Studies on Mechanical Properties of Ternary Blended Self Compacting Concrete Using Different Percentages of Recycled Aggregate

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Abstract— Concrete is the most widely used construction material. Inadequate compaction of concrete results in large number of voids, concrete pouring and compaction on structural element with dense reinforcement and beam column joint are difficult. Self compacting concrete (SCC) is new type of concrete that has flow ability, filling ability, passing ability and stability. Coarse aggregate is one of these factors that have a significant influence on SCC. The use of recycled coarse aggregate (RCA) in any concrete is an effort of recycle waste and new development in environmental friendly concrete. Ternary blended concrete (TBC) improves strength, durability and also it is eco friendly in nature. In this research ternary blended SCC of 50 grades is designed by replacing natural coarse aggregate with recycled aggregate from roof slab of 25years old. The % replacements are 0, 25, 50, 75 and 100. Also, the cement is partially replaced with 10% Metakaolin by weight of binder. Super-plasticizer is added at a dosage of 1.0%, by cement weight, to achieve the flow characteristic of SCC. The mix that has the large slump flow is tested with V-funnel and L-box and the results are presented. Further the compressive strength, split tensile strength and flexural strength are conducted at the age of 7days, 28days and 56days for SCC 50 grade of concrete. The results indicated that the compressive strength of 25% and 50% replaced recycled aggregate Self compacting concrete is nearly equal to natural aggregate Self Compacting Concrete at 7, 28, 56 days age of concrete. The split tensile and flexural strength of 25% replaced recycled aggregate Self compacting concrete is nearly equal to Natural aggregate Self Compacting Concrete at respective age of concrete. At all ages Flexural strength shown decrease in trend with the increase in replacement of recycled aggregate. From the research work keeping economy, eco-friendliness and compressive strength in point of view convectional aggregate can be replaced with recycle aggregate concrete by 50% in ternary blended self compacting concrete.

Key words: Metakaolin, Recycled Aggregate (RCA), Superplasticiser, Natural Aggregates etc

I. SELF COMPACTING CONCRETE INTRODUCTION

Self Compacting Concrete as the name signifies that, it can be able to compact itself without any additional vibration or compaction i.e. without application of any other external energy. It should be able to assume any complicated form work shapes without cavities and entrapped of air. The reinforcement should be effectively covered and the aggregates should be fully soaked with the concrete mix. In addition, the concrete should be self-compacting type and self-deforming without any external mode of compaction.

II. TERMINOLOGY

- Scc- Self Compacting Concrete
- Psc- Portland Slag Cement
- Nca- Normal Coarse Aggregate
- Rca- Recycled Coarse Aggregate
- Asr- Alkali-Silica Reactivity
- Tbc- Ternary Blended Concrete
- Ra - Recycled Aggregate

III. OBJECTIVE OF PAPER

The main objective of the present work is to study the behavior of Self-Compacting Concrete at different % replacement of recycled aggregate. The strength parameters consider was Compression strength, Split Tensile strength and Flexural strength. The strengths are studied at 7 days, 28days and 56days of curing.

In the present study, it is planned to produce SCC by trial and error using locally available materials and study the fresh concrete properties. Elaborate experimental programme is produced to make SCC satisfying all the minimum requirements in the laboratory.

IV. INGREDIENTS OF MATERIALS

Different ingredients used in this work are

1) Portland slag Cement
2) Fine aggregate
3) Coarse aggregate
   1) Normal coarse aggregate (NCA)
   2) Recycled coarse aggregate (RCA)
4) Metakaolin
5) Water
6) Super Plasticizer

A. Test Data for Materials

a) Cement used -Portland Slag Cement
   - Specific Gravity = 3.12

b) Specific gravity of recycled coarse aggregate=2.64
   - Specific Gravity of natural Coarse Aggregate=2.76
   - Specific Gravity of Fine Aggregate =2.56

c) Water Absorption Normal Coarse Aggregate = 0.4%
   - Water Absorption Recycled Coarse Aggregate =0.5%
   - Water Absorption Fine Aggregate =0.4%

d) Free Moisture
   - Coarse Aggregate=nill
   - Fine Aggregate= nill

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V. DESIGN OF SELF-COMPACTING CONCRETE MIX BY NAN SU METHOD

A. S/a Ratio

It is the ratio of fine aggregate to total aggregate which ranges usually between 50-57%. Now for the present study s/a is taken as 52%

B. PF (Packing Factor)

It is defined as a ratio of mass aggregate of tightly packed state to of that loosely packed state.

