement of PPC 53 grade was used. The physical properties of this cement is found by laboratory test conducted on basis of IS code provisions.

S.NO	Particulars	Cement
1	Normal Consistency	30 %
2	Fineness of cement	5.7 %
3	Setting time	
	Initial setting time	30 min
	Final setting time	10 hours
4	Specific gravity of cement	3.15
5	Soundness of cement	5.5mm

Physical Properties of Cement

B. Coarse Aggregate

The aggregate which are retained on 4.75 mm IS sieve is normally termed as coarse aggregate. The size of the coarse aggregate determined by various considerations such as the thickness of the section, clear cover, reinforcement spacing, mixing and placing methods. Normally the large size of the aggregates are used as economy but the size of the aggregate not more than ¼th of the minimum thickness of the member as per IS 456-2000. The size of the coarse aggregate should b at least of the 5 mm less than the clear cover or 20mm.In this experimental work used of the coarse aggregate are 20 mm and 12.5 mm crushed aggregates. The coarse aggregate taking from Chandragiri quarry near Chandragiri Kota Chittoor (Dist), Andhra Pradesh.

S.No	Particulars	Coarse aggregate
1	Crushing value	19.61 %
2	Impact value	17.93%
3	LOS ANGELS ABRASION TEST ON COARSE AGGREGATE	32.48 %
4	Shape test	
	Flakiness index	9.41 %
	Elongation index	9.71%

5	Bulk density	
	Bulk density without compaction	1.39 Kg/lit
	Bulk density with compaction	1.53 Kg/ lit
6	Specific gravity	2.668
7	Water absorption	0.25

Physical Properties of Coarse Aggregate

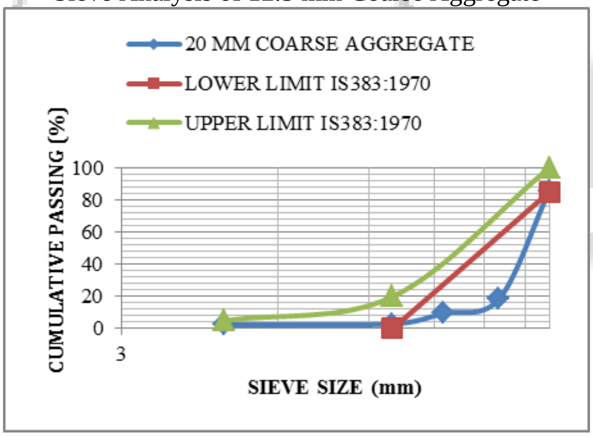
The sieve analysis of the coarse aggregate of 20 mm and 12.5 mm as per IS: 383-1970.

S. No	Sieve Size (mm)	Cumulative Passing (%)	
		20 mm	IS 383-1970
1	20	82.12	85-100
2	16	18.36	N/A
3	12.5	9.45	N/A
4	10	2.92	0-20
5	4.75	0.45	0-5

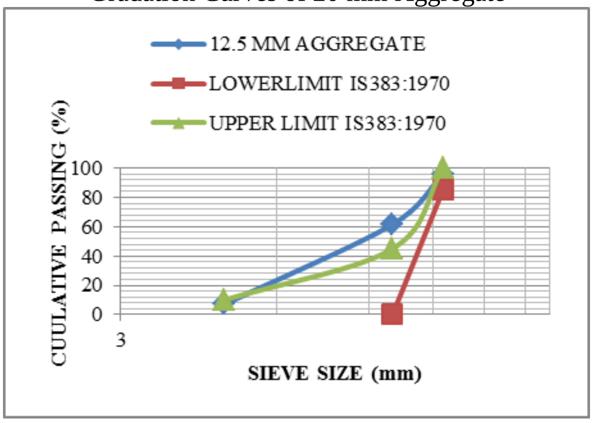
Sieve Analysis of 20 mm Coarse Aggregate

S.No	Sieve Size (mm)	Cumulative Passing (%)	
		12.5 mm	IS 383-1970
1	12.5	95.4	85-100
2	10	61.54	0-45
3	4.75	7.28	0-10

