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Justifying novelty of natural and recycled coarse aggregates using IS code method and Tarantula curve method in pavement quality concrete

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Abstract:

Human civilization since the roman period witnessed modern use of materials like the volcanic ash as a construction material. Inclusion of volcanic ash in construction is evident since availability of modern marvels like the great wall of chine and the pyramids of Giza and the great gardens of the Babylonia. Concrete is a manmade wonder, being used after air and water as the third largest material. Content of concrete, the cement is responsible for 5% plus global greenhouse gases evolution. The mix of cement must be limited or evaluated cautiously in concrete leading to sustainable growth, without compromising quality and strength. Aggregates are responsible for body and strength in concrete. Selection and gradation are paramount along with cement for concrete overall performance. When these ingredients are selected using new methods like the Tarantula curve method and the tradition IS code method, comparisons show they are very similar in evaluation of strength and overall performance. The shortage and natural aggregates and their nonstop demand has caused concern, recycled concrete aggregates on the other hand are produced enormously and have proved to have similar strength as natural aggregates. In this work, slump cone test and other parameters proved that both are showing the same results for workability once the fine aggregates are quantified. Water to cement ratio for natural and RCA is responsible for good workability and impacting other engineering properties. Cement content on the RCA and natural aggregates causing changes in strength due to surface effect is evaluated in this work. The results show that 7-day strength for the RCA and NA are nearly similar whereas the 28-day final strength for the NA is more as compared to RCA. The IS code method and Tarantula curve method for the evaluation of compressive strength, split tensile strength indicates that both fits better and resembles similar strength. The strength displayed by the RCA and NCA aggregates concrete has a split tensile strength difference of 7%. The pavement quality concrete can be produced using these two new methods with multiple combinations of NA and RCA is proved in the work.

Keywords — **Aggregates, IS Code Method, Tarantula Curve Method, Compressive Strength, Split Tensile Strength, Specific Gravity, Concrete, Porosity, RCA, Natural Aggregates**.

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I. INTRODUCTION

Materials are part of every structure and gives strength and volume to the matrix. This is seen in the great pyramids and the great wall of China. The more strength a material displays the more in demand it will be and more will be its harnessing. This will lead to scarcity and enormous demand leads to its sustainable solutions like alternatives for the same. Such materials are available in finite proximity and limited to a localized source. This causes an urge for the material replacement and

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keeping in mind the strength criteria, recycled materials of the demolished one are expected to fit them. The Indian codal provisions make IS 456 a better choice for design aspects of concrete. A very popular method of concrete mix design is the use of tarantula curves for finding the optimal grades and mixes along with gradation of aggregates in the western countries particularly the United States. This tarantula mix design tool curves help in lying the concrete roads in India also nowadays. For this a little modification are done are in the Indian codal method and this is taken along with around 500 samples of concrete being laid with machine mix design. This is an optimization method for grading of aggregates and popularly used in the design and lying of concrete pavements at good condition of variations of temperature ranges. The workability condition of such concrete is optimal for use in Indian conditions too. When fresh concrete is used it is paramount to have the design mix at the simplest form and less complexity will help in easy lying of the pavement with least knowhow of the field workmanship. For this suffice workability is needed else addition or water modification in the mix will be a headache. Hence good mix will enable optimal water content and well gradation of the mix. When low volume of water is added to the mix it too will be sufficient workable without any extra extrapolation of water. The strength and other working parameters will not be impacted although with the quantity of the cement. The cost criteria will not be impacted and mix will be best workable under all conditions.

IS code method:

The concrete mix designed according to the Indian Standard mix proportioning guidelines are used to achieve specific characteristics such as workability of fresh concrete, strength and durability of hardened concrete at specified age. The guidelines are applicable to ordinary and standard concrete grades only. All the requirements of IS 456-2000 are also satisfied in the mix design process.

