CHAPTER 6

CONCLUSION

The following conclusions are drawn from the present experimental investigation.

6.1 CHARACTERISTICS OF QUARRY ROCK DUST

1. Sieve analysis of several samples show that quarry rock dust contains particles predominantly in the range of 600 µm to 75 µm. Quarry rock dust contains about 10-20%, material below 75 µm and about 20-70% material between 75 µm -1.18 mm.

2. Specific gravity of different quarry rock dust samples does not show any notable variation. The value ranges from 2.54-2.60. In comparison to the values of specific gravity of natural sand from local River beds do not show any difference.

3. Bulk relative density of quarry rock dust is about 6 % higher than river sand due to the presence of higher fine particles.

4. Quarry rock dust has higher water absorption in the range of 1.20 to 15% because it is hundred percent dry materials. But river sand is under water for a long time. So it has saturated a surface dry condition.
5. In a few quarry rock dust samples the fineness modulus value is very low and has less than 2.

6. From chemical analysis it is found that quarry rock dust has higher reactive silica content (up to 20%) compared with conventional sand.

6.2 QUARRY ROCK DUST AND ITS FRESH CONCRETE PROPERTIES

In workability studies, three experimental investigations were carried out: slump test, compacting factor test and vebe test. The following conclusion emerges from these studies.

1. Natural sand as fine aggregate is easier to place and finish compared to quarry rock dust as fine aggregate.

2. Slump test studies on quarry rock dust concrete are 11%-13% lower than reference concrete.

3. In compacting factor test studies of M20, M30 and M40 mix proportion quarry rock dust concrete has 10%-14% lower CF value of than conventional concrete.

4. Vebe test studies show that quarry rock dust concrete is 10%-19% lower than natural sand concrete.

5. To restore workability levels admixtures are required from 0.60% to 2.15% (weight of cement) for quarry rock dust concrete.
6.3 MIX PROPORTION

1. The design of concrete mixes by the British method has lower cement content and Indian standard method have higher cement content for all the three grades (M20, M30 and M40).

2. The British method of mix design resulted in concrete of compressive and flexural strength, which is very nearly equal to the desired characteristic strength for all the three grades of concrete with economical cement content mixes.

3. Detailed mix proportion is explained in Appendix 1.

6.4 EFFECT OF AGGREGATE SIZE

From this study, the size of coarse aggregate (10mm, 20mm and 40mm) have influenced concrete strength.

1. Thus concrete with 10mm aggregate has 7% higher compressive strength, 13% higher flexural strength and 9% higher split tensile strength than 20mm aggregate concrete.

2. Thus concrete with 20mm aggregate has 2.5% higher compressive strength, 11% higher flexural strength and 10% higher split tensile strength than 40mm aggregate concrete.

6.5 STRENGTH OF QUARRY ROCK DUST CONCRETE

The variation of strength of quarry rock dust concrete in comparison to reference concrete is 10%-15% higher up to the age of 7, 28 and 90 days for various mixes and difference methods. This may be quarry rock dust has higher silica content (up to 20%) and well-graded particles.
6.6 DURABILITY STUDIES ON QUARRY ROCK DUST CONCRETE

1. The result of this investigation shows that drying shrinkage strain of quarry rock dust concrete is quite larger than the shrinkage strain of conventional concrete due to quarry rock dust having water absorption higher than natural sand.

2. In permeability studies, the depth of penetration of quarry rock dust concrete is lower than of that conventional concrete because well graded particles are bonding excellently in quarry rock dust concrete and higher bulk density than in natural sand concrete.

3. It is observed that quarry rock dust concrete has higher water absorption due to the dry sample.

4. The durability of quarry rock dust concrete under sulphate and acid action is inferior to conventional concrete This may be due to low iron, aluminum and magnesium constituents and higher silica content.

6.7 COST FACTORS

1. The elements, which influence the material cost, are processing cost and transportation cost. In most of the cases, it is only transportation cost since crusher units are willing to give quarry rock dust free of cost from their plants.

2. The cost of river sand will vary from location to location depending on the source and availability. Based on PWD and Govt. of Tamilnadu schedule of rates, the cost of river sand
(fine aggregate) in Dindigul district is approximately Rs.812/m$^3$. The quarry rock dust cost (after washing) is Rs.440/m$^3$.