Sieve Analysis of 12.5 mm Coarse Aggregate



Gradation Curves of 20 mm Aggregate



Gradation Curves of 12.5 mm Aggregate

C. Fine Aggregate

The aggregate which passes through 4.75 mm IS sieve and retained 60 μ IS sieve. They can be made available from river banks or crushing of the stones. In this investigation the fine aggregate is used as M sand

1) M Sand

In this experimental investigation used M sand is replacing of river sand. This M sand is taking from crushed stone from Chandaragiri quarry near Chandaragiri, Chittoor (Dist), Andhra Pradesh.

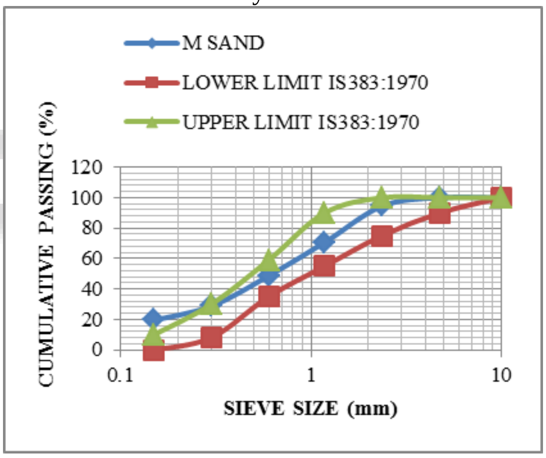
S.No	Particulars	River sand
1	Specific gravity	2.63
2	Bulk density	
	Bulk density without compaction	1.571 Kg/lit
	Bulk density with compaction	1.77 Kg/ lit
3	Water absorption	1.1%
4	Bulking of M sand	14%

Physical Properties of M Sand

The sieve analysis is conducted on M sand based on IS 383:1970. It gives the gradation of the M sand.

S.No	Sieve size (mm)	Percentage of Cumulative passing (%)	
		M sand	IS 383-1970 (Zone II)
1	10	100	100
1	4.75	100	90-100
2	2.36	94.45	75-100
3	1.18	70.6	55-90
4	0.6	48.65	35-59
5	0.3	28.7	8-30
6	0.15	19.55	0-10

Sieve Analysis of M Sand



Grading Curve of M Sand

Based on the sieve analysis according to the IS383:1970 is confirming to the Zone II. The M Sand fineness modulus is 2.38.

III. METHODOLOGY

By using the optimization of combined aggregate gradation such as maximum density line or power curve, coarseness factor chart, fineness modulus and surface area and also IS 10262:2009 prepared four concrete mix designs normal strength concrete of 20MPa on bases of the physical properties of the materials.

The proportion of the volume of aggregates in concrete (Coarse and Fine) are not fixed based on the Zone confirming. Based on the optimization of combined aggregate gradation technique of power curve fixing the trail proportions to the volume of the concrete.

The well grade concrete is prepared based on the coarseness factor chart.

A. Mix Design

Stipulation For Proportioning	
Grade of designation	M_{20}
Type of cement	PPC
Max. size of the aggregate	20 mm
Min. cement content	320 Kg/m^3
Max. cement content	450 Kg/m^3
Max. water cement ratio	0.4
Exposure condition	Severe (for reinforced concrete)
Method of concrete placing	Pumping
Type of the aggregates	Crushed angular aggregates
Material test data	
Specific gravity of the cement	3.15
Specific gravity of water	1
Specific gravity of the coarse aggregate	2.688
Specific gravity of the fine aggregate (M Sand)	2.65
Water absorption of coarse aggregate	0.25 %
Water absorption	1.5%

The combined passing with 0.5 power curve the proportion of aggregate are 0.27 : 0.33 : 0.4, 0.252 : 0.308 : 0.44, 0.235: 0.285 : 0.48 and 0.216 : 0.264 : 0.52 respectively

The combined individual retaining with proportion of aggregate are 0.27 : 0.33 : 0.4, 0.252 : 0.308 : 0.44, 0.235: 0.285 : 0.48 and 0.216 : 0.264 : 0.52 respectively

The coarseness factor charts show the proportion of aggregate are 0.27 : 0.33 : 0.4, 0.252 : 0.308 : 0.44, 0.235: 0.285 : 0.48 and 0.216 : 0.264 : 0.52 respectively.

