A parametric study for assessing the effects of coarseness factor and workability factor on concrete compressive strength

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ABSTRACT

Aggregate as the main constituent of concrete (about 60 to 70% by volume) highly affects both fresh and hardened concrete properties. Thus to minimize concrete cost and improve its quality it is necessary to achieve optimum aggregate gradation. Coarseness Factor chart is one of the recent popular methods for achieving an optimum aggregate gradation, which represents the relationship between Coarseness Factor and Workability Factor of a mix. This paper utilizes several trial mix data to explore the relationship of Coarseness Factor and Workability Factor with different fresh and hardened concrete properties.

Keywords: Aggregate, Gradation, Concrete, Coarseness Factor, Compressive strength

1. Introduction

Concrete consist of two segments-1) Aggregate, 2) Paste (Abrams, 1918), and the main vulnerable part is the paste portion. Minimum paste will mean less quantity of cement, less quantity of water, which will further mean increased economy, higher strength, lower-shrinkage and greater-durability (Shetty, 2002). All these properties of concrete can be improved by having well graded aggregates. Thus, the importance of optimum aggregate gradation arises. The most suitable aggregate gradation for a concrete mix, however, will depend upon the actual grading, particle shapes and surface texture.

The optimization of aggregate gradation is advantageous for economical and technical reasons. There are various methods proposed by many researchers for achieving optimum aggregate gradation. One way to achieve optimum gradation is to achieve maximum density. But it was also found that aggregate with very high density will result in harsh mix (Talbot et al. 1923; Walsh, 1933; Besson, 1935). Another method of achieving optimum aggregate gradation is the use Coarseness Factor chart simultaneously with “8-18” band gradation. Coarseness Factor chart was first introduced by Shilstone (1990). Coarseness Factor chart mainly graphically characterizes the relationship between Coarseness Factor and Workability Factor of a mix. However, still the relationships between various properties of concrete with Coarseness Factor and Workability Factor
are unclear. It has been observed in some research that these aggregate properties do not have any clear effects on hardened concrete properties (McCall et al. 2005).

In this paper, to observe the effect of Coarseness Factor and Workability Factor on concrete properties, eight concrete mix results are discussed. These mixes were so designed that the water to cementitious material ratio (w/c ratio) and aggregate to cementitious material ratio (a/c ratio) for all mixes were same, only the aggregate gradations were kept variable. Thus only the aggregate gradation related properties were varied (i.e. Coarseness Factor, Workability Factor, fine aggregate to total aggregate ratio etc), where other important parameter remaining the same (i.e. w/c ratio, a/c ratio etc).

1.1. Coarseness Factor

Coarseness Factor was derived from the aggregate gradation to predict the workability of the concrete mix (Shilstone, 1990). Coarseness Factor is the proportion of plus 3/8" coarse particles in relation to the total coarse particles, expressed as a percent. Total aggregate gradation can be divided into three fractions - (i) Coarse Fraction (Q): Materials retained on 3/8" sieve, (ii) Intermediate Fractions (I): Passing 3/8" sieve and retained on #8, and (iii) Fine Fraction (W): Passing #8 and retained on # 200 (Shilstone, 1990).

Thus Coarseness Factor expressed as,

\[ CF = \frac{Q}{Q+I} \times 100\% \]

Here, CF = Coarseness Factor.

A Coarseness Factor = 100 would represent a gap-graded aggregate where there was no #8 to 3/8inch material. A Coarseness Factor = 0 would be an aggregate that has no material retained on the 3/8inch sieve.

1.2. Workability Factor

Workability Factor is the percent of the combined aggregate that passes the No. 8 sieve. The Coarseness Factor Chart is based upon 6.0 sacks (564 pounds) of cementitious materials per cubic yard (335 kg/m³). Thus, Workability Factor needs to be adjusted in order to account for different cementitious amounts. When the amount of cement exceeds 6.0 sacks, the Workability Factor is adjusted plus 2.5 percent per sack of cement equivalent. When the amount of cement is below 6.0 sacks, the Workability Factor is adjusted minus 2.5 percent per sack of cement equivalent.

\[ WF = W + \frac{2.5(C - 564)}{94} \]

Where,
WF = Workability Factor

W = % of aggregate passing # 8 sieve.

C = Cement Content of the mix in kg/m³

Here, it is noteworthy that Workability Factor does not correlate with slump (Shilstone, 2002).

1.3. Coarseness Factor Chart

In regard to the Coarseness Factor chart, the X-axis represents the Coarseness Factor, and the Y-axis represents the Workability Factor. Figure 1 shows the Coarseness Factor chart with its different zones. The Coarseness Factor chart is a method of analyzing the size and uniformity of the combined aggregate distribution, balanced with respect to the fine aggregate content of the mix. The Coarseness Factor defines the relationship between the coarse and intermediate particles. There are five zones identifying regions for acceptance or rejection. If the plot of x and y falls within the optimum zone, this indicates that the mix is acceptable but it does not tell exactly what to fix if it is not acceptable. This is useful as a quick check and the plot can be changed with modifications in the fine aggregate (Fricks, 2007). The diagonal bar is the Trend Bar that divides sandy from rocky mixtures. Zone I mixtures segregate during placement. Zone II is the desirable zone. Zone III is an extension of Zone II for 0.5-in. (13 mm) and finer aggregate. Zone IV has too much fine mortar and can be expected to crack, produce low strength, and segregate during vibration. Zone V is too rocky (Shilstone, 2002). The rectangular box within the zone-II represents the optimum zone. This optimum zone was first marked by Harrison (2004).

