Flexural behavior of RC Beam, Strength and Durability studies of Concrete made with Recycled Concrete Aggregate, M Sand and Different Mineral Admixtures

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The continuous increasing demand of raw materials in concrete production requires good quality and cost proficient alternate materials like recycled concrete aggregate (RCA - 30%) and Manufactured sand (50%) replacement to natural coarse and fine aggregate. Mineral admixtures Fly Ash (FA), Silica Fume (SF) and Meta kaolin (MK) are also partially replacing to Ordinary Portland Cement (OPC) to appraise the effect on M30 grade concrete with water cement ratio of 0.40. Replacement of these raw materials is an added advantage not only to reduce emission of carbon dioxide and also to protect the depleting natural resources. Introduction of new materials in the construction industry lead to attain good quality aggregates at reasonable prize and provide economical benefits. The compressive, flexural strength and chloride penetrability of the control and the concretes incorporated with FA, SF & MK with water-binder (w/b) ratio of 0.4 shows SF concrete has superior strength development and high resistance to chloride attack. Compressive strength on concrete cubes and flexural strength on prism shows positive approach to the construction field. Flexural strength on reinforced concrete beam with different replacements of SF shows significant result in terms of shear compared to control specimen. Replacements of recycled materials in terms of fine and coarse aggregate, mineral admixtures in cement experiences the better result compared to the design mix which intern assist to use these kinds of materials in normal usage which helps to conserve the natural resources.

Keywords: Recycled concrete aggregate, Manufactured Sand, Flexural strength, Compressive strength, Fly Ash (FA), Silica fume (SF), Meta kaolin (MK)

Introduction
Concrete is a widely used construction material and their properties are changing due to incorporation of new materials through technological development. Vast infra structural development in the recent years creates dumping of waste materials obtained from the production of new materials or through the demolition of concrete structures and the waste obtained from the thermal power plant are increasing gradually. However, these wastes are second-hand as an substitution material for back filler or land reclamation. Utilization of recycled concrete aggregates obtain from the recycling of construction and demolition waste in the low–medium compressive strength (20–45 MPa) with 25% replacement achieves the equivalent mechanical properties as that of conventional concrete employing the similar quantity of cement and the equal effective w/c ratio. The properties of actual concrete have significant influence on mechanical properties of recycled aggregate concrete; it is possible to obtain recycled concrete with higher compressive strength than the original one. Mix design method for recycled concrete aggregate is very similar to the procedure for normal concrete with natural aggregate. Corrections in water content are necessary to obtain proper workability due to incorporation of recycled materials which require more water due to few mortar content. On the other hand accessibility of construction sand (river sand) is creating a serious environmental pressure due to reduction of natural resource by extracting sand from rivers. With the ban on sand mining implemented by different states and with the increasing demand for river sand for construction works, many civil engineers have articulated the need to promote the use of manufactured sand in the construction industry. As per information, manufactured sand is broadly used all around the world and technicians of major projects around the world insist on the compulsory use of manufactured sand because of its consistent gradation and zero impurity. Nowadays dirt free sand is necessary for the construction from the durability point of view. The three essential elements for supporting an environment friendly concrete technology for sustainable development are the conservation of
primary materials, the enrichment of the durability of concrete structures and a holistic approach to the technology. Compressive and flexural potency of concrete can be improved by partial replacement of cement by silica fume and manufactured sand for natural fine aggregates with optimum replacement of natural sand by manufactured sand as 50%. Sharp boundaries in manufactured sand provide better bond with the cement than the rounded parts of natural sand.

Many states prohibited the utilization of river sand there by influencing the use of manufactured sand for the construction purpose. While using, the water absorbing tendency is relatively high when compared to natural sand and this affects the workability and results in formation of honey combs and lesser strength of the structure. To overcome this effect, super plasticizer named Conplast SP430 is used to increase the workability of the concrete. In the quarries huge rocks are sized by blasting, crushing and screening to produce coarse aggregate for the construction purpose. By this process, manufactured sand also prepared by crushing, screening and washing of very fine particles below 150 microns.