S. No	Sieve Size (mm)	Aggregate 1 20 mm	Aggregate 2 12.5 mm	Aggregate 3 4.75 mm	Combined passing (%)	Combined retaining (%)	Individual retaining (%)	0.5 Power curve	Coarseness factor	Workability factor
1	25	100	100	100	100.00	0.00	0	100.0		
2	20	82.120	100	100	95.17	4.83	4.83	89.4		
3	16	18.360	100	100	77.96	22.04	17.22	80.0		
4	12.5	9.450	95.4	100	74.03	25.97	3.92	70.7		
5	10	2.920	61.54	100	61.10	38.90	12.94	63.2		
6	6.3	0.910	14.7	100	45.10	54.90	16.00	50.2	57.31	32.12
7	4.75	0.450	7.28	100	42.52	57.48	2.57	43.6		
8	2.36	0	0.6	79.8	32.12	67.88	10.41	30.7		
9	1.18	0	0.5	57	22.97	77.04	9.15	21.7		
10	0.6	0	0	25.7	10.28	89.72	12.69	15.5		
11	0.3	0	0	5.6	2.24	97.76	8.04	11.0		
12						0.15				

Combined Aggregate Grading Analysis for Aggregate Proportion 0.27:0.33:0.40
(Fineness Modulus of M Sand is 2.4)

S. No	Sieve Size (mm)	Aggregate 1 20 mm	Aggregate 2 12.5 mm	Aggregate 3 4.75 mm	Combined passing (%)	Combined retaining (%)	Individual retaining (%)	0.5 Power curve	Coarseness factor	Workability factor
1	25	100	100	100	100.00	0.00	0	100.0		
2	20	82.120	100	100	95.49	4.51	4.51	89.4		
3	16	18.360	100	100	79.43	20.57	16.07	80.0		
4	12.5	9.450	95.4	100	75.76	24.24	3.66	70.7		
5	10	2.920	61.54	100	63.69	36.31	12.07	63.2		
6	6.3	0.910	14.7	100	48.76	51.24	14.93	50.2	56.12	35.30
7	4.75	0.450	7.28	100	46.36	53.64	2.40	43.6		
8	2.36	0	0.6	79.8	35.30	64.70	11.06	30.7		
9	1.18	0	0.5	57	25.23	74.77	10.06	21.7		
10	0.6	0	0	25.7	11.31	88.69	13.93	15.5		
11	0.3	0	0	5.6	2.46	97.54	8.84	11.0		
12						0.15				

Combined Aggregate Grading Analysis for Aggregate Proportion 0.252:0.308:0.44
(Fineness Modulus of M Sand is 2.4)

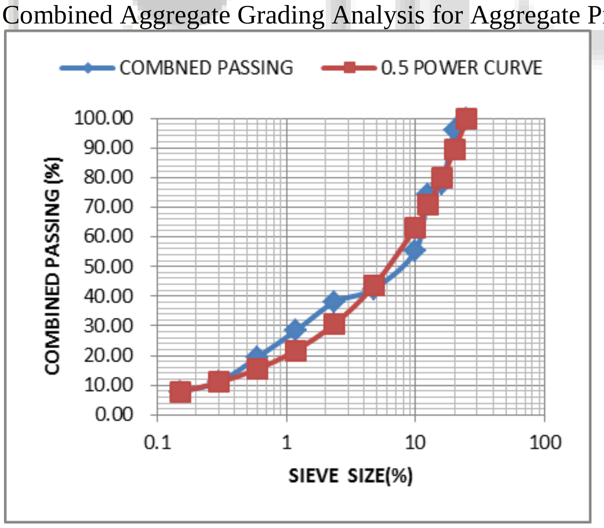
S. No	Sieve Size (mm)	Aggregate 1 20 mm	Aggregate 2 12.5 mm	Aggregate 3 4.75 mm	Combined passing (%)	Combined retaining (%)	Individual retaining (%)	0.5 Power curve	Coarseness factor	Workability factor