3. The cost of conventional concrete for 1 m$^3$ of M20 (1:1.62:3.00) is Rs. 2684/m$^3$. The cost of quarry rock dust concrete for 1 m$^3$ for M20 (1:1.50:3.00) is Rs. 2502/m$^3$. The quarry rock dust has high potential for its use in economic terms. (Detailed cost analysis is explained in Appendix 2).

6.8 SUMMARY OF RECOMMENDATION

1. Quarry rock dust has properties similar to of river sand except that it has higher water absorption up to 15%. This absorption is mainly responsible for the reduced workability levels of quarry rock dust concrete and higher drying shrinkage properties.

2. Quarry rock dust contains up to 10%-15% of particles less than 0.075 mm. These fine particles consume more cement due to increasing surface area. This fine particles are removed through washing plant. (Detailed washing techniques are explained in Appendix 3).

3. Introducing suitable washing plant at crusher units rectifies these two problems. This washing plant removes excess fine particles and artificially converts dry quarry rock into saturated quarry rock dust and introduces artificial moisture content. This saturated quarry rock dust is kept for 24 hours. Hence it is converted in to saturated surface dry quarry rock dust.
4. The 100 percent replacement of quarry rock dust enhances the compressive, flexural and split tensile strength at age of 7 days, 28 days and 90 days. Thus enhanced strength can be taken into consideration for the design of quarry rock dust concrete mixes for economy.

5. The durability studies show that this type of quarry rock dust concrete can be used in aggressive environments.

### 6.9 RECOMMENDED PROCEDURE FOR USE OF QUARRY ROCK DUST

The quarry rock dust collected by the user for its use in concrete construction should be checked for the following properties.

#### 6.9.1 Physical Properties

1. Specific gravity - 2.4 to 2.65
2. Residue < 0.075mm - 10% - 15%
3. Bulk density in Kg/m$^3$ - 1700-1850
4. Moisture content - 0 - 4%
5. Water absorption - Less than 2%
6.9.2 Chemical Analysis

SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ - Minimum 80%
LOI - Maximum 10%
Combined Alkalis - Maximum 3%
SO$_3$ - Maximum 2%
Alkali soluble silica - Minimum 3 ppm

6.9.3 Fresh Concrete Properties

Table 6.1 Fresh concrete properties

<table>
<thead>
<tr>
<th>Degree of workability</th>
<th>Slump mm</th>
<th>Compacting factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>25-75</td>
<td>0.85</td>
</tr>
<tr>
<td>Medium</td>
<td>50-100</td>
<td>0.92</td>
</tr>
<tr>
<td>High</td>
<td>100-150</td>
<td>0.95</td>
</tr>
</tbody>
</table>

6.9.4 Mix design of quarry rock dust concrete

The quarry rock dust can be incorporated into concrete with the following mix design procedures.

1. The physical and chemical properties of quarry rock dust have to be investigated through the experimental procedure with relevant code.

2. Based on the physical properties of quarry rock dust, required grade of concrete may be designed using absolute volume
method explained below or any established procedure of mix
design explained in Appendix 1.

3. Method adopted to arrive at the optimum mixtures

The mix calculations were carried out based on absolute
volume. For any given volume of mix

$$V_p + V_{ca} + V_{fa} = 1$$

where

- $V_p$ = Volume of paste (cement + water)
- $V_{ca}$ = Volume of coarse aggregate and,
- $V_{fa}$ = Volume of fine aggregate

If one chooses to make a concrete, say, of $V_p = 0.30$ then,

$$V_{ca} + V_{fa} = 0.70 \text{ (constant for } V_p = 0.30)$$

For one cubic meter of concrete $VP = 0.30m^3$

When $w/c = 0.60$ by weight and for specific gravity of cement

$= 3.14$

$$W/c \text{ by volume} = \frac{0.6 \div 1}{1 \div 3.14} = 1.872 \approx 1.9$$

Water

$$= \frac{1.9 + 0.3 + 1000}{2.9} = 197 \text{ lit} / m^3 \text{ and}$$

Cement

$$= \frac{197}{0.6} = 328 \text{ kg} / m^3$$

If the fine aggregate volume $V_{fa}$ is 0.27

$$FA = 0.27 \times 2.60 \times 1000 = 702 \text{ kg}$$

$$CA = (0.7 - 0.27) \times 2.65 \times 1000 = 1140 \text{ kg}$$
The mixture by weight becomes