1) Step 1: Calculation of coarse aggregate and fine aggregate

The measure of coarse aggregate and fine aggregate was determined by knowing packing factor

W_{fa} =PF x W_{fal} x $\frac{s}{a}$

Where W_{fal} = Unit weight of the fine aggregate=1543.7 gm

PF = packing factor = 1.078;

s/a = 52%

W_{fa} = 1.078 x 1543.7 x 0.52

W_{fa} = 865.3 kg

W_{ca} = PF x W_{cal} x(1- $\frac{s}{a}$)

Where W_{fal} = Unit weight of the coarse aggregate=1468.15 gm

PF = packing factor = 1.098; 1-s/a = 48%

W_{ca} = 1.098 x 1468.15 x 0.48

W_{ca} = 773.78 kg

C. Step 2: Calculation of cement content

Generally High Performance Concrete (HPC) and SCC are used in Taiwan, Yield a compressive strength of 0.14Mpa/kg of cement. Therefore, the cement content to be used was calculated from the equation

$$C=\frac{fc}{0.14}$$

Where f_c= Designed strength of concrete=58.25 N/mm^2

$$C=\frac{58.25}{0.14}=416.071 \text{ kg}$$

1) Step 3: Calculation of mixing water content required by weight of cement

The relationship between compressive strength and water-cement ratio for SCC is similar to that of conventional concrete.

W_{wc} = $\frac{w}{c}$ x C

where C = Compressive strength ,0.14Mpa/kg of cement=58.25

W_{wc} = Mixing water content required by cement , kg/m^3

$\frac{w}{c}$ = The water-cement ratio by weight, which can be determined by compressive strength=0.35

W_{wc} = 0.35 x 416.071

W_{wc} = 145.62 kg

2) Step 4: Calculation of Filler

Filler is used to increase the content of powder. The volume of the filler paste V_{pf} can be calculated as followes,

V_{pf}= 1- $\frac{Wca}{1000XGca}$ - $\frac{Wfa}{1000XGfa}$ - $\frac{C}{1000XGc}$ -$\frac{Ww}{1000XGc}$-V_a

Where W_f =Mass of filler,

V_a =Air content in %,

G_f = Specific gravity of filler,

$\frac{w}{p}$ = Water-powder ratio.

volume of Metakaolin

V_{pf} = 1- $\frac{773.78}{1000X2.76}$ - $\frac{865.3}{1000X2.64}$ - $\frac{416.071}{1000X3.03}$ -$\frac{145.62}{1000X1}$-0.02

V_{pf} =1-0.28-0.328-0.137-0.145-0.02

V_{pf} = 0.09%

Amount of Metakaolin required

W_f=$\frac{[Vpf\ X\ 1000\ XGpf]}{[1+(\frac{w}{p})XGf]}$

= $\frac{[0.09X\ 1000\ X2.6]}{[1+(0.82)X2.6]}$

W_f = $\frac{234}{3.132}$ =75 kg

Mixing water content required by filler was calculated using equation

W_{wf} = $\frac{w}{F}$ + W_f

W_{wf} = 0.9 x75 = 67.5 kg

Where , W_{wf} =Quantity of water required for filler

3) Step 5: Calculation of mixing water content needed in SCC

The mixing water content required(W_f) for SCC is the total amount of water needed and filler in mixing. therefore, it can be calculate as follows

W_w = W_{wc} + W_{wf}

=145.62 +67.5

=213.12kg

4) Step 6: Calculation of super plasticizer dosage

The quantity of super plasticizer is determined from experience or from its saturation point. water content to be added in the mix can be corrected, so that requirement of SCC can be satisfied.