1	25	100	100	100	100.00	0.00	0	100.0		
2	20	82.120	100	100	92.16	7.84	7.84	89.4		
3	16	18.360	100	100	78.45	21.55	13.71	80.0		
4	12.5	9.450	95.4	100	75.31	24.69	3.13	70.7		
5	10	2.920	61.54	100	64.94	35.06	10.38	63.2		
6	6.3	0.910	14.7	100	52.09	47.91	12.84	50.2	56.98	38.46
7	4.75	0.450	7.28	100	50.03	49.97	2.07	43.6		
8	2.36	0	0.6	79.8	38.46	61.54	11.56	30.7		
9	1.18	0	0.5	57	27.49	72.51	10.97	21.7		
10	0.6	0	0	25.7	12.34	87.66	15.16	15.5		
11	0.3	0	0	5.6	2.69	97.31	9.65	11.0		
12						0.15				

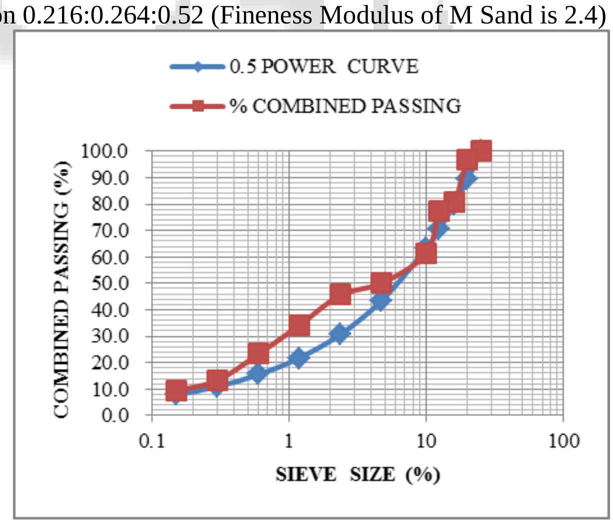
Combined Aggregate Grading Analysis for Aggregate Proportion 0.235:0.285:0.48
(Fineness Modulus of M Sand is 2.4)

S. No	Sieve Size (mm)	Aggregate 1 20 mm	Aggregate 2 12.5 mm	Aggregate 3 4.75 mm	Combined passing (%)	Combined retaining (%)	Individual retaining (%)	0.5 Power curve	Coarseness factor	Workability factor
1	25	100	100	100	100.00	0.00	0	100.0		
2	20	82.120	100	100	96.14	3.86	3.86	89.4		
3	16	18.360	100	100	82.37	17.63	13.77	80.0		
4	12.5	9.450	95.4	100	79.23	20.77	3.14	70.7		
5	10	2.920	61.54	100	68.88	31.12	10.35	63.2		
6	6.3	0.910	14.7	100	56.08	43.92	12.80	50.2		
7	4.75	0.450	7.28	100	54.02	45.98	2.06	43.6	53.34	41.65
8	2.36	0	0.6	79.8	41.65	58.35	12.36	30.7		
9	1.18	0	0.5	57	29.77	70.23	11.88	21.7		
10	0.6	0	0	25.7	13.36	86.64	16.41	15.5		
11	0.3	0	0	5.6	2.91	97.09	10.45	11.0		
12	0.15	0	0	1.4	0.73	99.27	2.18	7.7		
Combined Fineness Modulus						5.7				