Properties of recycled materials in concrete may be significantly improved by adding mineral admixtures like Fly Ash, silica fume and metakaloin. Similar to the concrete made with natural aggregates minimum water absorption and total pore volume for the recycled aggregates concrete were observed 30% for recycled coarse aggregate and 50% for manufactured sand. When water absorption and total pore volume increase, the replacement of recycled concrete aggregate also increases. When the natural coarse aggregate is replaced by 30% of the recycled aggregates from old concrete or old masonry, the resulting recycled concrete will likely be same and occasionally better results. Replacement percentage has a considerable influence on the stress–strain curves. For all considered cases of recycled concrete aggregate form 0% to 100% replacement, stress–strain curves show a similar performance. The compressive strengths of prism and the cube compressive strengths generally decrease with increasing RCA contents. But the ratio of the prism compressive strength and the cube compressive strength is higher than that of the normal concrete. The modulus of elasticity of Recycled Concrete Aggregate is lesser than that of the normal concrete. The properties of concrete prepared with recycled aggregates are generally inferior to those of conventional concrete. However, the drawbacks of by means of recycled aggregate could be ameliorated by employing a lower water-to-cement (w/c) ratio and using fly ash as a mineral admixture in the mix design. It was found that the use of a lower percentage of w/c ratio or fly ash as an addition of cement is a good way to reduce the potential high drying shrinkage of concrete prepared with recycled aggregate. Drying shrinkage of recycled aggregate concrete tended to decrease with an increase in compressive strength. W/c ratio with 0.40 was a more efficient to mitigate the drying shrinkage of concrete compared to adding 25% fly ash in the concrete mix. Chloride ion penetration could be significantly minimized with a proper mix design. Concrete with low w/c ratio and fly ash as an addition of cement performs more resistance to chloride ion penetration compared to that with high w/c ratio and without fly ash addition.

The moisture states of the aggregates affect the change of slump of the fresh concretes. The initial slump of concrete was strongly dependent on the initial free water content of the concrete mixes. The major negative effect on the concrete strength might be endorsed to bleeding of excess water in the pre wetted aggregates in the fresh concrete. 50% recycled aggregate replacement is optimum for normal strength recycled aggregate concrete production. Fly ash and Meta kaolin individually act as mineral admixtures in the cement replacement and increase in percentage replacement increase the compressive strength up to certain limit and further increase reduces the strength of concrete in cube compression. Incorporation of Silica fume as cement replacement produce better result in higher percentage replacement ratio compared to fly ash and metakaolin. Best performance is observed at 7 days and 28 days compressive strength of silica fume replacements due to the physical nature of better packing and fineness.

ordinary portland cement (OPC) and silica fume (SF) / metakaolin (MK) / low-calcium fly ash at
various replacement levels. Substitution of FA, SF or MK under certain conditions has been shown to increase the chemical resistance of mortars over those made with plain Portland cement. Chemical resistance increased in the order of SF to MK to FA series and decreased as the replacement level is increased. Chemical resistance increased with increase in W/C ratios. Compressive strength increased in the order of FA to SF to MK. No marginal change in compressive strength was found as a function of replacement level for SF and MK series. Nevertheless, the compressive strength decreased as the FA replacement increases.

This clearly shows that low-calcium fly ash is less reactive than SF and MK and needs an external activation. On the other hand, fly ash is an effective chemical resistance as compared to SF and MK. Under certain conditions the accumulation of FA, SF, or MK improves the acid resistance of concrete.

MK greatly influences the mechanical and durability properties of concrete. It is also noted that concrete mixture incorporating high-reactivity MK gave comparable performance to silica fume mixtures in terms of strength, permeability and chemical resistance. The utilization of this material is also environmentally friendly since it helps in reducing the CO2 emission to the atmosphere by the minimization of the Portland cement (PC) consumption.

