CHAPTER 6

DURABILITY PROPERTIES OF CONCRETE
WITH MANUFACTURED SAND

6.1 GENERAL

When properly designed and carefully produced with good quality control, concrete becomes inherently a durable material. However, under adverse conditions, concrete is potentially vulnerable to deleterious attacks such as frost, sulfate attack, alkali-aggregate reaction, and corrosion of steel. Each of these processes involves the movement of water or other fluids, transporting aggressive agents through the pore structure of concrete. Therefore, porosity and permeability are important properties which affect the durability of concrete.

6.2 DURABILITY TESTS ON CONCRETE

Durability is the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. The nature, intensity and mechanism implied in each of these different attacks could vary considerably. No standardized method exists for measuring the durability of concrete in general. Similarly, there are no units in which to evaluate the durability of the concrete.

The durability of concrete, which is also governed by the aggressiveness of the environment, has not yet received enough attention in
most national codes. Hence the durability properties of concrete with manufactured sand are studied so as to recommend manufactured sand in concrete at various atmospheric and aggressive conditions. The aggressive agents that attack the concrete can be classified schematically into two broad categories: external agents and internal agents. These include chloride ions, carbon dioxide, sulfates, freeze-thaw cycles, bacteria, abrasives and cement alkalis.

In the previous chapter, the mechanical properties of concrete with various replacement level of manufactured sand were studied and the optimum replacement level was found to be the concrete containing 70% manufactured sand blending with 30% natural sand. So in this chapter the following tests are carried out for assessing the durability properties of mortar and concrete with 100% natural sand, 100% manufactured sand and for the optimum replacement level of 70% manufactured sand.

- Alkali aggregate reaction
- Drying shrinkage
- Abrasion resistance
- Impact resistance
- Rapid chloride ion penetration
- Corrosion
- Acid attack
- Water permeability
- Water absorption and
- Sorptivity
6.2.1 Alkali Aggregate Reaction (ASTM C 1260-07)

This test is commonly used to assess the reactivity of an aggregate. It is developed to provide a way to identify the reactive aggregates in a cost-effective and timely manner. Being able to obtain results within 14 days, this test is quick and economical. The equipment is shown in Figure 6.1.

The mortar bars of size 25mm x 25mm x 250mm were cast with cement and fine aggregate in the ratio of 1:3 and water/cement ratio of 0.47. Three mortar prisms were cast. The mortar prisms were cured for 24 hours in a room at 21 ± 2°C, demoulded, and immersed in water in a closed container maintained at 80°C. After 24 hours, the length of the specimens was measured. They were then immersed in a closed container of 1M sodium hydroxide solution maintained at 80°C. The specimens were removed periodically from the containers and measured before significant cooling occurred. The length change of the prisms was measured up to 32 days after casting.

Figure 6.1 Length comparator with mortar bar specimens
6.2.2  Drying Shrinkage (IS 4031(Part 10) 1988)

The drying shrinkage occurs when the concrete or mortar is subjected to drying conditions. It is the loss of water held in gel pores that causes the change in volume. To measure the drying shrinkage, the mortar bars of size 25mm x 25mm x 250mm were used. The mortar was mixed with required proportions (CM 1:3) and compacted by hand operation. Gauge studs were inserted in the bar moulds coaxial with the bar before the mortar was poured into the moulds. After 24 hours, the mortar bar specimens were demoulded and subsequently submerged in water for curing for 7 days. Length of each specimen was measured using a length comparator immediately after curing. Soon after measuring the initial length, the specimens were kept under the laboratory conditions. The average temperature in the laboratory was 35 ± 2° C. The length of the specimens was measured at different periods of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 and 110 days to calculate the drying shrinkage.

6.2.3  Abrasion (ASTM C 944)

Abrasion resistance is an important factor for roads, airfield pavements, factory floors, dock yards and warehouse floors etc. This test is used to determine the percentage wear of the concrete. The test involved the specimens of size 37mm x 75mm x 75mm against rotating metal disc sprinkled with quartz sand. The loss in weight of the sample after 300 revolutions was determined. The percentage wear was expressed in the following empirical formula:

\[
\% \text{ wear} = \left( \frac{\text{Loss in weight}}{\text{Original weight}} \right) \times 100
\]

(6.1)
6.2.4 Impact Strength (ACI 544.2R-89)