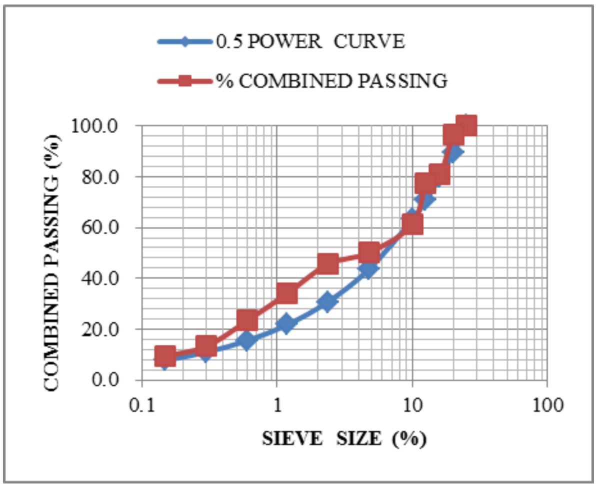
Combined Aggregate Grading Analysis for Aggregate Proportion 0.216:0.264:0.52 (Fineness Modulus of M Sand is 2.4)



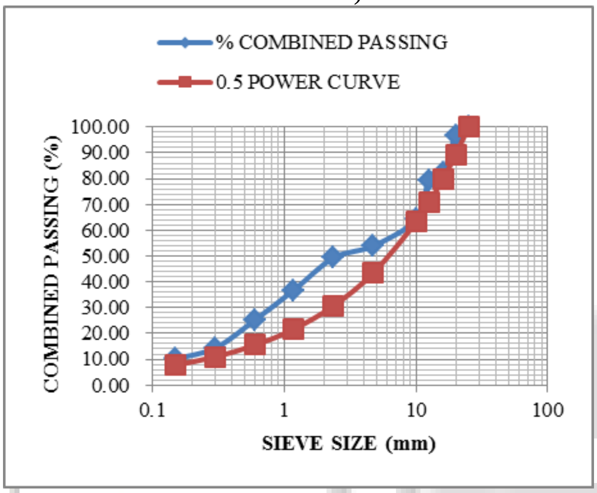
Combined Passing With 0.5 Power Curve for Aggregate Proportion 0.27:0.30:0.40
(Fineness Modulus of M Sand is 2.4)



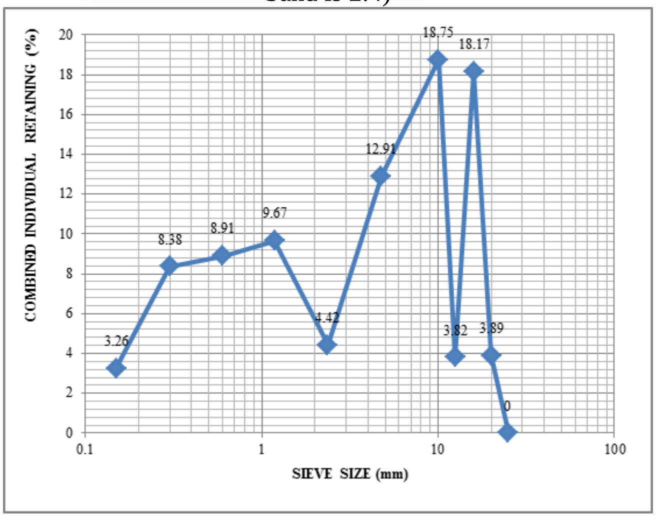
Combined Passing With 0.5 Power Curve for Aggregate Proportion 0.252:0.308:0.44 (Fineness Modulus of M Sand is 2.4)