5) Step 7: Mix proportions

Total powder content =Cement + Metakaolin

W_p = 416.071+67.5

W_p = 483.571 kg's

W_w =Total water -20% due to adding of super plasticizer

W_w = 213.12 -20%

W_w =170.496 kg's

Therefore, the mix proportions of SCC mix were

Mix proportion of SCC is

483.571:865.3:773.78

1: 1.78:1.60: 0.35

Where 1 means cement and metakaolin fine aggregate

1.60 means coarse aggregate

0.35 means water cement ratio

VI. TEST RESULTS OF CUBES, CYLINDERS & PRISMS

SCC test methods have two main purposes. First is to judge whether the concrete is self-compatible or not and the second is to evaluate deformability or viscosity for estimating proper mix proportionality. Conventional workability tests, devised for normal range of concrete mixture are not adequate for SCC, because they are not sensitive enough to detect the tendency to segregation. Therefore test equipment were fabricated for judging the following characteristics are Filling ability, Passing ability, Resistance to segregation.

A. Filling Ability:-

1) Slump Flow Test
2) V-Funnel Test
3) T_{50} Slump Flow

B. Passing Ability:-

1) L-Box Test
2) U-Box Test
3) CONCRETE FLOW

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The results of workability tests are shown in Table 5.1. The results obtained are within the range of acceptance criteria of Self-Compacting Concrete according to EFNARC standards.

S.No	Method	Test Results
1	Slump flow, mm	670
2	T_{50} Slump flow, sec	5
3	V-Funnel, sec T_{5min}	10 12
4	L-Box Test (H_2/H_1) H_1 (mm) H_2 (mm) H_2/H_1	0.83 95 115 0.83

Table 1:

The specimens were tested as per IS 516:1959 and strengths were calculated for 14,28 days& 56 days

- Compressive strength test is conducted on 1000 KN capacity compression testing machine.

  GPC cubes (100x100x100mm) are cast by varying molarity and cured in ambient conditions. All specimens were tested for different ages (14, 28,56days).
- Flexural Test was conducted to obtain the modulus of rupture or first crack developed and full collapse of the beam. The flexural test was conducted on sunlight cured prism beams (500mm x 100mm x 100mm). The test was conducted after 14 & 28and 56 days age of concrete.
- Split Tensile Strength The cylindrical specimens (150mmDia and 300mm height) are tested on tensile testing machine 1000KN capacity.

C. Compressive Strength of SCC

Fig. 1:

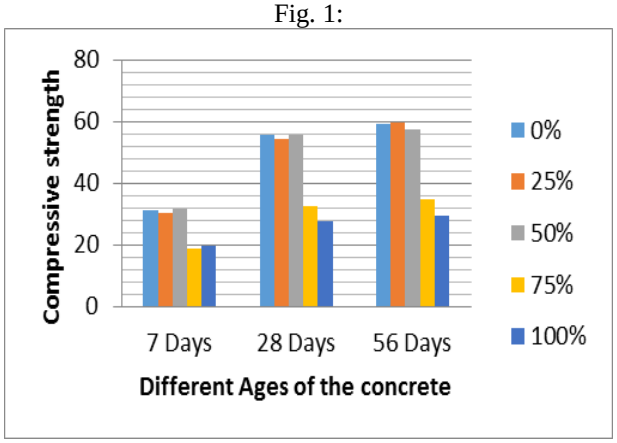

Fig. 2: Compressive strength of M50 grade concrete at all ages with different % replacement of RA.

Compressive strength (MPa) for M50 grade concrete is observed at 7, 28 & 56 days for different % replacement of RA (i.e. 0%, 25%, 50%, 75%, and 100% respectively).

From the figure 1, at 7 days age, the compressive strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 50.45% for 75% replacement and 45.3% for 100% replacement.

From the figure 1, at 28 days age, the compressive strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 52.21% for 75% replacement and67.62% for 100% replacement.