This investigation is carried to find out the effect of fly ash, silica fume and metakaolin as mineral admixtures on the properties of fresh and hardened concrete by means of workability test, compressive strength on concrete cubes, flexural strength of beam and durability test on concrete specimens.

Materials and Methods
Four types of concrete mixes were prepared at the w/c ratio of 0.4. In each series, cement is partially replaced by FA, SF and MK with different proportions, Fine aggregate is replaced with 50% by manufactured sand, Coarse aggregate replaced by 30% of RCA and a control mix without any admixture to assess their influence on compressive, Flexural strength and chloride resistance of concrete after curing. Experimental investigations for various properties of concrete such as workability, compression, flexure and chloride penetrability have been done for various mixes. The compressive strength and flexural strength were determined after 28 days curing and the resistances to chloride-ion penetration were measured according to ASTM C 1202 at different stages up to 90 days. pH of each concrete mixture was measured to find the alkalinity of concrete.

Materials Used
Ordinary Portland cement of specific gravity 3.15 & 53 grade12 and the sand conveyed from the kavery river basin (Fineness modulus 2.85 and Specific gravity 3.62) conforming to grading zone II of was used13. Manufactured sand (Fineness modulus 2.61 and Specific gravity 2.58) obtain from RPP crushers Private Limited, Coarse aggregate (Specific gravity 2.64) of nominal size 12.5mm and recycled concrete aggregate (Specific gravity 2.42) are used. Different mineral admixtures like fly ash, silica fume, meta kaolin are partially replaced with cement and their chemical compositions are given in Table 1.

<table>
<thead>
<tr>
<th>% Composition</th>
<th>In Cement</th>
<th>In Fly Ash</th>
<th>In Silica Fume</th>
<th>In Meta Kaolin</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>22</td>
<td>56</td>
<td>94.60</td>
<td>95.85</td>
</tr>
<tr>
<td>Magnesium oxide (MgO)</td>
<td>2.50</td>
<td>5.00</td>
<td>0.45</td>
<td>0.10</td>
</tr>
<tr>
<td>Al2O3</td>
<td>4.50</td>
<td>25.3</td>
<td>0.55</td>
<td>0.30</td>
</tr>
<tr>
<td>Loss on ignition (LOI)</td>
<td>1.75</td>
<td>2.00</td>
<td>1.80</td>
<td>0.66</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>0.50</td>
<td>6.00</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Calcium Oxide (CaO)</td>
<td>65.6</td>
<td>3.40</td>
<td>0.30</td>
<td>0.39</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>3.15</td>
<td>2.30</td>
<td>2.05</td>
<td>2.40</td>
</tr>
</tbody>
</table>

Mix Proportions
M30 Grade concrete (Control Mix) was designed with 0.40 water cement ratio as per Indian Standard concrete mix design method\(^2\). Design mix required for different admixture is as per the control mixes which were prepared as per BIS Code and for the same design mix different replacement were experimented using recycled materials and admixtures. Different mix proportions are revealed in Table 2.

<table>
<thead>
<tr>
<th>% of NCA</th>
<th>% of RCA</th>
<th>% of NFA</th>
<th>% of MS</th>
<th>% of FA</th>
<th>% of SF</th>
<th>% of MK</th>
<th>% of Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>90</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>80</td>
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<tr>
<td>70</td>
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<td>50</td>
<td>50</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>70</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>90</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>12.5</td>
<td>-</td>
<td>87.50</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>15</td>
<td>-</td>
<td>85</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>95</td>
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<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>90</td>
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<tr>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>85</td>
</tr>
</tbody>
</table>

Table 2-- Mix Proportion

**Casting of Specimen**
Concrete cubes of size 150 mm each side, prism 500mm x 100mm x 100mm and Reinforced concrete beam of size 1000 mm x 100 mm x 150 mm using 10mm and 12mm diameter bars with 6mm diameter stirrups were made to check the results of compression and flexural behavior of proposed concrete mix. Super plasticizer Conplast SP 430 was added at the time of mixing the concrete for better workability and to maintain the uniform slump for all the mix proportions.