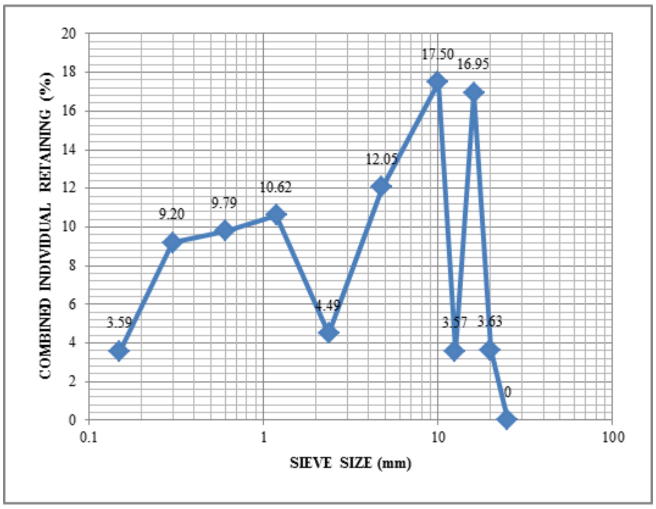
Combined Passing With 0.5 Power Curve for Aggregate Proportion 0.234:0.286:0.48 (Fineness Modulus of M Sand is 2.4)



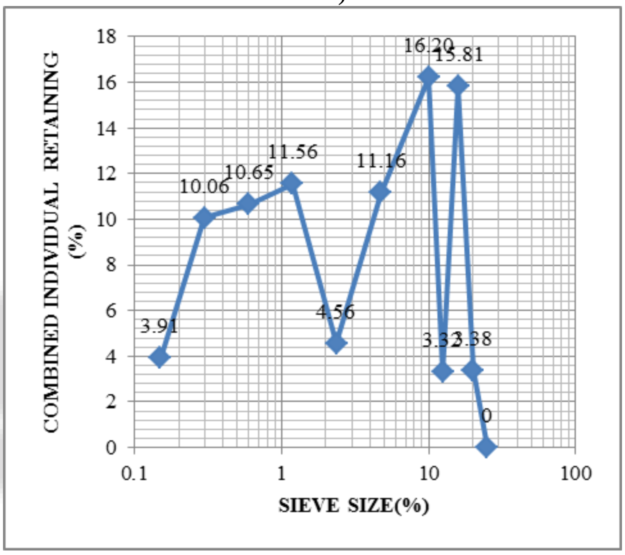
Combined Passing with 0.5 Power Curve for Aggregate Proportion 0.216:0.264:0.52 (Fineness Modulus of M Sand is 2.4)



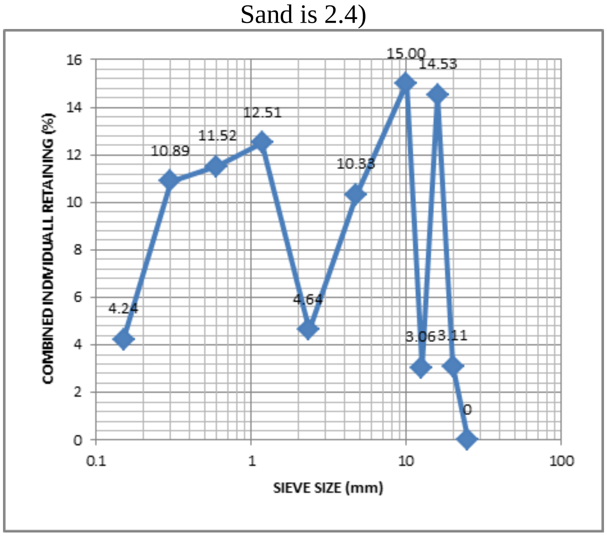
Combined Individual Retaining Curve for Aggregate Proportion 0.27:0.33:0.40 (Fineness Modulus of M Sand is 2.4)



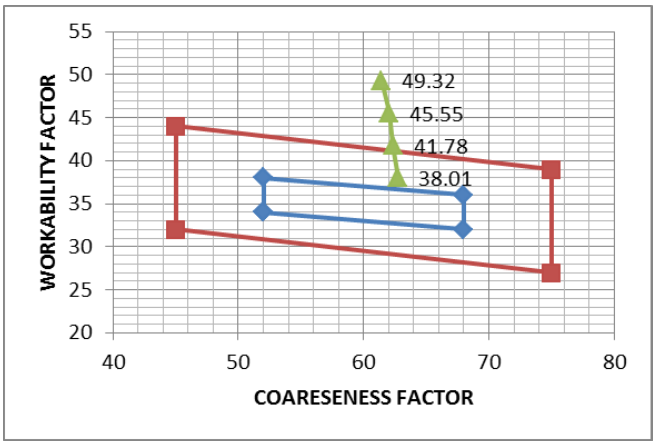
Combined Individual Retaining Curve for Aggregate Proportion 0.252:0.308:0.44 (Fineness Modulus of M Sand is 2.4)