From the figure 1, at 56 days age, the compressive strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 52.31% for 75% replacement and 67.57% for 100% replacement.

The strength of 75% and 100% replacement of RA decreases gradually when compare with 50% replacement at all ages. The percentage decreases in strength is within the range 50-65% at 75% and 100% replacement at all ages when compare with 0% replacement. The strength variation for 25% and 50% is very marginal (only 3%) where 50% replacement shown higher strengths at all ages . It is observed that normal aggregate can be replaced with recycled aggregate by 50% in the view of developing eco friendly concrete.

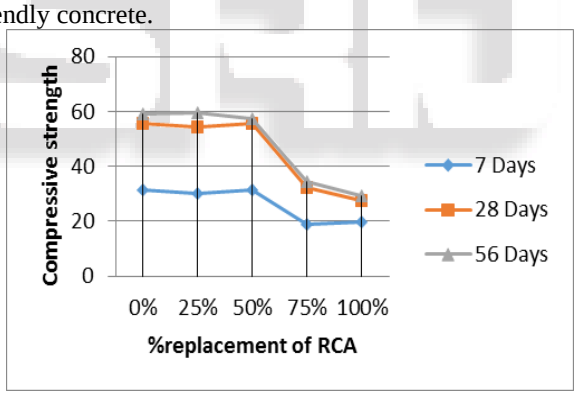

Fig. 3: Variation in compressive strength of different % of RCA

It is observed that the strength increases at 50% when compare with 25% but the trend is decreases At 56 days and 50% replacement of RA but the rate of increase in strength is low.

- Rapid increase in strength at 28days when compare with 7days
- There is not much variation strength between 28days and 56days marginal 2-5%.
- For 0%, 25%, 50% replacements the rate of increase is about 50% in strength when compare with 7days in age of 28 and 56days.
- For 75% and 100% replacement the strength is increase by 10-12% in strength when compare with 7days in age of 28 and 56days
- At all ages up to 50% strength does not decrease remarkably when compare to 0% replacement but for 75% and 100% strength decreases gradually.

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- It is observed that recycled aggregate can be replacing 50%.
- Beyond 50% replacement the rate of increase in strength reduced remarkably from 7 to 28days.This indicates that further replacement of recycled aggregate gives no better than 7days strength

D. Split Tensile Strength

Fig. 4:

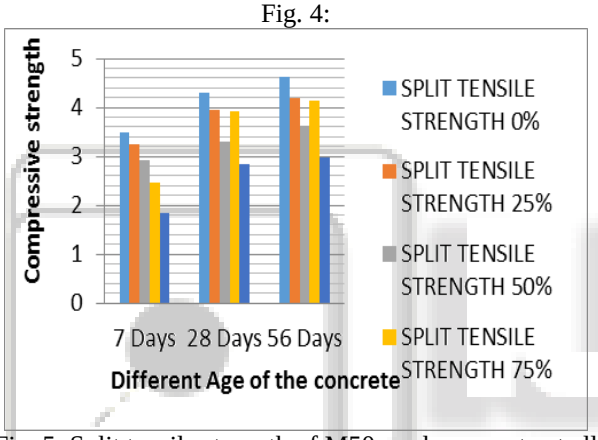

Fig. 5: Split tensile strength of M50 grade concrete at all ages with different % replacement of RA.

Split tensile strength (N/mm^2) for M50 grade concrete is observed at 7, 28 & 56 days for different % replacement of RA (i.e. 0% , 25% , 50% , 75% , 100% respectively).

From the figure1 at 7 days age, the split tensile strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 35.29 % for 75% replacement and 62.2 for 100% replacement. From the figure 1, at 28 days age , the split tensile strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 9.26 % for 75% replacement and 41% for 100% replacement.

From the figure 1, at 56 days age, the split tensile strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 10.7 % for 75% replacement and 43.4% for 100% replacement.