Based on the guidelines, the preliminary or trial mixes are made and desired properties of the trial mixes are checked; suitable adjustments are made to produce concrete possessing specified properties both in fresh and hardened states with the maximum overall economy. The design of plastic concrete mixes of medium strength can be based on the following two criteria:

1. The compressive strength of concrete is governed by its water-cement ratio.
2. For the given aggregate characteristics, the workability of concrete is governed by its water content.

What is Tarantula Curve Method

In this method the grading suitability is evaluated in the pavements made of concrete. Here the recommended limits of the different aperture sizes and sieves taken shall looks like the shape/profile of the spider “TARANTULA”. This shape is shown in the chart. If the recommended and proposed aggregates size and grading limits falls between the minimum and maximum levels, then the drawn shape must be looks like the tarantula.

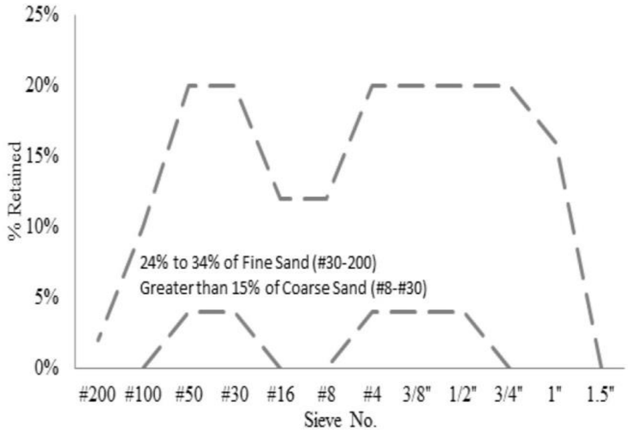

fig.1: profile of the tarantula

Concrete tensile strength-

when concrete is taken for shrinkage rising from thermal action and cracking due to loss in moisture, strength is impacted and affected. Hence the strength is a critical factor to be considered while keeping the moisture and cracking in limits and this can be done by carefully mentioning the water to cement ratio and application of admixtures. The tensile stamina is hence critical for early strength analysis and this being disturbed due to cracking and water loss from the pores. The stresses in the

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pores are impacted due to variations in the water content. When more stress is induced in the concrete then it will show cracks and this is vital for pavements and other non-reinforcement structures. The coarse particles along with cement paste makes the matrix of concrete strong due to fine size of cement and least porous. Hence this is tough from compression point but lacks the tensile strength and the reason can be the bonding among the cement paste and aggregates. The overall materials lack this stamina hence the difference is seen in the compression and tension behavior.

Tensile strength maturity

When the tensile strength behavior is seen as compared to flexural and compression of concrete, it is seen a similar behavior and tensile strength is gained slowly as like that of compressive and flexural strength. The indirect tensile stamina achieved by the concrete is calculated from the compressive strength values. Each mix of concrete gains strength in a different way and this relation is used for finding the strength gained by pavements at different ages and different moisture and curing conditions along with temperature variations. Hence, the pavement quality concrete is estimated for strength and age.

Gradation/grading of aggregates in concrete mixture:

The most important estimate is to do the gradation of particles like coarse aggregates in the concrete mix, as this will be affecting the workability of the freshly prepared concrete and its cement content will affect the coasting of the mix proportion and after that shrinkage will affect the final finished product matrix.

Well graded aggregates impact on the mix-

When the amount of cement is minimum and number of aggregates maximized this is the ideal condition for the workability of fresh concrete, water content is also having certain impact and this can be seen from the slump cone test. All these things will be governed with the shape and grading of the aggregates taken in the mix. Apparently, aggregates well graded will help more and fill almost more voids than their counterpart's fill. Hence, amount of cement paste reduces and voids gap will be least.