**Results and Discussion**

**Mechanical Properties**

The compression test on concrete cubes and flexural test on prisms (Fig. 1 and Fig. 2) are carried out\(^4\). From the experimental results the compressive strength increase in all the percentage replacement with addition of admixtures in concrete. The performance of silica fume series shows better result than the Fly Ash and Meta kaolin series. However higher replacements of silica fume have resulted in reduction of strength but marginally above the control specimen strength. Normally at the early stage, pozzolanic reactions are very low in case of mineral admixture to increase the compressive strength gradually. Due to increase in age of concrete lower pozzolanic reaction increases the compressive strength of the concrete. Mineral admixture replacement exhibits air voids between the cement particles but the lower pozzolanic reaction reacts with the lime present in the admixtures enhances the compression values by the hydration process of CSH provides better binding capacity to the concrete specimen. The gradual increase in the result may due to presence of mineral admixtures. The end result shows that the replacements of recycled materials in terms of fine and coarse aggregate, mineral admixtures in cement experiences the better result compared to the normal mix which intern assist to use these kinds of materials in normal usage which helps to conserve the natural resources in future.

Fig. 1--28 Days Compressive Strength
A rapid chloride ion permeability test was carried out to evaluate the permeability of concrete specimens\(^{15}\). A specimen 50 mm thickness and 100 mm diameter was prepared and tested after a curing period of 28 and 90 days. The specimen is cured in two chambers, one is filled with 3.0% Sodium chloride and another chamber filled with 0.30% of sodium hydroxide for each one liter of water to form an electrolyte. A 60V electric charge is applied to the electrodes continuously for 6hrs and monitored at every half an hour (30 minutes). The total voltage passed through the cell for 6hrs was measured to determine the penetrability of concrete. It is noted that higher the level of charge indicates higher the level of permeability as shown in Table 3. After measuring the charge, 0.1 M silver nitrate was applied to the concrete to examine the penetration depth of chloride ions. The interior concrete surface turns silver when chloride ions survive. The penetration depth of chloride ion was measured using a ruler at three different locations to determine the diffusivity of chloride ions\(^{16}\) after 28 days and 90 days as shown in figure Fig. 3 and Fig. 4.

### Table 3--Chloride Ion Penetrability

<table>
<thead>
<tr>
<th>Charge passed (Coulombs)</th>
<th>Chloride ion penetrability</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>High</td>
</tr>
<tr>
<td>2000-4000</td>
<td>Moderate</td>
</tr>
<tr>
<td>1000-2000</td>
<td>Low</td>
</tr>
<tr>
<td>100-1000</td>
<td>Very low</td>
</tr>
<tr>
<td>&lt;100</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

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Fig. 2--28 Days Flexural Strength

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Fig. 3--Coulomb values @ 28 Days

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Fig. 4--Coulomb values @ 90 Days
Depth of Penetration Measurement

The depth of penetration of chloride ion into concrete sample was measured by breaking the specimen into two halves and applying silver nitrate solution of Normality 0.1 over the exposed surface. The depth upto which the chloride ion penetration indicates as change in color observed as white in the surface of the specimen. Percentage loss of coulomb observed after 28 days and 90 days are shown in Fig. 5 and Fig. 6, which indicates that there is not a much of coulomb loss observed comparing with 28 and 90 days.

![Fig. 5--Percentage loss @ 28 Days](image)

![Fig. 6--Percentage loss @ 90 Days](image)

pH measurements

Addition of admixture in reinforced concrete not only imparts the strength of concrete but also subject to change in alkalinity proportion in concrete. It is very important to check the presence of hydrogen ions in concrete. Concrete specimens were crushed and sieved through 75 micron sieve, collected for all the mix ratios of Fly Ash, Silica Fume and Meta Kaolin admixed concrete. The collected sample is mixed with distilled water in the ratio of 1:10. Solution was filtrated and its pH was measured using a portable pH meter. The results of pH for control concrete (Fig. 7) slight rises as the age of the concrete increases. During hydration more calcium hydroxide is liberated and this results in the increases of pH. The observed values are marginally lower than the control mix, but the reduction in the value may sometimes irrelevant. Addition of mineral admixture does not adversely affect the alkalinity of concrete. Materials constituting the recycled concrete may sometimes be porous in nature. It is necessary to check the concrete after casting and curing. Scanning Electron microscope analyzes is done to identify the pore structure of concrete specimens made with different materials. It is found that the concrete with different constituents like recycled concrete aggregate, manufactured sand, FA, SF and MK are non porous in nature.