The strength of 75% and 100% replacement of RA decreases gradually when compare with 50% replacement at all ages. The percentage decreases in strength is within the range 45-62% at 75% and 100% replacement at all ages when compare with 0% replacement. The strength variation for25% and 50% is very marginal (only 15%) where 50% replacement shown higher strengths at all ages. It is observed that normal aggregate can be replaced with recycled aggregate by 50% in the view of developing eco friendly concrete.

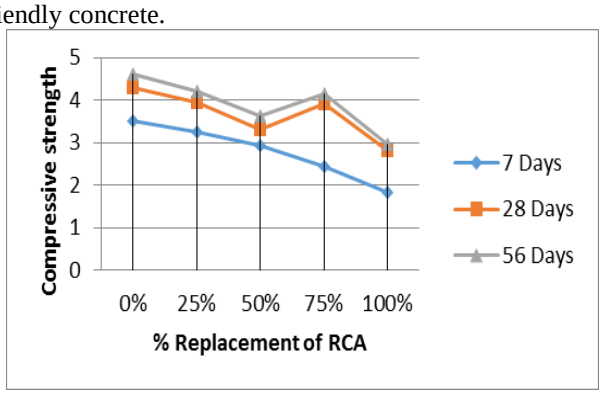

Fig. 6: variation in split tensile strength of different % of recycled

It is observed that the strength increases at 50% when compare with 25% b At 56days and 50% replacement of RA but the rate of increase in strength is low. Rapid increase in strength at 28days when compare with 7days.There is not much variation strength between 28days and 56days marginal 2-5%.

For 0%, 25%, 50% replacements the rate of increase is about 20% in strength when compare with 7days in age of 28 and 56days For 75% and 100% replacement the strength is increase by 20-25% in strength when compare with 7days in age of 28 and 56days but the trend is decrease when compare with 25% and 50% ,At all ages up to 50% strength does not decrease remarkably when compare to 0% replacement but for 75% also increases and 100% strength decreases gradually It is observed that recycled aggregate can be replace 50%Beyond 50% replacement the rate of increase in strength reduced remarkably from 7 to 28days.This indicates that further replacement of recycled aggregate gives no better than 7days strength

E. Flexural Strength of SCC

Fig. 7:

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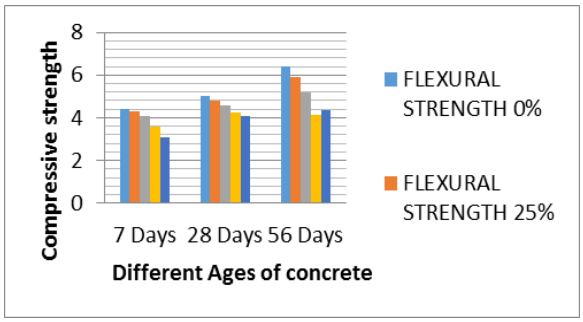

Fig. 8: Flexural strength of M50 grade concrete at all ages with different % replacement of RA

Flexural strength (N/mm^2) for M50 grade concrete is observed at 7, 28 & 56 days for different % replacement of RA (i.e. 0% , 25% , 50% , 75% , 100% respectively)From the figure 5.1.3, at 7 days age , the flexural strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 20.82% for 75% replacement and 35.29 for 100% replacement.

From the figure1 at 28 days age , the Flexural strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 17.24% for 75% replacement and 21.05% for 100% replacement.

From the figure1 at 56 days age , the flexural strength of 25% and 50% replaced recycled aggregate SCC is nearly equal to natural aggregate SCC. Strength is found to be decreased as the % replacement increased for 75% and 100% replacement. The decrease in strength is up to 34.64% for 75% replacement and 37.69% for 100% replacement.

The strength of 75% and 100% replacement of RA decreases gradually when compare with 50% replacement at all ages. The percentage decreases in strength is within the range 30-40% at 75% and 100% replacement at all ages when compare with 0% replacement. The strength variation for25% and 50% is very marginal (only 9%) where 50% replacement shown higher strengths at all ages . It is observed that normal aggregate can be replaced with recycled aggregate by 50% in the view of developing eco friendly concrete.