Poorly graded aggregates impact on the fresh concrete mix-

More cement paste will be required for more voids being present in this type of matrix, making it more exothermic centric and more shrinkage prone leading to more cracks. More amount of money wasted on this type of mix. Workability will be affected for the fresh concrete as it coats and covers the aggregates with more cement paste over the particles. More honeycombing and more segregation seen along with uneasiness in finishing the fresh materials made.

Gap graded materials impact on the concrete-

Gap in mixing and mingling of the rough and fine aggregates causes' gap graded concrete. This will even require more cement paste than the well-graded mix of the concrete matrix. The large sized and oversized particles cause problems in mixing, making it more sticker than the other above said mixes, finishing will not be smooth. Reduction in workability is visible, more water to cement ratio seen, more cement demand, more water demand causes more bleeding and segregation. Overall, the finish and texture are least and not good. Isolated materials in the matrix distinguishes them owing to size effect.

Coarse aggregate gradation:

Avoiding the gap grading of the concrete mix the gradation of fine and coarse aggregates is done altogether. For this, coarse aggregates gradation made in order with the overall grading of the mix. For this, medium-sized particles are included in the coarse aggregates making the mix comparable to be good as per the need else two different combinations can also be done with different ways and different grading of aggregates sizes. This shall not be simply taking coarse and fine aggregates in any way.

Fine aggregates gradation:

Workability depends on the quantity of the fine aggregates and its total content in the mix; well this also influences the well-graded combination of the aggregates in the concrete matrix.

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Measure of the gradation of the aggregate particles in the concrete mix:

Done by sieve analysis of various sizes and apertures having higher aperture size at the top and lower in size from top to bottom in the series put up at the sieve shaker. The aggregates of the size fitting to the aperture held captive in the sieve and rest left as per lower size. They pass in the still lower sizes as per the shaper factor and lastly retain on the pan, which being the last limit. How the optimization of the overall aggregates in the mix done: generally, 4 to 5 different mixes of the aggregates taken having at least one or two intermediate coarse aggregates then the overall poorly graded aggregates mix will not be affected and now can be taken for the fine and coarse mixing and reduces the chance of gap gradation.

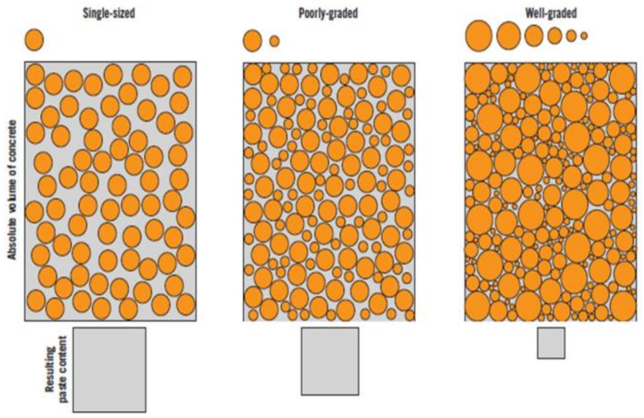

Fig. 2 different composition of the mixes in the particles

The compressive strength of the sample concrete depends upon the workmanship and the water to cement ratio of the mixture. When the matrix hardens then voids exist making them venerable to apply the reverse pressure as against compression. These voids are small if workmanship is good and water to cement ratio is optimal along with good degree of compaction. However, when the voids are more and large, they make the whole properties change and thereby cause cracks to propagate, enlarge and thereby making concrete to fail. Large air-filled voids are due to poor compaction, capillary holes are due to early hydration of water from the pores.