Figure 1: Different zones in coarseness factor chart

Figure 2: Trial mix positions on Coarseness Factor chart.
2. Experiment

To observe the effect of Coarseness Factor and Workability Factor of aggregate on concrete, mix design was done for a fixed w/c ratio, where only the size distribution of aggregate were varied. 4” X 8” concrete cylinder-samples were prepared and tested according to ASTM standards at 7 days, 14 days and 28 days. Three samples were cast in each case. The tests were done using local materials in Dhaka, such as local cement brand (ensuring CEM II-B/M standards), local sand (FM = 1.13), Sylhet sand (FM = 2.75) and local coarse aggregate (stone chips). Total eight trial mixes were prepared. For all these trial mixes nominal maximum size of aggregate was 19mm.

2.1. Mix Proportion

As it is mentioned earlier, for all the trial mixes w/c ratio and a/c ratio were kept constant. Thus for all the mixes, quantity (weight basis) of water, aggregate and cement were the same for a given moisture condition. Table 1 shows the mix proportions in saturated surface dry (SSD) condition of aggregates.

<table>
<thead>
<tr>
<th>Component</th>
<th>Required (kg/m³)</th>
<th>By Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>195</td>
<td>4.0</td>
</tr>
<tr>
<td>Cement</td>
<td>440</td>
<td>9.1</td>
</tr>
<tr>
<td>Aggregate</td>
<td>1790</td>
<td>36.9</td>
</tr>
</tbody>
</table>

Table 1: Mix Proportions in SSD Condition of Aggregates

2.2. Aggregate Properties

Table 2 shows the combined aggregate properties for different trial mixes, obtained from standard tests. The shaded areas represent the maximum value of particular parameters. From Table 2 it was observed that % void for all type of gradation are nearly same, irrespective of well graded or not well graded aggregate, as it was proved by many researchers (Karthik, 2008; Ashraf and Noor, 2011).

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Fine aggregate to total aggregate ratio</th>
<th>FM</th>
<th>CF</th>
<th>WF</th>
<th>Aggregate Density (kg/m³)</th>
<th>% Void Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix-1</td>
<td>0.47</td>
<td>2.82</td>
<td>71</td>
<td>47</td>
<td>1664</td>
<td>36</td>
</tr>
<tr>
<td>Mix-2</td>
<td>0.48</td>
<td>2.57</td>
<td>57</td>
<td>45</td>
<td>1647</td>
<td>37</td>
</tr>
<tr>
<td>Mix-3</td>
<td>0.35</td>
<td>2.37</td>
<td>55</td>
<td>35</td>
<td>1701</td>
<td>35</td>
</tr>
<tr>
<td>Mix-4</td>
<td>0.54</td>
<td>3.28</td>
<td>52</td>
<td>45</td>
<td>1682</td>
<td>35</td>
</tr>
<tr>
<td>Mix-5</td>
<td>0.54</td>
<td>3.59</td>
<td>45</td>
<td>42</td>
<td>1664</td>
<td>36</td>
</tr>
<tr>
<td>Mix-6</td>
<td>0.38</td>
<td>3.15</td>
<td>56</td>
<td>34</td>
<td>1663</td>
<td>36</td>
</tr>
<tr>
<td>Mix-7</td>
<td>0.33</td>
<td>2.83</td>
<td>65</td>
<td>31</td>
<td>1666</td>
<td>36</td>
</tr>
<tr>
<td>Mix-8</td>
<td>0.49</td>
<td>2.81</td>
<td>59</td>
<td>44</td>
<td>1656</td>
<td>36</td>
</tr>
</tbody>
</table>
2.3. Concrete Properties

Table 3 shows primary concrete properties, such as, fresh concrete density (kg/m\(^3\)), slump (mm) and compressive strength (MPa) for the trial mixes.

### Table 3: Concrete Properties for Different Mixes

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Fresh Concrete Density (kg/m(^3))</th>
<th>Slump (mm)</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>7 Days</td>
<td>14 Days</td>
</tr>
<tr>
<td>Mix-1</td>
<td>2302</td>
<td>32</td>
<td>18</td>
</tr>
<tr>
<td>Mix-2</td>
<td>2256</td>
<td>65</td>
<td>21</td>
</tr>
<tr>
<td>Mix-3</td>
<td>2204</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Mix-4</td>
<td>2258</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Mix-5</td>
<td>2284</td>
<td>6.5</td>
<td>35</td>
</tr>
<tr>
<td>Mix-6</td>
<td>2292</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>Mix-7</td>
<td>2290</td>
<td>25.5</td>
<td>28</td>
</tr>
<tr>
<td>Mix-8</td>
<td>2266</td>
<td>32</td>
<td>29</td>
</tr>
</tbody>
</table>

3. Discussion

3.1. Positions in Coarseness Factor Chart

Figure 2 shows the positions of the trial mixes in the Coarseness Factor chart. As it was mentioned earlier, cement content of these mixes was 195 kg/m\(^3\) (742lb/yd\(^3\)) which was greater than 6.0 sacks of cement (564lb/yd\(^3\)). Therefore the Workability Factor was adjusted for this increased cement content as following-

\[ WF = W + \frac{2.5(742 - 564)}{94} \]

From the positions of the trial mixes in the Coarseness Factor chart it can be observed that, only two mixes (mix-3 and mix-6) fall in optimum mix range. From table 4 it can also be revealed that the concrete properties of these mixes, being obtained from standard tests, were very close to each other.