Concrete structures are often subjected to impact loads such as earthquake, blast, machine vibration, vehicle impact, etc. for a short duration. So impact resistance energy must be required, when concrete is subjected to an impact force. Impact resistance energy was measured by using drop weight hammer test recommended by ACI committee 544.2R-89. The concrete specimen of 150mm diameter and 64mm thickness was placed on the base plate and four positioning lugs were put in at the periphery of the base plate. A cylindrical sleeve was placed over the test specimen. Hardened steel ball was placed within the sleeve on the top of the specimen. The steel ball was free to move vertically within the sleeve. This set up is shown in Figure 6.2. A drop hammer was used to apply the impact load. The weight of the hammer was 45N. The number of blows required by dropping the hammer through a height of 457mm to cause the first visible crack and to cause the ultimate failure was recorded. Ultimate failure is defined in terms of number of blows required to open the crack in the specimen to enable the fractured pieces to touch three or four positioning lugs on the base plate. Each blow of the hammer represents 20.2Nm of energy.

Figure 6.2 Drop weight impact test set up
6.2.5 Rapid Chloride Ion Penetration (ASTM C1202)

This test originally developed by Whiting (1981), is commonly referred to as the “Rapid Chloride Permeability Test” (RCPT). In this thesis, the test was conducted as per AASHTO T277 (ASTM C1202). In this test, a water-saturated 50mm long and 95mm diameter concrete specimen was subjected to a 60 V applied DC voltage for 6 hours using the apparatus shown in Figure 6.3. One reservoir contains 3.0% NaCl solution and the other reservoir contains 0.3 M NaOH solution. The total charge passed was determined and this was used to rate the concrete.

Figure 6.3 Rapid chloride ion penetration test set up
6.2.6 Accelerated Electrolytic Corrosion

Literatures and case studies reported that 40% of the failure of the structure occurred on account of corrosion of embedded steel reinforcement in concrete. So it is necessary to study the corrosion behaviour of concrete with steel reinforcement. This test fundamentally measures the resistivity of concrete. The test was carried out in a 6% NaCl solution with an embedded reinforcement bar working as an electrode and a rectangular copper bar as a counter electrode. The test set up is shown in Figure 6.4. The variable parameter voltage was recorded at every 15 minutes interval for 6 hours in constant current study. The specimen was then taken out, visually inspected, and carefully split open to access the corroded steel bar. The reinforcement bar was then cleaned as per ASTM G1 of 1981 by dipping it in Clark’s solution (hydrochloric acid of specific gravity 1.19 litre + antimony trioxide 20gm + stannous chloride 50gm) for 25 minutes. Each bar was weighed again to the accuracy of 0.01mg to find out the change in weight.

Figure 6.4 Accelerated corrosion test set up
6.2.7 Acid Attack

The acid attack has been one of the primary causes of chemical deterioration of concrete for many years. Concrete is not a chemically stable material under the condition of acidic environment. It is susceptible to acid attack because of its alkaline nature. Acids come from the external sources to the concrete such as the earth surrounding a concrete structure, groundwater, rainwater, and pollutants in the air. Certain aggregates including siliceous (containing silica) will not be attacked by acid, but calcareous (containing calcium) aggregates readily react with acids. Mineral Acids like hydrochloric, nitric, sulphuric and chromic acids are some of the most dangerous acids that affect the concrete. So it is necessary to study the deterioration effect on concrete due to sulphuric acid.

In the present study, the deteriorating effects of 0.1 normality of sulphuric acid solution on concrete had been assessed. The standard cube samples of size 150mm x 150mm x 150mm were immersed in the 0.1 normality of sulphuric acid solutions with pH value kept between 1.9 and 3.2. The changes in weight and strength of the concrete samples were found at 28, 56, 90, 180 and 365 days of immersion.

6.2.8 Water Permeability (IS: 3085 (Part 7) – 1965)

The durability of concrete depends on the permeability of concrete which is defined as the property that governs the rate of flow of a fluid into a porous solid. The test was conducted as per IS: 3085 (Part 7) – 1965. The permeability test set up is shown in Figure 6.5. Standard cubes of 150mm size were cast, cured for 28 days and the four faces of the cubes were painted to prevent the penetration of water from sides. The top surface was effectively
sealed to achieve water tightness. Pressure was applied to the water column. The quantity of water passing through the cube was collected at the bottom, in the glass bottle through the funnel. The operating pressure, quantity of water collected and time of observation were recorded. The co-efficient of permeability was calculated using the given formula:

\[
K = \frac{QL}{ATH}
\]  \hspace{1cm} (6.2)

\(K\) = Co-efficient of permeability in cm/sec.

\(Q\) = Quantity of water percolating over the entire period of test.

\(A\) = Effective area of specimen in cm\(^2\).