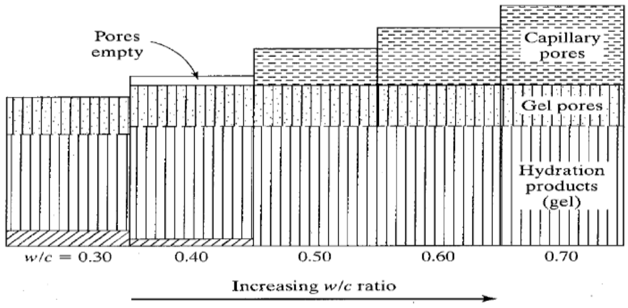

Fig.3 relationship between porosity and water to cement ratio

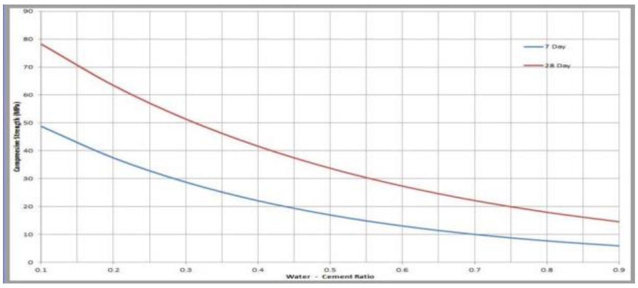

Fig. 4 compressive strength at 7 and 28 days

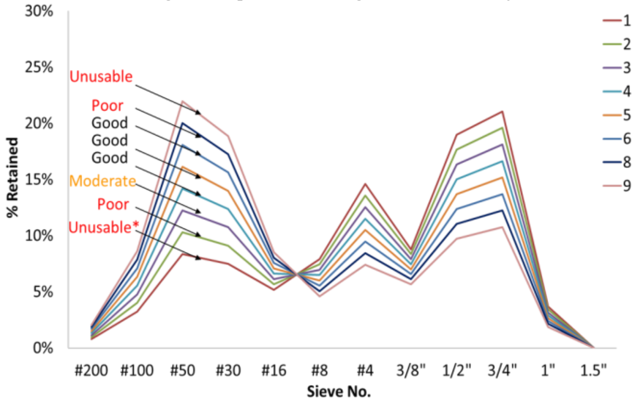

Fig. 5: aggregate mapping with regard to gradation

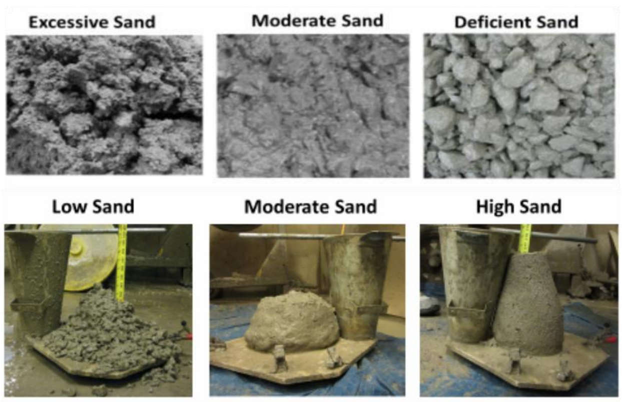

Figure 6: sand variation and slump cone type

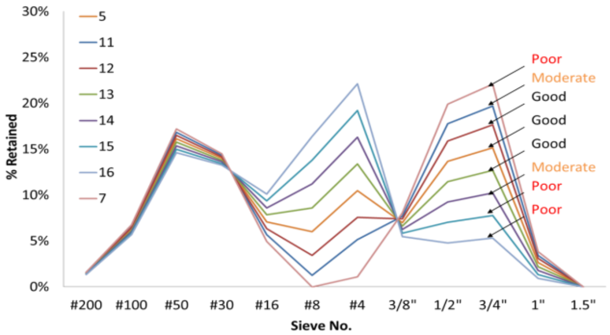

Fig. 7: coarse particles gradation as per tarantula graph

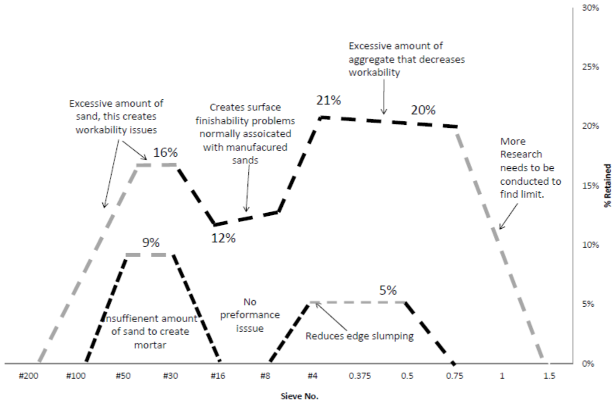

Figure 8: feature of concrete on tarantula graph

II. Laboratory Investigation: SIEVE ANALYSIS

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation. Grading pattern of a sample of coarse aggregate or fine aggregate is assessed by sieving a sample successively through all the sieves mounted one over the other in order of size, with larger sieve on the top. The material retained on each sieve after shaking, represents the fraction of aggregate coarser than the sieve below and finer than the sieve above. Sieving can be done either manually or mechanically.

In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve. Operation should be continued till such time that almost no particle is passing through. Mechanical devices are actually designed to give motion in all possible direction, and as such, it is more systematic and efficient than hand-sieving.

From the sieve analysis the particle size distribution in a sample of aggregate is found out. In this connection a term known as "Fineness Modulus" (F.M.) is being used. F.M. is a ready index of coarseness or fineness of the material. Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The larger the figure, the coarser is the material.