Flexural Behavior of RC Beam

A reinforced concrete beam of dimension 1000mm*100mm*150mm is reinforced with Fe500 TMT bars of 10mm and 12mm diameter with 6mm stirrups were tested in a loading frame. Reinforcement details, Schematic diagram of loading set-up, the pivots arrangement for measuring strain and LVDT are fixed for deflection measurements (Fig. 8 and Fig. 9). Table 4 illustrates the yield stress, ultimate stress and percentage elongation of steel used in this study. Stress strain curve of 10mm and 12mm steel as in Fig. 10 and Fig. 11 shows mostly
similar behavior. Middle third loading concept is applied for the specimen simply supported at both ends. Deflections were measured under the loading point using Linear Variable Differential Transducers (LVDTs). The crack patterns were recorded at every load increment. The failure pattern for control mix, Fly Ash, Silica fume and Meta kaolin concrete are shown in Fig. 12A and Fig. 12B. The ultimate load carried by the beam with different mix proportions and its load Vs Deflection curve are noted as in Fig. 13. Computation analysis has been done using ANSYS 15 software as per Fig. 14. The investigated values coincide with the analytical modeling. The variation is observed about 8.5% compared with the investigated values.

<table>
<thead>
<tr>
<th>Diameter of the Rod</th>
<th>Yield Stress N/mm²</th>
<th>Ultimate Stress N/mm²</th>
<th>% Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6mm</td>
<td>455.52</td>
<td>610.92</td>
<td>25</td>
</tr>
<tr>
<td>10mm</td>
<td>500.32</td>
<td>631.85</td>
<td>20</td>
</tr>
<tr>
<td>12mm</td>
<td>479.17</td>
<td>646.67</td>
<td>16.67</td>
</tr>
</tbody>
</table>

Fig. 8 --Steel Reinforcement details of RC Beam

Fig. 10 --Stress Strain curve of 10mm Diameter Bars

Fig. 11 --Stress Strain curve of 12mm Diameter Bars

Fig. 12A --Crack Patterns of beam under flexure

Fig. 12B --Crack Patterns of beam under flexure
Fig. 13--Load deflection behavior of Beams with control mix and different Admixtures
Conclusions
The performance of different recycled materials and mineral admixtures on various properties are as follows.

- Concrete mixes had a satisfactory performance in the fresh state. From the different mineral admixtures, SF series exhibit a good workability than Fly ash and Meta kaolin series.
- The results of the mechanical properties (compression and flexure) shown significant performance with higher compressive and flexural strength at 12.5% replacement of cement by silica fume.
- The concrete with recycled materials and admixture increases the compressive strength with respect to silica fume series.
- Flexural behavior of RC beam shows similar crack pattern as of conventional mix.
- Usage of super plasticizer shows improved cohesion minimizes the particle dispersion, segregation, bleeding, improves pump ability and chloride free, safe for use in reinforced concrete.
- Durability of recycled materials shows reliable result and used by suitable mix design.
- The concept of replacement of coarse and fine aggregate along with locally available different admixture in the present investigation could be taken into consideration during mix design of High strength concrete with high workability.
- From the research, recycled concrete aggregate and M sand can be used to replace with conventional concrete with a suitable mix design to withstand massive load.

Acknowledgments
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References
6. IS 9103-1999 and BS 5075 part 3, ASTM 494 Type F & Type G, High performance water reducing super plasticizers.