\(T\) = Time in seconds over which ‘Q’ is measured.

\(H\) = Pressure head in cm.

\(L\) = Length of specimen in cm.

Figure 6.5 Water permeability test set up
6.2.9 Saturated Water Absorption (ASTM C: 642 - 81)

Water absorption is one of the important parameters, which affects the durability of the structure due to the corrosion of steel reinforcement. The test specimens of 150mm x 150mm x 150mm cubes were dried at a temperature of 105°C for a period of 24 hours with the help of an oven. The dried specimens were cooled at the room temperature and the corresponding dry weight was noted. The dried specimens were immersed in water for a period of 24 hours. After 24 hours the weight of the concrete cubes was taken. The water absorption of the concrete was calculated in percentage by the given formula:

\[
\text{Water absorption (\%) = } \frac{(\text{Saturated weight} - \text{Dry weight}) \times 100}{\text{Dry weight}} \quad (6.3)
\]

6.2.10 Sorptivity (ASTM C 1585)

Sorptivity measures the rate of penetration of water into the pores in the concrete by capillary suction. The test was conducted as per the ASTM C 1585 standards. The cube specimens of size 150mm x 150mm x 150mm were painted on all the sides except at the top surface. All the other sides were protected with rubber membrane. The water penetrated through the top surface of the specimen by capillary suction. The cumulative volume of water that penetrated per unit surface area of the exposure ‘q’ was plotted against the square root of time of exposure ‘\(\sqrt{t}\)’. The resulting graph could be approximated by a straight line passing through the origin. The slope of this straight line was considered as a measure of rate of movement of water through the capillary pores and this is called sorptivity.
6.3 DISCUSSION OF TEST RESULTS

6.3.1 Alkali Aggregate Reaction

The expansion of mortar prisms due to alkali aggregate reaction with 100% natural sand (A), optimum replacement level of 70% manufactured sand (H) and 100% manufactured sand (K) are enumerated in Figure 6.6.

From Figure 6.6, it may be noticed that the percentage expansion got reduced while using the manufactured sand and it was the minimum for an optimum replacement level of 70% of manufactured sand. This is due to the rough and angular particles of manufactured sand creating better interlocking between the particles and hydrated cement paste, thus creates an impermeable surface. The impermeable surface prevent the penetration of moisture inside the specimens, thus reduces the de polymerisation of silica, which is the reason for less expansion.

Figure 6.6 Expansion of mortar bar due to alkali aggregate reaction with MS

From Figure 6.6, it may be noticed that the percentage expansion got reduced while using the manufactured sand and it was the minimum for an optimum replacement level of 70% of manufactured sand. This is due to the rough and angular particles of manufactured sand creating better interlocking between the particles and hydrated cement paste, thus creates an impermeable surface. The impermeable surface prevent the penetration of moisture inside the specimens, thus reduces the de polymerisation of silica, which is the reason for less expansion.
6.3.2 Drying Shrinkage

Drying shrinkage of the mortar with 100% natural sand, optimum replacement level of 70% manufactured sand and 100% manufactured sand was measured at different periods of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 and 110 days. The results are conveyed in Figure 6.7.

![Figure 6.7 Drying shrinkage of mortar bar with MS](image)

Figure 6.7 informs that the drying shrinkage is reduced while using manufactured sand due to the larger particles, less strain, less clay content and less absorption capacity values. When compared to 100% manufactured sand, the optimum replacement level of 70% manufactured sand has very less shrinkage due to the less absorption capacity.

6.3.3 Abrasion

The percentage wear of M 20, M 30 and M 40 grade concrete with 100% natural sand, optimum replacement level of 70% manufactured sand and 100% manufactured sand are given in Table 6.1.
Table 6.1 Percentage wear of M 20, M 30 and M 40 grade concrete with MS

<table>
<thead>
<tr>
<th>Mix</th>
<th>Designations</th>
<th>% Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 20</td>
<td>A</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>1.01</td>
</tr>
<tr>
<td>M 30</td>
<td>A</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>0.94</td>
</tr>
<tr>
<td>M 40</td>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>0</td>
</tr>
</tbody>
</table>

From Table 6.1, it is found that the percentage of wear is reduced while using the manufactured sand due to its better interlocking between the particles. Percentage of wear is less for the optimum replacement level of 70% manufactured sand due to the small amount of fines present in it. It may also be noted that the higher grade concrete has more abrasion resistance than the lower grades of concrete due to better packing.