Many a time, fine aggregates are designated as coarse sand, medium sand and fine sand. These classifications do not give any precise meaning. What the supplier terms as fine sand may be really medium or even coarse sand. To avoid this ambiguity fineness modulus could be used as a yard stick to indicate the fineness of sand.

Table 1 - fineness modules range of aggregates

Type	Fineness Modulus
Fine sand	2.2 – 2.6
Medium sand	2.6 – 2.9
Coarse sand	2.9 – 3.2

Sieve analysis for natural coarse aggregate (NCA) (10-4.75mm):

Table 2: sieve analysis of 10- 4.75 mm sieve

Sieve Number	Material(g)	Individual % Retained	Percent Passing
10 mm	110.00	7.60%	92%
6.3 mm	903.00	62.36%	30%
4.75 mm	435.00	30.04%	0%
	Total = 1448.00		

Sieve analysis for recycled coarse aggregate (RCA) (20-10mm):

Table 3 : sieve analysis of 20-10 mm RCA

Sieve Number	Material(grams)	Individual % Retained	% Passing
20 mm	120.00	4.93%	95%
16 mm	537.50	22.09%	73%
14 mm	1021.00	41.96%	31%
11.2 mm	610.00	25.07%	6%
10 mm	145.00	5.96%	0%
	Total = 2433.50		

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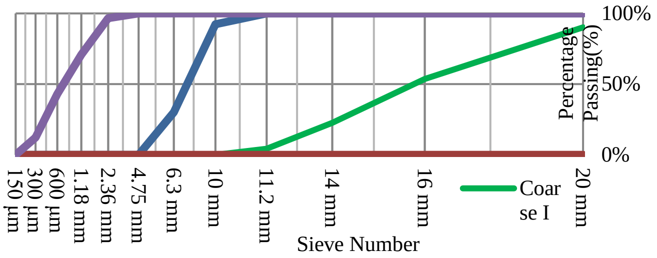

Fig 9: particles gradation graph

Sieve analysis for recycled coarse aggregate (RCA) (10-4.75mm):

Table 4 : particles sieve analysis 10-4.75 mm

Sieve Number	Material(grams)	Individual % Retained	Percent Passing
10 mm	143.00	12.73%	87%
6.3 mm	443.00	39.45%	48%
4.75 mm	537.00	47.82%	0%
	Total = 1123.00		

