ROLE OF AGGREGATES IN PRODUCTION OF ULTRA HIGH STRENGTH CONCRETE

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ABSTRACT: Use of Ultra High Strength Concrete (UHSC) is not yet started in Pakistan. In the present study an effort is made to produce UHSC with materials available in the local market. Role of aggregates is becoming more and more important for strength enhancement. 1st of all Margalla Crush is used which is most extensively used in Lahore. Then Havellian crush obtained from riverbed gravel is tried but both these stones did not produce the desired results. Finally heavy mineral aggregates having appreciable amount of chromites is tried and UHSC is successfully produced on the laboratory scale.

Keywords: Margalla crush, Havellian gravel aggregates, ACV, AIV, High Strength.

INTRODUCTION

Construction of buildings using ultra high strength concrete is unfamiliar in Pakistan especially in Lahore. As the cost of land and materials is ever growing, engineers/designers shall soon switch over to high and ultra high strength concrete. The major benefit of ultra high strength concrete is reduction in member x-sections, hence saving in material cost as well as space occupied by structural members.

Concrete may fail due to failure of matrix, coarse aggregates or bond failure between aggregates and matrix. High strength concrete can be produced only by preventing such failures. Space between aggregate and matrix is called ITZ (Interfacial Transition Zone). Matrix as well as transition zone properties can be improved by adjusting water to cement ratio and cement content. Addition of micro-fillers, pozzolanas, pore reduction and even changing the mixing sequence may prove helpful towards strength enhancement. On the other hand if aggregates are of poor quality then strength enhancing efforts will not work and only option left is to change source of aggregates.

LITERATURE REVIEW

Concrete can be classified in different ways depending upon its properties in fresh as well as in hardened state. It is broadly divided into three groups, NSC (Normal Strength Concrete), HSC (High Strength Concrete) and UHSC (Ultra High Strength Concrete). There are no well accepted boundaries existing between these groups. In fact limits are kept on changing with the advancement of knowledge. According to Bill Price a simple definition of high strength concrete would be, concrete with a compressive strength greater than that covered by current codes and standards. Concrete Association of Finland (L T Phan, N J Carino) prescribes HSC as 10,000-14,500 psi (70-100 MPa). This means that concrete below 10,000 psi (70 MPa) is NSC and above 14,500 psi (100MPa) is UHSC. S K Al-Oraimi *et al* states that "in seventies 6000 psi (42 MPa) concrete was considered high strength and recently 8700 psi (60 MPa) is the lower boundary for high strength concrete". R. L. Day considers less than 2900 psi (20MPa) as low strength, 3000-8700 psi (20-60 MPa) as normal strength, 8700- 14,500 psi (60-100 MPa) as high strength and more than 14,500 psi (100 MPa) as very high strength concrete.

Strength classification for Pakistan: From the above discussion it is clear that no agreed boundaries are available for different types of concrete. Different researchers postulate these classifications as per their regional requirements. Instead of following any individuals judgment let us classify concrete on the logic of fracture. As already mentioned there are three types of fracture in concrete. Below 6000 psi (42 MPa) the properties of coarse aggregate has no effect on concrete strength (S K Al-Oraimi *et al*). Upto 12,800 psi (90 MPa) concrete fracture is controlled by transition zone. Beyond this level concrete fracture is largely controlled by aggregate strength (O E Gjorv). Based upon the above logic following division seems suitable for strength based concrete classification for Pakistan. Less than 6000 psi(42MPa) is NSC(Normal Strength Concrete), 6000-12,800 psi(42-90MPa) HSC (High Strength Concrete) and above this level is UHSC (Ultra High Strength Concrete).

Importance of aggregate for ultra high strength concrete: Peitru Lura observed that the strength of concrete is severely influenced by the weakest component; hence strength of aggregate tends to provide a ceiling strength for the strength of concrete. Aggregate has the major contribution in controlling the strength of ultra high strength concrete. It is the mineralogy and the strength of the coarse aggregate itself that control the ultimate strength for concrete (S K Al-Oraimi *et al*). It is also believed that in high strength concrete tensile strength is controlled by mortar strength where as compressive strength is significantly influenced by strength and surface characteristics of coarse aggregate (T Dzturan and C Ceqen). Concrete comprising weak aggregates will also be weak. Rocks with low intrinsic strength are unsuitable for use as aggregates (www.understanding-cement.com). Each characteristic of coarse aggregate like specific gravity, bulk density, aggregate impact value and aggregate crushing value has certain influence on ultimate strength of concrete. As discussed earlier, concrete failure can be characterized as paste failure, paste aggregate bond failure and failure of aggregates. For the first two types of failures there are number of methods available to improve the properties of concrete i.e. if paste is weak it can be made stronger by increasing cement fineness, increasing the cement content, reducing water content through use of water reducing agents, using pozzolanic materials and also by improving its density by addition of micro fillers. In addition to its pozzolanic nature silica fumes are very good micro fillers as well. The 15% replacement of the cement mass by silica fumes will add approximately two million particles to each replaced cement grain (G C Isaia *et al*). The bond failure between paste-aggregate can be avoided by improving the interfacial transition zone (ITZ). Accumulation of water around aggregate particles is one of the sources of ITZ weakness. Use of water reducing agents, viscosity modifiers and improving the grading of constituent materials may help in minimizing this ITZ. Addition of pozzolanic materials like silica fumes, fly ash, GGBS etc. reacts with $Ca(OH)_2$ crystals forming CSH. Silica fume particles consumes $Ca(OH)_2$