6.3.4 Impact Strength

Impact resistance energy of M 20, M 30 and M 40 grades of concrete with 100% natural sand, optimum replacement level of 70% manufactured sand and 100% manufactured sand at 7th day, 28th day and 56th day are delineated in Figures 6.8 (a), (b) and (c). The tested specimens are furnished in Figure 6.9.
(a) M 20 grade concrete

(b) M 30 grade concrete

(c) M 40 grade concrete

Figure 6.8 Impact strength of M 20, M 30 and M 40 grade concrete with MS
From Figures 6.8 (a), (b) and (c), it is seen that the impact resistance energy is improved for higher grade concrete when compared to the lower grade concrete. It also implies that the energy is increased while using the manufactured sand. This is due to the angular particles of the manufactured sand developing better interlocking between the particles which increase the impact resistance energy. When compared to the 100% manufactured sand, optimum replacement level of 70% manufactured sand exhibited higher impact resistance energy due to the less amount of fines present in it.

6.3.5 Rapid Chloride Ion Penetration

Rapid chloride ion penetration of M 20, M 30 and M 40 grades of concrete with 100% natural sand, optimum replacement level of 70% manufactured sand and 100% manufactured sand are provided in Table 6.2.
Table 6.2 Chloride ion penetration of M 20, M 30 and M 40 grade concrete with MS

<table>
<thead>
<tr>
<th>Mix</th>
<th>Designations</th>
<th>Charge Passed (coulombs)</th>
<th>Chloride ion Penetrability (According to ASTM C 1202)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M20</td>
<td>A</td>
<td>4014.0</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>2258.5</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>3546.0</td>
<td>Moderate</td>
</tr>
<tr>
<td>M30</td>
<td>A</td>
<td>3384.0</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>1008.0</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>1612.8</td>
<td>Low</td>
</tr>
<tr>
<td>M40</td>
<td>A</td>
<td>1228.5</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>639.0</td>
<td>Very Low</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>792.0</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

From Table 6.2, it becomes clear that in all the three grades of concrete, the charge passed is high for conventional concrete and it is reduced while using the manufactured sand, and it is further reduced for optimum replacement level of 70% manufactured sand due to the less absorption capacity. It may also be noted that the chloride ion penetrability is higher for M 20 grade concrete when compared to the M 30 and M 40 grades of concrete. This may be due to the lower grade concretes being heated more as the temperature rises due to the supply of current and voltage. So, more heat energy is produced in lower grade concrete. This additional heat leads to a further increase in the charge passed, over what would be experienced. The results in the lower grade concrete look even worse than it would otherwise be.
6.3.6 Accelerated Electrolytic Corrosion

The corrosion test results of M 20, M 30 and M 40 grade concrete with natural sand, 70% manufactured sand and 100% manufactured sand are arranged in Table 6.3. The corroded concrete specimens appear in Figure 6.10.

Table 6.3 Corrosion test results of M 20, M 30 and M 40 grade concrete with MS

<table>
<thead>
<tr>
<th>Mix</th>
<th>Weight loss of steel bar (%)</th>
<th>Visual observation of specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>M 20</td>
<td>A 10.11</td>
<td>Severe corrosion</td>
</tr>
<tr>
<td></td>
<td>H 1.99</td>
<td>Mild corrosion</td>
</tr>
<tr>
<td></td>
<td>K 2.28</td>
<td>Mild corrosion</td>
</tr>
<tr>
<td>M 30</td>
<td>A 7.76</td>
<td>Moderate corrosion</td>
</tr>
<tr>
<td></td>
<td>H 1.78</td>
<td>Mild corrosion</td>
</tr>
<tr>
<td></td>
<td>K 2.11</td>
<td>Mild corrosion</td>
</tr>
<tr>
<td>M 40</td>
<td>A 4.38</td>
<td>Mild corrosion</td>
</tr>
<tr>
<td></td>
<td>H 1.22</td>
<td>Mild corrosion</td>
</tr>
<tr>
<td></td>
<td>K 1.65</td>
<td>Mild corrosion</td>
</tr>
</tbody>
</table>

Table 6.3 clarifies that the weight loss of steel bars decreased while using the manufactured sand and it is least for the optimum replacement level of 70% of manufactured sand in all the three grades of concrete. This is due to the better interlocking of the particles creating less voids in concrete. Due to its less voids, the entry of chloride solution is limited, which reduces the corrosion of steel bar in concrete. Similarly, the corrosion effect is reduced for higher grade concrete due to less w/c ratio. It substantially reduces the rate of oxygen diffusion and reduces the corrosion process as well.
6.3.7 Acid Attack

The loss in weight and the compressive strength of M 20, M 30 and M 40 grade concrete specimens in sulphuric acid solution are illustrated in Figures 6.11 and 6.12.