Table 5: percentage passing of particles

Sieve Number	Sieve wt	Material & Sieve wt	Material	Individual % Retained	Percent Passing	% Retained
20 mm	0.00	0.00	0.00	0%	100%	0%
16 mm	0.00	0.00	0.00	0%	100%	0%
14 mm	0.00	0.00	0.00	0%	100%	0%
11.2 mm	0.00	0.00	0.00	0%	100%	0%
10 mm	0.00	0.00	0.00	0%	100%	0%
6.3 mm	0.00	0.00	0.00	0%	100%	0%
4.75 mm	0.00	0.00	0.00	0%	100%	0%
2.36 mm	0.00	33.50	33.50	3%	97%	3%
1.18 mm	0.00	263.00	263.00	26%	71%	29%
600 µm	0.00	285.00	285.00	28%	43%	57%
300 µm	0.00	313.50	313.50	31%	12%	88%
150 µm	0.00	124.00	124.00	12%	0%	100%
		Total=	1019.00		Finess Modulus =	2.77

Sieve analysis for fine aggregate:

Table 6 : particles (fine) sieve analysis

Sieve Number	Materials (g)	Individual % Retained	Percentage Passing	Percentage Retained
4.75 mm	11.00	11	99	1
2.36 mm	33.50	3	96	4
1.18 mm	263.00	26	70	30
600 µm	285.00	28	42	58
300 µm	313.50	30	12	88
150 µm	124.00	12	0	100

Fineness modulus = 2.81

Grading Zone - II

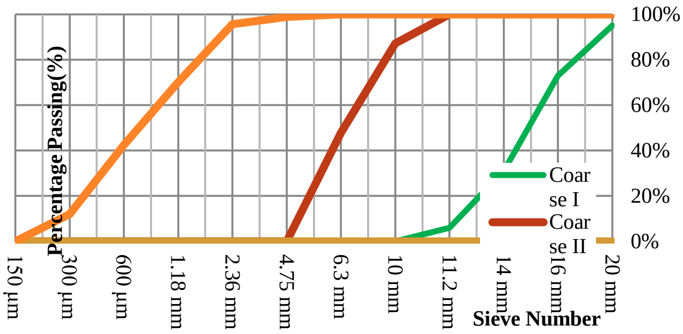

fig. 10 particles passing- gradation curves

Fig. 11: prepared samples of natural aggregates and RCA

III. RESULTS

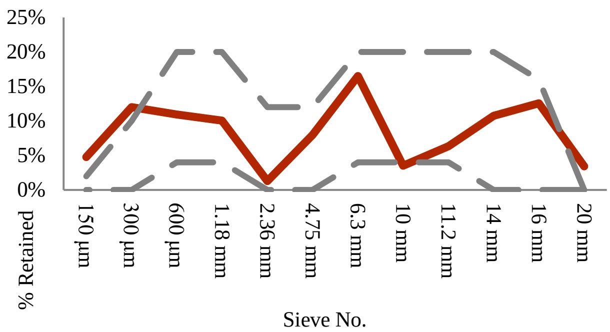

Fig.12 tarantula curve for the sample

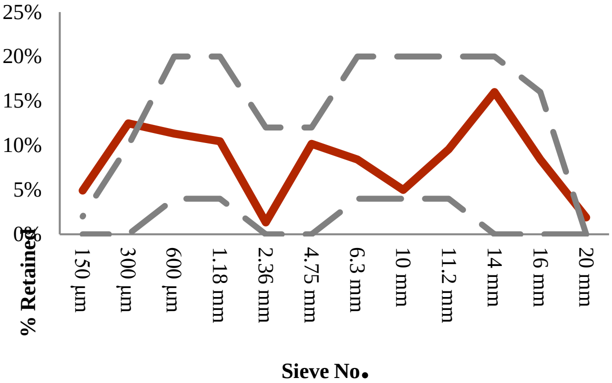

Fig. 13 Tarantula curve for the sample of RCA

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Fig. 14: samples after failure