The fine aggregate proportions in total aggregate are 0.27 / 0.70 = 0.386 or 39% and coarse aggregate proportion is 0.614 or 61% by volume. The mix represents one mix for Vp = 0.30, with a cement content of 328 kg/m$^3$. Likewise, several mixes can be obtained by varying the relative proportions of fine aggregate and coarse aggregate but retaining Vp = 0.30 and w/c ratio as 0.6, and the total aggregate at 0.70 of the mix. Initially, a mix is designed with a low value coarse aggregate proportion, mixed and its Vebe time ascertained. Then the coarse aggregate proportion in the total aggregate is increased (the fine aggregate proportion will decrease as a consequence). The Vebe time of the second mix decreases due to specific surface effect. This process of decreasing the fine aggregate proportion and increasing the coarse aggregate proportion is carried on mixes while are made and Vebe times ascertained. Vebe time decreases as coarse aggregate proportion increases. But after a particular value of coarse aggregate proportion, Vebe time increases again. This is due to the phenomenon of particle interference. That proportion of coarse aggregate (and corresponding fine aggregate proportion), which exhibited the least Vebe time, is the mix of best workability. The aggregate proportions of such a mix can be considered as optimal proportion. Workability should be normally chosen for concreting as it gives the best 'value' for the water used.

In order to obtain the optimal mix, as many as needed, but normally three to five variations of aggregate proportions are made for each value of Vp. Also, for each mix proportion, two or three repetitions are made for obtaining a better accuracy. The mean value of the repetitions was taken as the Vebe time at a given proportion of aggregate.
The mix proportions calculated for making concretes of the $V_p = 0.28$ and cement content = 306 are shown in Table 6.2.

### Table 6.2 Absolute volume mix proportion

<table>
<thead>
<tr>
<th>Mix number</th>
<th>Batch quantity Kg/m³</th>
<th>% Of CA in Total aggregate</th>
<th>Vebe time sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fine aggregate (FA)</td>
<td>Coarse aggregate (CA)</td>
<td></td>
</tr>
<tr>
<td>QC1</td>
<td>780</td>
<td>1113</td>
<td>59</td>
</tr>
<tr>
<td>QC2</td>
<td>728</td>
<td>1166</td>
<td>62</td>
</tr>
<tr>
<td>QC3</td>
<td>676</td>
<td>1219</td>
<td>64</td>
</tr>
<tr>
<td>QC4</td>
<td>650</td>
<td>1245</td>
<td>66</td>
</tr>
<tr>
<td>QC5</td>
<td>598</td>
<td>1298</td>
<td>68</td>
</tr>
</tbody>
</table>

### Table 6.3 Mix proportion and strength of concrete

<table>
<thead>
<tr>
<th>Mix number</th>
<th>Mix proportion</th>
<th>*28 days compressive strength, MPa</th>
<th>*28 days flexural strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>QC1</td>
<td>1:2.54:3.64</td>
<td>28.50</td>
<td>4.00</td>
</tr>
<tr>
<td>QC2</td>
<td>1:2.37:3.81</td>
<td>26.50</td>
<td>3.90</td>
</tr>
<tr>
<td>QC3</td>
<td>1:2.25:3.98</td>
<td>26.10</td>
<td>3.70</td>
</tr>
<tr>
<td>QC4</td>
<td>1:2.12:4.07</td>
<td>26.00</td>
<td>3.70</td>
</tr>
<tr>
<td>QC5</td>
<td>1:1.95:4.24</td>
<td>25.20</td>
<td>3.60</td>
</tr>
</tbody>
</table>

*Test carried out as per IS 516:1959*
4. The experiments were similarly conducted for other values of $V_p$ with different w/c ratio of the mixes.

5. The choice of admixtures for workability is made in the usual manner as per manufacturer guidelines with the code provision.

6. The fresh and hard concrete properties have to be investigated for workability studies and strength properties.

6.10 SCOPE FOR FURTHER RESEARCH

1. In order to ascertain the variability of quarry rock dust from different sources of the country an integrated research is urgently required.

2. Comparative study of quarry rock dust with other marginal materials like fly ash, Silica fume, recycled aggregate in concrete (as explained in chapter 2) can be carried out.

3. Mix design research with code provision is required in order to incorporate marginal materials such as fly ash, silica fume and recycled aggregate (as explained in chapter 2) with quarry rock dust in structural concrete.

4. More durability studies are necessary to introduce this quarry rock dust concrete in aggressive environments.

5. Behaviors of quarry rock dust with ready mix concrete and self-compacting concrete have to be investigated.

6. In building construction 60% of fine aggregate is used for masonry and plastering works. Quarry rock dust incorporation with cement mortar and masonry needs to be further explored.