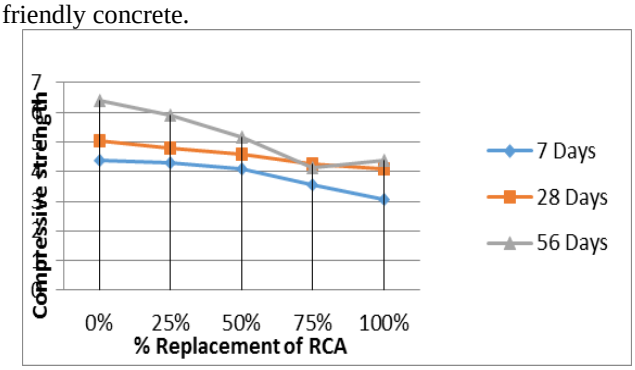

Fig. 9: variation in compressive strength of different % of recycled

It is observed that the strength increases at 50% when compare with 25% but the trend is decreases

At 56days and 50% replacement of RA but the rate of increase in strength is low Rapid increase in strength at 28days when compare with 7days There is not much variation strength between 28days and 56days marginal 2-5% For 0% , 25% , 50% replacements the rate of increase is about 30% in strength when compare with 7days in age of 28 and 56days For 75% and 100% replacement the strength is decrease by 10-12% in strength when compare with 7days in age of 28 and 56days At all ages up to 50% strength does not decrease remarkably when compare to 0% replacement but for 75% and 100% strength decreases gradually It is observed that recycled aggregate can be replace 50%

Beyond 50% replacement the rate of increase in strength reduced remarkably from 7 to 28days.This indicates that further replacement of recycled aggregate gives no better than 7days strength but the trend is decreases

VII. Relation between Compressive Strength and Split Tensile Strength

Table 5.2 exhibits results of splitting tensile strength at 28days for all RA replacement percentages in SCC.

These values vary between 9.3% and 13% of their respective original compressive strengths. Several researchers and different codes proposed relation between compressive strength and split tensile strength as below.

The American Concrete Institute (ACI) [31] recommends the following equation

Ft = 0.56 X (fc) 0.5 …….. Eq-1

Hueste et al. (2004) [29] proposed similar equation as below

Ft= 0.55 X (fc) 0.55 …….. Eq-2

Yun Wang Choi et al. (2004) [30], proposed relation between compressive strength and split tensile strength for light weight self compacting concrete as below

Y= 0.076 X + 0.5582 ……. Eq-3

Where X = Compressive strength and

Y= split tensile strength at 28 days.

S.No	Percentage replacement	Split tensile strength (MPa)	Compressive Strength (MPa)	Estimated Split Tensile Strength (MPa) as per equations 1, 2 and 3		
1	0	4.29	55.7	4.18	5.02	4.79
2	25	3.96	54.2	4.12	4.94	4.68
3	50	3.3	55.7	4.18	5.02	4.79
4	75	3.91	32.3	3.18	3.72	3.01
5	100	2.38	27.6	2.94	3.41	2.65

Table 2: Results of splitting tensile strength at 28days for all RA replacement percentages in TB SCC

The split tensile strength values obtained by the experimental work are lesser values when compared to theoretical values.

VIII. Relation between Compressive Strength and Flexural Strength

Table exhibits results of flexural strength at 28days for all RA replacement percentages in SCC. These values vary between 9.8% and 10.4% of their respective original compressive strengths. Several researchers and different

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codes proposed relation between compressive strength and Flexural strength as below.

The following equation is used in Indian standards IS-456-2000[32] to compute the flexural strength from its compressive strength.

Flexural strength = 0.7 X $fck^{0.5}$ …… Eq-4

While Central Road Research Institute **(CRRI)** [28] has suggested:

Y=11.0x – 3.4.....Eq-5

Where Y=Comp. Strength and x = Flexural strength Results of flexural strength at 28days for all RA replacement percentages in TB SCC.

