CHAPTER-7
CONCLUSIONS,
RESEARCH OUTCOME
AND
FUTURE SCOPE
Conclusion

(A) **Ingredients**
1. All the ingredients for the conventional concrete and recycled aggregate concrete were tested as per relevant standards and all the properties in the terms of physical and chemical composition founds satisfactorily for the use.

(B) **Rheological Properties**
1. All the mix conventional and mix with partial replacement of coarse aggregate by 20-100% with recycled aggregate founds workable with a required W/C ratio as per IS 456-2000 for different grades of concrete.
2. The density of wet concrete and dry concrete falls in the range of 2300 to 2450 kg/m$^3$ or 23.00 to 24.50 kN/m$^3$. It is as per the standard value 24.00 kN/m$^3$.
3. The workability in terms of compaction factor shows satisfactory results in the range of 0.85 to 0.90 on an average for concrete grade M20 to M40. This is as per the specified limit 0.8 to 0.95 in IS 456-2000.
4. For all the design mix 40% replacement of natural aggregates gives the optimum value of a compaction factor in the range of 0.860 to 0.920 on an average as indicated in the graphical comparative presentation.
5. Further replacement beyond 40% reduces the workability leading to bleeding, segregation and honeycombing.
6. From the physical observation, W/C ratio and compaction factor results of RAC, the concrete can be utilized for ready mix applications.

(C) **Mechanical Properties**
All the mix conventional and mix with partial replacement of coarse aggregate various mechanical properties like compressive, Split, Flexural, Modulus of Elasticity, Pullout and durability were found out and conclusions are shown below.

**C.1 Compressive Strength**
Conclusions for cube as well as cylinder compressive strength are drawn.

**C.1.1 Cube Compressive Strength**
1. For grade of concrete M20 to M45 40% replacement with recycled aggregate gives the design strength at 28 days.
2. For richer mix M50, M55 and M60 20% replacement is observed as an optimum replacement value.
3. For design mix M20 to M35 grade concrete all the replacements with RCA gains early strength at 3 days and required strength of 66% at 14 days age. Average increase in strength from 3 to 28 days for grade M20 to M45 with an optimum replacement of natural aggregate with recycled aggregate (40%) founds to be 28.5%.

4. For richer mix M50, M55, M60 the gain in strength is lower as compared to M20 to M45 mixes and it is in order of 15% on an average. This may be due to retardation in hydration by virtue of excess silica in recycled aggregates.

5. Beyond 28 days all mixes and all the replacement value show very marginal gain less than 5% for normal mix and 1% for the richer mix.

6. All the mixes reflect progressive gain in strength linearly from the age of 3 days to 56 days.

7. The regression analysis of a mathematical model for the prediction of cube compressive strength reflects the regression constant 0.6112 for linear, 0.5934 for logarithmic, 0.643 for quadratic, 0.6193 for exponential and 0.6064 for power formula which are near to the actual value.

C.1.2 Cylinder Compressive Strength

1. For grade of concrete M20 to M45 40% replacement with recycled aggregate gives design strength at 28 days and for richer mix M50 to M60 20% replacement design strength at 28 days is nearly gained.

2. Average compressive strength from 28 to 56 days for grade M20 to M45 at the optimum replacement of natural aggregate with recycled aggregate of (40%) founds to be 28.5%.

3. Beyond 28 days all mixes and all the replacement value show very marginal gain, which is less than 5%.

4. All the mixes reflect the progressive gain in strength linearly from 28 to 56 days.

C.2 Cube and Cylinder Split Tensile Strength

Following conclusions were drawn for the splitting tensile test for cubes and cylindrical specimens.

1. All the samples at 28 days with optimum 40% replacement gains the required splitting tensile strength as per IS 456-2000.

2. Beyond 40% replacement there is a decrease in the strength for all mixes and all the % replacement.
3. For design mix M50, M55 and M60 optimum replacement of recycled aggregate observed is 20% as an optimum value.

4. Beyond 28 days at 56 days age, there is no significant gain in the strength, it is in order of 2% to 3.5% on an average for different samples.