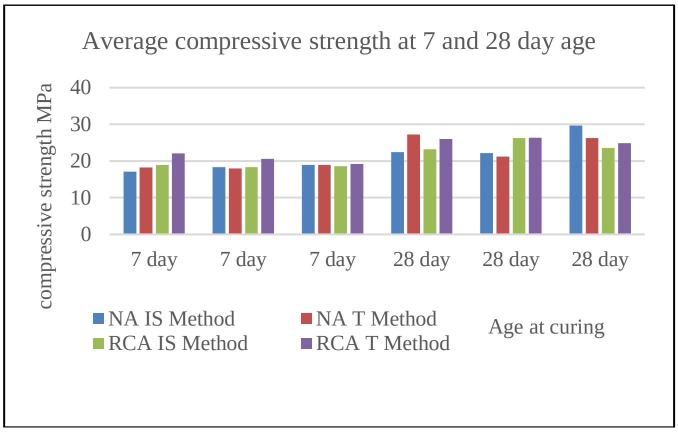

Figure 15 average compressive strength of the cubes at 7- and 28-days age

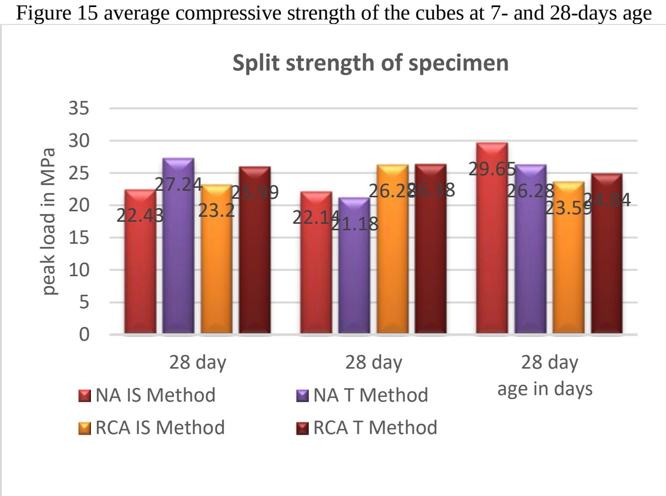

Fig 16 : split strength comparison for the cylinder

CONCLUSIONS

1. Mixture design are chosen based on experience and availability of aggregates from the local market and quarries.
2. The prime goal of the gradation process is to obtain the optimum aggregate gradation, that can provide less cement content maintain the workability and strength.
3. The slump cone and the box test results indicated better workability and the strength of the aggregates is optimal
4. The box test is an indication of workability and the point template of glass is an extension leading to better performance of the concrete made with least distortion in the edges.
5. The IS code method and the Tarantula curve method results are closer for the natural aggregates and recycled concrete aggregates.
6. The seven-day result of the natural aggregates as per IS code is displaying not too much variations in strength as the Tarantula curve method.
7. The seven-day age results of the recycled aggregates as per the IS method and the Tarantula method is much lower than the natural aggregates, it may be due to the presence of mortar layer over the RCA and absorption of water and affecting the water absorption and workability of the concrete.
8. The results displayed by the 28-day strength of the concrete cube sample for the natural aggregates as per the IS code method are good than the Tarantula curve method, this may be due to aggregate cement paste and water to cement ratio performance along with permeability of the cement paste into the aggregates.
9. The seven-day performance of the natural aggregates in the Tarantula method is 6.59 percent better than the IS code method and for the RCA it is almost 15 percent better than the IS method as compared to the Tarantula method, showing a ray of hope for the RCA performance with the Tarantula curve method
10. The 28-day strength of the RCA as per the Tarantula method is still having good strength as compared to the IS method. This difference may be due to the absorption and variation in moisture content of RCA and differentiation of cement paste over the ITZ (interfacial transition zone) in the aggregates, causing a variation in the void's formation owing to strength and workability, impacting the overall performance.

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11. Much better can be done if the voids, permeability and w/c ratio of the RCA is analyzed using XRD sampling.

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