Combined Individual Retaining Curve for Aggregate Proportion 0.235:0.285:0.48 (Fineness Modulus of M Sand is 2.4)



Combined Individual Retaining Curve for Aggregate Proportion 0.216:0.264:0.52 (Fineness Modulus of M Sand is 2.4)



Coarseness Factor Chart (Fineness Modulus of M Sand is 2.4)

B. *Mix Proportion*

S.No	% of M Sand	Cement Kg/m³	Water lit/m³	SP lit/m³	20 Mm Aggregate Kg/m³	12.5 Mm Aggregate Kg/m³	Fine Aggregate Kg/m³	W/C Ratio
1	40%	417	167	3	492	601.41	718.68	0.4
2	44%				459.2	561.32	790.55	
3	48%				428.23	519.32	862.42	
4	52%				393.65	481.13	934.28	

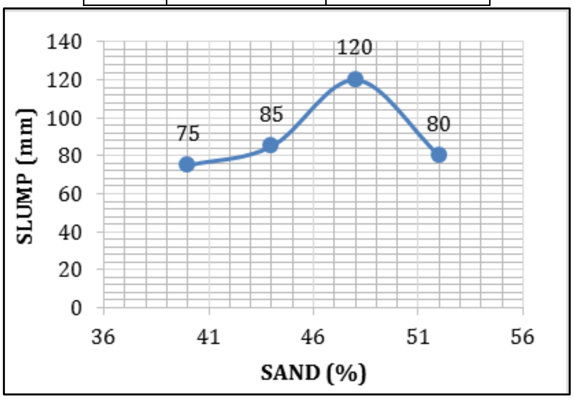
IV. RESULTS & DISCUSSIONS

The results of the tests conducted on fresh concrete and hardened concrete. The tests conducted on fresh concrete are slump test and bulk density of concrete and the tests conducted on hardened concrete are destructive test as well as non-destructive tests, such as compressive strength, Rebound hammer, ultrasonic pulse velocity respectively.

A. *Slump Test*

Slump for Different Percentages of the Sand for Concrete Mix of 2.4 Fineness Modulus of M Sand

S.No	M Sand (%)	Slump (mm)
1	40	75
2	44	85
3	48	120
4	52	80



Slump Curve for Different Percentages of the Sand for Concrete Mix

B. *Bulk Density of Concrete*

S. No	Sand (%)	Bulk density of concrete (Kg/lit)
1	40	2.65
2	44	2.51
3	48	2.57
4	52	2.44

Bulk density of concrete for Different Percentages of the Sand for Concrete Mix

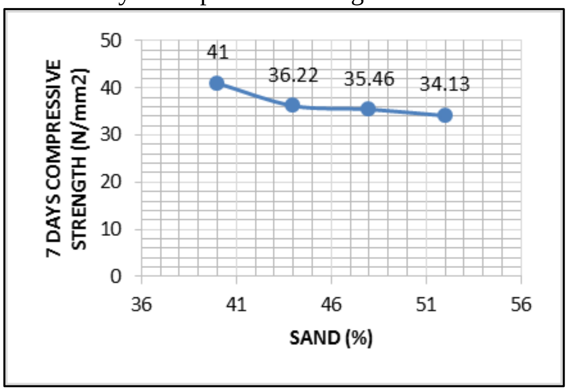
C. *Compressive Strength*

S.No	Sand (%)	7 Days Compressive Strength (N/mm²)
1	40	41
2	44	36.22
3	48	35.46
4	52	34.13