5. The variation in splitting tensile strength from 3 days to 56 days is of parabolic nature.

6. The regression analysis of a mathematical model for the prediction of cylinder splitting tensile strength reflects the regression constant 0.9588 for linear, 0.9489 for logarithmic, 0.9629 for quadratic, 0.9615 for exponential and 0.9564 for power formula which are closer to the actual value.

C.3 Flexural Strength

1. From the experimental investigation, it is concluded that all samples up to 40% replacement gains required flexural strength at 28 days and beyond 40% replacement there is less in strength.

2. Average loss of flexural strength is observed 12% for design mix M20 to M45 and 18% for design mix M50, M55, M60.

3. There is no significant gain in flexural strength from 28 days to 56 days. All the samples reflect the gain of 1.5% to 3% on an average.

4. The regression analysis of a mathematical model for the prediction of beam flexural strength reflects the regression constant 0.9096 for linear, 0.9056 for logarithmic, 0.9102 for quadratic, 0.9112 for exponential and 0.9256 for power formula which are closer to the actual value.

C.4 Modulus of Elasticity

1. With 40% as an optimum replacement all the design mix has required value of Modulus of Elasticity as per IS 456-2000.

2. Beyond 40% replacement there is a sudden drop in the observed value of MOE which is of an order 29% for mix M20 to M45 and 20% for richer mix M50 to M60 as compared to natural aggregate concrete.

3. No significant gain beyond 28 days observed value in gain for all mixes is less than 5% on an average.

4. The regression analysis of a mathematical model for the prediction of cylinder splitting tensile strength reflects the regression constant 0.7226 for linear, 0.6922 for
logarithmic, 0.7853 for quadratic, 0.7326 for exponential and 0.7078 for power formula which are near to the actual value.

C.5 Pullout test
1. With 40% as an optimum replacement all the design mix has required value of Pullout test.
2. Beyond 40% replacement of natural aggregate with recycled aggregate there is a sudden drop in the observed value of Pullout strength is found to be 29% for mix M20 to M45 and 20% for richer mix M50 to M60.
3. No significant gain beyond 28 days observed value in gain for all mixes is less than 5% on an average.
4. The regression analysis of the mathematical model for the prediction of cylinder splitting tensile strength reflects the regression constant 0.9978 for linear, 0.9676 for logarithmic, 0.9982 for quadratic, 0.9788 for exponential and 0.9965 for power formula which are closer to the actual value.

C.6 Durability Parameters
Following conclusions were drawn for the Durability test for cubes.

C.6.1 Water Absorption
1. All the samples shows an ideal property of impervious concrete with maximum water absorption 0.4% and minimum 0.22%, which is less than the specified value.
2. The percentage water absorption decreases as the grade of concrete increases.
3. For all design mixes 40% replacement with RCA gives the minimum value of water absorption with an average value of 0.37 for M20 to M45 and 0.335 for M50 to M60 grade.

C.6.2 Alkali Attack (NaOH)
1. All the samples shows an ideal property of concrete with maximum loss in weight due to Alkali Attack (NaOH)0.28% and minimum 0.09% which is less than the specified value.
2. The percentage loss in weight due to Alkali Attack (NaOH)increases as the grade of concrete increases.
3. For all design mixes 40% replacement with RCA gives the minimum value of loss in weight due to Alkali Attack (NaOH) with an average value of 0.10 for M20 to M45 and 0.17 for M50 to M60 grade.

4. All the samples shows an ideal property of concrete with negligible loss in compressive strength due to Alkali Attack (NaOH).

5. The percentage loss in compressive strength due to Alkali Attack (NaOH) increases as the grade of concrete increases.

6. For all design mixes 40% replacement with RCA gives the minimum value of the loss in compressive strength due to Alkali Attack (NaOH) with an average value of 10% for M20 to M45 and 14% for M50 to M60 grade.

C.6.2 Sulphate Attack (MgSO₄ and Na₂SO₄)

1. All the samples shows an ideal property of concrete with maximum loss in weight due to Sulphate Attack (MgSO₄ and Na₂SO₄) 0.45% and minimum 0.13% which is less than the specified value.