S.no	Percentage replacement	Flexural strength (MPa)	Compressive Strength (Mpa)	Estimated flexural strength Strength (Mpa) as per equations 4 and 5	
1	0	5.04	55.7	2.61	5.37
2	25	4.78	54.2	2.58	5.24
3	50	4.57	55.7	2.61	5.37
4	75	4.24	32.3	1.99	3.24
5	100	4.08	27.6	1.84	2.81

Table 2:

The flexural strength values obtained by the experimental work are in between Equations 4 and 5. These values are nearly equal to CRRI equation. The relationship between split, compression and flexural strengths shown similar trends as observed by Pamnani Nanak J., et al [28]

The split tension and flexural strengths obtained shown little deviation from the empirical values because present concrete is Ternary blended self-compacting recycled aggregate concrete which is slightly different from other concrete

IX. Results and Conclusions

From the limited research work conducted the following conclusions are drawn

1) The compressive strength of 25% and 50% replaced recycled aggregate Self compacting concrete is nearly equal to natural aggregate Self Compacting Concrete at 7, 28, 56 days age of concrete.
2) The decrease in strength is up to 50.45% for 75% replacement and 45.3% for 100% replacement for 7 days.
3) And it is about 52.21% and 67% for 28days and 56days.
4) The compressive strength decreased with the increase in replacement percent of recycled coarse aggregate beyond 50%.
5) The compressive strength of the 7, 28, 56 days of recycled aggregate self compacting concrete achieved required compressive strength up to 50% replacement of recycle coarse aggregate.
6) The split tensile strength of 25% replaced recycled aggregate Self compacting concrete is nearly equal to Natural aggregate Self Compacting Concrete at 7, 28, 56 days age of concrete.
7) At an age of 7, 28, 56 days split tensile strength of concrete decreased as the % replacement increased.
8) The Flexural strength of 25% replaced recycled aggregate Self compacting concrete is nearly equal to Natural aggregate Self Compacting Concrete at 7, 28, 56 days age of concrete.
9) At all ages Flexural strength shown decrease in trends with the increase in replacement of recycled aggregate.
10) As the replacement of recycled aggregate increased beyond 50% , the strength improvement is not remarkable beyond 7days of age.
11) The obtained values shown slight deviations from the empirical values.
12) The split tensile and flexural strengths of Ternary blended self compacting recycled concrete is varies from conventional concrete and conventional self compacting concrete. Hence relation between the strength parameters should be established.

From the present research work, keeping economy, eco friendly and compressive strength in point of view, convectional aggregate can be replaced with recycle aggregate concrete by 50% in ternary blended self compacting concrete

X. Scope

Scope of the thesis is followed below:

Effect of different curing methods on mechanical properties like compressive strength, split tensile strength and flexural strength of Ternary Blended Recycle Coarse Aggregate Self Compacting Concrete can be studied.

Durability studies like Temperature effects , Acid attacks of Ternary Blended Recycle Coarse Aggregate Self Compacting Concrete can be studied.

Mechanical properties like compressive strength, split tensile strength and flexural strength of binary Blended Recycle Coarse Aggregate Self Compacting Concrete can be studied.

Effect of different curing methods on mechanical properties like compressive strength, split tensile strength and flexural strength of Binary Blended Recycle Coarse Aggregate Self Compacting Concrete can be studied.

Durability studies like Temperature effects, Acid attacks of Binary Blended Recycle Coarse Aggregate Self Compacting Concrete can be studied.

Acknowledgement

The author would like to thank to P.RAMALINGA CHARI, ASST.Professor, department of civil engineering, DMS SVH College of Engineering, Machilipatnam, Andhra Pradesh, India,

For his extensive guidance. The author would also like to thank the Department of Civil Engineering, lab technicians of DMS SVH College of Engineering,

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Machilipatnam, and Andhra Pradesh, India to make this work Successful.

The author would like to thank to P.VENKATESWARA PRSAD, Professor& Head of civil engineering, vikas Engineering College, Vijayawada Andhra Pradesh, India,

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