### Table 4: Concrete Properties for Optimum zone mixes

<table>
<thead>
<tr>
<th>Mix-ID</th>
<th>Strength (MPa)</th>
<th>Slump (mm)</th>
<th>CF</th>
<th>WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix-3</td>
<td>46</td>
<td>0</td>
<td>55</td>
<td>35</td>
</tr>
<tr>
<td>Mix-6</td>
<td>50</td>
<td>3</td>
<td>56</td>
<td>34</td>
</tr>
</tbody>
</table>

Again considering another group of mixes, that is, mix-2, 4 and 8, it is clear from Figure 2 that all these mixes are in Zone-IV of Coarseness Factor chart for which the properties are shown in table 5. From this table it is observed that although these mixes fall into the
same zone and also the CF, WF values are very close, there are hardly any similarities in their major concrete properties.

Table 5: Concrete Properties for zone-IV mixes.

<table>
<thead>
<tr>
<th>Mix-ID</th>
<th>Strength (MPa)</th>
<th>Slump(mm)</th>
<th>CF</th>
<th>WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix-2</td>
<td>31</td>
<td>65</td>
<td>57</td>
<td>45</td>
</tr>
<tr>
<td>Mix-4</td>
<td>47</td>
<td>0</td>
<td>52</td>
<td>45</td>
</tr>
<tr>
<td>Mix-8</td>
<td>40</td>
<td>31.75</td>
<td>59</td>
<td>44</td>
</tr>
</tbody>
</table>

Another observation from Table 3 is that the mix-5 is a better mix than mix-3 and mix-6 (mixes which fall within optimum zone) when compared only on the basis of slump and 28-days compressive strength. Thus, it has the indication regarding a fact that any mix within the optimum zone may not always provide better results for compressive strength and workability than any other mix outside the optimum zone.

3.2. Coarseness Factor and Compressive Strength

Figure 3 shows that the compressive strength of concrete mix decreases with the increase of Coarseness Factor and vice-versa. This is because an increase in Coarseness Factor implies a decrease in intermediate size particles, as defined in section 2. Thus higher the Coarseness Factor, the more the mix tends to be gap-graded, giving away a lower compressive strength.

Focusing only on the aggregate density, mix-3 was the densest and mix-6 was the most gap-graded mix as featured in Table 2. But while only the Coarseness Factor (i.e. the presence of intermediate particles) is under consideration, Table 2 clearly indicates that mix-1 was the most gap-graded and mix-5 was the densest mix with sufficient intermediate particles. Although the density of mix-3 was maximum, but there may not be sufficient amount of intermediate particles, since its Coarseness Factor was higher than mix-5. As a result of that the 28-days compressive strength of mix-5 was found to be higher than that of mix-3 (see Table 3).

Table 2 features another important observation, that is, the aggregate density of both mix-5 and mix-1 was the same (1664 kg/m$^3$). Even though these two mixes possess the same aggregate density, persistent differentiation is noticeable in between. That is, the 28-days compressive strength of mix-5 was 51 MPa and Coarseness Factor was 45 and where as for mix-1, the 28-days compressive strength was 30 MPa and Coarseness Factor was 71. Thus the presence of intermediate particles highly affects the compressive strengths of concrete which is in turn gives way to a definite relationship between compressive strength of concrete and the Coarseness Factor.
3.3. Workability Factor and Compressive Strength

From Figure 4, it seems that the compressive strength of concrete increases with the increase of Workability Factor up to a certain limit, after that the strength starts decreasing reversibly. This may be due to the fact that, finer particles are required to fill up the inter-particle voids of coarse particles. But after a certain limit, when the amount of finer particles are higher than the required the mix will become more sandy. Hence, there should be a suitable range of Workability Factor to get a higher strength, as indicated by Figure 4; it can be 0.30 to 0.37. But this range needs to be more precise by applying large-scale data sets.
properties. From this research, it has been found that both the Coarseness Factor and Workability Factor might have relationships with concrete compressive strength. But the precise form of these relationships must be established through a comprehensive research with large scale data sets.

Acknowledgement

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5. References

1. Abrams, D. A., 1918, Design of Concrete Mixtures, Bulletin 1, Structural Materials Research Laboratory, Lewis Institute, 1918.
12. Walsh, H. N., 1933, Simplified Concrete Mix Design, American Concrete Institute Journal, 5 (2), pp 110-120.