2. The percentage loss in weight due to Sulphate Attack (MgSO₄ and Na₂SO₄) increases as the grade of concrete increases.

3. For all design mixes 40% replacement with RCA gives the minimum value of loss in weight due to Sulphate Attack (MgSO₄ and Na₂SO₄) with an average value of 0.16 for M20 to M45 and 0.20 for M50 to M60 grade.

4. All the samples shows an ideal property of concrete with hardly loss in compressive strength due to Sulphate Attack (MgSO₄ and Na₂SO₄).

5. The percentage loss in compressive strength due to Sulphate Attack (MgSO₄ and Na₂SO₄) increases as the grade of concrete increases.

6. For all design mixes 40% replacement with RCA gives the minimum value of the loss in compressive strength due to Sulphate Attack (MgSO₄ and Na₂SO₄) with an average value of 15% for M20 to M45 and 18% for M50 to M60 grade.

C.6.2 Chloride Resistance (NaCl)

1. All the samples shows an ideal property of concrete with maximum loss in weight due to Chloride Resistance (NaCl) 0.30% and minimum 0.08% which is less than the specified value.

2. The percentage loss in weight due to Chloride Resistance (NaCl) increases as the grade of concrete increases.
3. For all design mixes 40% replacement with RCA gives negligible loss in weight and compressive strength due to Chloride Resistance (NaCl).

4. The percentage loss in compressive strength due to Chloride Resistance (NaCl) increases as the grade of concrete increases.

5. For all design mixes 40% replacement with RCA gives the minimum value of the loss in compressive strength due to Chloride Resistance (NaCl) with an average value of 11% for M20 to M45 and 20% for M50 to M60 grade.

C.6.2 Sea Water Attack:-

1. All the samples shows an ideal property of concrete with maximum loss in weight due to Sea Water Attack 0.40% and minimum 0.08% which is less than the specified value.

2. The percentage loss in weight due to Sea Water Attack increases as the grade of concrete increases.

3. For all design mixes 40% replacement with RCA gives the minimum value of loss in weight due to Sea Water Attack with an average value of 0.12 for M20 to M45 and 0.22 for M50 to M60 grade.

4. All the samples shows an ideal property of concrete with maximum loss in compressive strength due to Sea Water Attack 0.48% and minimum 0.8% which is less than the specified value.

5. The percentage loss in compressive strength due to Sea Water Attack increases as the grade of concrete increases.

6. For all design mixes 40% replacement with RCA gives the minimum value of the loss in compressive strength due to Sea Water Attack with an average value of 12% for M20 to M45 and 22% for M50 to M60 grade.

Research outcome:

1. Potential use of waste recycled material make green concrete leading to preservation of natural resources and contribution towards reduction of greenhouse emissions and reduces waste going to landfill.

2. The concrete with inclusion of recycled aggregates can be used for the high value application as it has both improved engineering as well as durability parameter.

3. Recycled coarse aggregate can be used without sacrificing the mechanical properties in terms of compressive strength, flexural strength, splitting tensile
strength, modulus of elasticity, pullout strength are as required in conventional concrete.

4. From rigorous experimental and analytical result it is concluded that RCA by replacing to the extent of 40% of the medium strength concrete up to M35 grade concrete and by 20% for high strength concrete up to M60 grade can be potentially used.

5. It is estimated that roughly 25 billion tonnes of concrete are manufactured globally each year. 35% of 25 billion tonnes that is 9 billion tonnes of concrete is utilized for subbase, PCC, foundation, mass concrete, etc. If we use 40% replacement of aggregates, then saving in cost will be 350 Rs/tonne on an average.

Looking to the overall gain in techno-economical parameters and impact on nature use of recycled coarse aggregate concrete can be potentially used as an economic and environmental point of view.

**Future Scope:-**

1. The behavior of the full size model with recycled coarse aggregate concrete of column and beam can be studied.

2. The efficiency of the beam column joint with gravity, lateral and cyclic loading on actual specimen can be studied with recycled coarse aggregate concrete.

3. Other durability aspects such as Carbonation, Rapid Chloride Penetration and Chloride Iron Penetration of recycled coarse aggregate concrete.