Figure 6.11 Percentage weight reductions of concrete cubes in acid attack
From Figure 6.11 makes it clear that the weights are decreased in acid solution. Since concrete is an alkaline substance, many of its components readily react with acids. The reaction between the acid and the calcium compounds will form calcium salts, which can be soluble in water. These salts are then leached away, causing a loss of volume and cohesion of the paste. It was also found that the percentage weight reduction was less in concrete with proportion K and it is the least for the proportion H, when compared to the concrete with natural river sand. This may be due to the impermeable characteristics of concrete with 70% manufactured sand. It was also noted that the percentage weight reduction was less for M 30 and M 40 grade concrete than for M 20 grade concrete, which reduce the leaching of calcium salts through the impermeable surface.

Figure 6.12 represents that the strength is reduced in acid solution. The mechanism of concrete deterioration caused by sulfuric acid can be explained by the fact that the sulphuric acid penetrating into the concrete reacts with calcium hydroxide of cement hydrates and produces gypsum. At this time, the volume of solid substances increases largely, which causes expansion of reaction of products resulting in erosion. Similarly, the
disintegration of hardened cement paste, as a result of interaction with the environment, causes a reduction in the compressive strength of concrete.

Figure 6.12 testifies that the percentage strength reduction rose higher for M 20 grade concrete, when compared to the M 30 and M 40 grade concrete. This is due to the concrete having a high water cement ratio and also because it has larger and more pores than that with a low water cement ratio. The acid solution enters through these large pores and erodes the concrete specimens. A visual inspection of concrete that has been attacked by acid reveals the corrosion of the paste that holds the aggregate in place.

### 6.3.8 Water Permeability

The permeability coefficient of M 20, M 30 and M 40 grades of concrete with 100% natural sand, optimum replacement level of 70% manufactured sand and 100% manufactured sand are revealed in Figure 6.13.

![Permeability coefficient of M 20, M 30 and M 40 grade concrete with MS](image)

**Figure 6.13** Permeability coefficient of M 20, M 30 and M 40 grade concrete with MS
Figure 6.13 expresses the fact that the coefficient of permeability is decreased while using the manufactured sand. This is due to the rough and angular particles of manufactured sand, which create better interlocking between the particles and cement paste, thus prevent the penetration of water inside the specimens. It was found that the coefficient of permeability is less for 70% manufactured sand. This is due to the presence of a small amount of micro fines in it. It was also noted that the permeability of water is reduced for higher grade concrete. This exhibits that there is less water penetration, due to the better interlocking between the particles.

### 6.3.9 Saturated Water Absorption

Water absorption of M 20, M 30 and M 40 grades of concrete with 100% natural sand, 100% manufactured sand and the optimum replacement level of 70% manufactured sand appear in Figure 6.14.

![Figure 6.14 Water absorption of M 20, M 30 and M 40 grade concrete with MS](image)

**Figure 6.14 Water absorption of M 20, M 30 and M 40 grade concrete with MS**

Figure 6.14 explains that the concrete with manufactured sand has less water absorption, when compared to the conventional concrete. This is due to the less voids of better packing and it is also found that the water
absorption is low for concrete with 70% manufactured sand due to the presence of less amount of micro fines in it. It also becomes evident that the absorption of water is reduced for higher grade concrete due to the less voids in it.

6.3.10 Sorptivity

The initial surface absorption of M 20, M 30 and M 40 grades of concrete with 100% natural sand, 100% manufactured sand and the optimum replacement level of 70% manufactured sand was measured by sorptivity method and the test results are expressed in Figure 6.15.

![Sorptivity of M 20, M 30 and M 40 grade concrete with MS](image)

**Figure 6.15** Sorptivity of M 20, M 30 and M 40 grade concrete with MS

Figure 6.15 denotes that the sorptivity of the concrete is decreased while using the manufactured sand and it is less for 70% manufactured sand due to the presence of less amount of micro fines in it. It is also found that sorptivity is less for M 40 grade concrete when compared to the M 20 and M 30 grades of concrete due to the impermeable surface.
6.4 CONCLUDING REMARKS

Durability properties of concrete consist of natural sand and manufactured sand in varying proportions has been dealt. It is observed that the blended mixture of natural sand and manufactured sand gives better results in the properties such as alkali aggregate reaction, drying shrinkage, abrasion, impact, chloride ion penetration, corrosion, acid attack, sorptivity, water absorption, water permeability and hence it increases the durability of the structure.