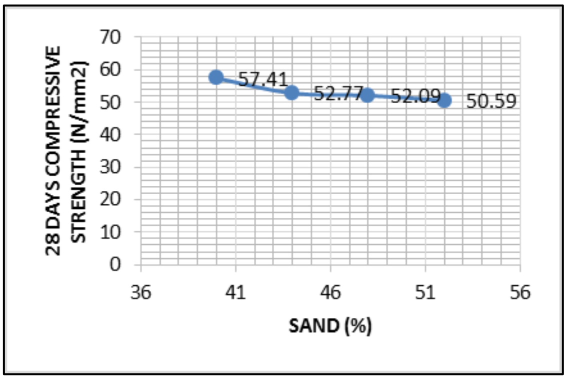
7 Days Compressive Strength for M Sand\

S.No	Sand (%)	28 Days Compressive Strength (N/mm²)
1	40	57.41
2	44	52.77
3	48	52.09
4	52	50.59

28 Days Compressive Strength for M Sand



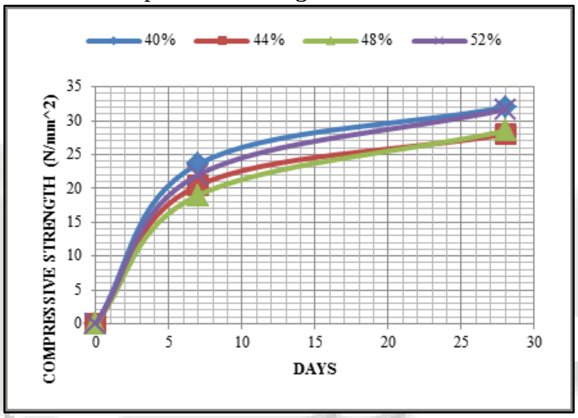
7 Days Compressive Strength for 2.4 Fineness Modulus of M Sand



28 Days Compressive Strength for 2.4 Fineness Modulus of M Sand

S.No	Sand (%)	7 Days compressive strength (N/mm^2)	28 Days compressive strength (N/mm^2)
1	40	41	57.41
2	44	36.22	52.77
3	48	35.46	52.09
4	52	34.13	50.59

Compressive Strength for of M Sand



Compressive Strength for M Sand

D. Rebound Hammer

S. No	% of MSand	7 days compressive strength (N/mm^2)	Rebound number
1	40	41	33
2	44	36.22	34
3	48	35.46	31
4	52	34.13	31

Rebound Hammer for 7 Days Compressive Strengths with Percentage of M Sand

S. No	% of MSand	28 days compressive strength (N/mm^2)	Rebound number
1	40	57.41	39
2	44	52.77	38
3	48	52.09	39
4	52	50.59	38

Rebound Hammer for 28 Days Compressive Strengths with Percentage of M Sand

E. Ultrasonic Pulse Velocity

S. No	% of MSand	7 days compressive strength (N/mm^2)	UPV m/s
1	40	41	4360
2	44	36.22	4310
3	48	35.46	4237
4	52	34.13	4274

UPV for 7 Days Compressive Strengths with Percentage of M Sand

S. No	% of MSand	28 days compressive strength (N/mm^2)	UPV m/s
1	40	57.41	4559
2	44	52.77	4559
3	48	52.09	4594
4	52	50.59	4491

UPV for 28 Days Compressive Strengths with Percentage of M Sand

V. CONCLUSIONS

This investigation attempts to develop the best aggregate blends and investigates the effect of aggregate packing on concrete performance (M50) through multiple criteria based on simulation and experiments. It was demonstrated that the aggregate packing can be used as a tool to optimize concrete mixtures and improve compressive strength and workability. The correlation between the grading, packing of aggregates and concrete performance is developed. The grading techniques based on power curves and coarseness chart provide valuable information on expected performance. There is no ideal method to obtain best aggregate blends; however initial mix for field trail can be used the above methods. Optimized aggregates gradations are found based on the theoretical methods and field trails only.

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