which is present in transition zone and make the zone dense and uniform(K Vivekanandam *et al*). The ITZ can also be improved by reducing maximum aggregate size and also by revising mixing sequence. The coarse aggregate is found to be the most important factor for fracture energy. For strong aggregates the crack runs around the aggregate, where as for weak aggregate the crack penetrates and fractures the aggregate (FHWA). Aggregate must act as crack obstacle, but if aggregate itself is failing then size reduction shall not be of much use and the only choice left is to use the aggregates from another source. Hence, selection of appropriate source of aggregate is much more critical for high and ultra high strength concretes than for conventional concretes (Bill Price). Suitability of aggregates is broadly decided on the basis of tests like aggregate crushing value (ACV) and aggregate impact value (AIV) and 10% fine values. Some other tests like Los angles abrasion value and point load test for rocks are also in use but they are less common. Some good efforts (A A Al-Harthi *et al* 2001, and 1997, I H Zarif) have been made to correlate the mechanical properties of aggregates, but a lot of work is yet required to be done before some reliable models are established. ACV may vary from 5% (for strong aggregate) to 30% (for weak aggregates) (M A Kamal *et al*). Aggregate strength cannot be easily related to concrete strength (P Zhou). Both ACV and AIV tests give only some indication regarding quality of aggregates. There is no explicit relation between the crushing value and the compressive strength. The crushing value is a useful guide when dealing with aggregates of unknown performance, particularly when lower strength may be suspected (A M Neville).

Experimentation: Experimentation is carried out to produce ultra high strength concrete. 1st of all Margalla crush was tried which is extensibly used in Lahore. To save lot of efforts and costly material, instead of carrying out trials for proper mix, a mix which can produce strength close to 90 MPa was searched from literature. S Bhanja and B Sengupta have given following mix for 13,500 psi (93MPa). The total binder content of Bhanja mix was 520 kg/m^3, which was slightly raised to 525 kg/m^3. Table: 1 gives the comparison of mix proportions.

Table: 1 Concrete mix proportions

	S Bhanja Mix	Present study
Cement	468 kg/m^3	472.5 kg/m^3
Silica Fume	52 kg/m^3	52.5 kg/m^3
Fine Agg.	667 kg/m^3	667 kg/m^3
Coarse Agg.	1146 kg/m^3	1146 kg/m^3
W/C Ratio	0.26	0.26
SP	3.5 %	3.5 %

Table: 2 Margalla Crush properties Comparison.

Properties	H Rehman	Present Study
Loose Bulk density	85.95 Pcf	85.29 Pcf
Rodded bulk density	96.03 Pcf	92.88 Pcf
Fineness modulus	6.77	-
AIV	17.61%	17.8%
ACV	26.8%	27.9%
Sp. Gavity	-	2.564

The aggregate crushing value is 27.9%, very close to 30, indicating that this aggregate is very week. M. A. KAMAL *et al*. reported ACV of Margalla as 21.98 %. This higher value is unusual as all other reported values are always above 26%. It is possible that stone supplied to Mr Kamal may be from some stronger portion of the rock. Table 2 gives a comparison of the properties of Margalla crush observed in this study with those reported by H Rehman in 1996. It is evident that after about twelve years time there is no appreciable change in the properties of aggregates. Notably the ACV has further reduced by about 1%. Margalla crush of half inch down size has following gradation, retained on 0.5 in 0 %, 3/8 in 52.5% and 3/16 in 47.25%. Other materials used are locally available Maple leaf cement of 42.5 MPa class (Manufacturer's Note: Clinker 95%, gypsum 5%, strength up to 5800 psi). Lawrencepur sand having 2.69 FM, , Cormix SF1 silica fume and Chryso Fluid Optima (Glenium 51) super plasticizer supplied by Cormix International

Cubes of 4x4x4 in (100x100x100 mm) were casted. To prevent moisture loss, specimens were covered with polyethylene sheet immediately after casting. Specimens were de-molded after 48 hours and then placed in water for moist curing. These were removed from water one day before testing and placed in the open air for drying. Testing was carried out for 7, 14, 28 and 56 days. The strength observed during testing was far less than expected. To improve the ITZ for the purpose of strength enhancement, w/c ratio was reduced to 0.24 and the aggregate size was also reduced. Now maximum aggregate size used was 3/8" instead of 1/2". Another two batches revealed that further improvement in the strength is not possible, hence experimentation was discontinued. 1st set of casting is designated as Mix (1/2-0.26) and 2nd as Mix (3/8-0.24).

The test results of Margalla crush was still unsatisfactory, so its use was discontinued and started searching more strong aggregates. M A Kamal also reported the ACVs of other available aggregates from Chiniot, Sikhanwali, Takial and Khairabad sites. Only Chiniot stone has ACV close to that of Margalla and all other were two to seven percent higher indicating them weaker than even Margalla crush. Then next phase of experimentation was carried out with Havellian river gravel crush. Though its use in Lahore is very less but it is available in Badami Bagh. Properties of aggregate are as follows. Passing 1/2", sieve 100 %, 3/8", 39 % and 3/16", 1 %. Loose bulk density 92.4 pcf, rodded bulk density 101.7 pcf, specific gravity 2.632, ACV 22.67 % and AIV 16.35 %. Since at least one face of crushed gravel is always smooth, so before casting some exercise of handpicking the larger smoothed surface particle was carried out. One more change in the mix proportions of previous casting was made, that the total binder content was increased from 525 to 600 Kg/m^3. Water to binder ratios was gradually reduced from 0.26 to 0.22. Castings with 0.24 and 0.22 revealed that targeted strength is difficult to achieve with this aggregate. Then search was started for heavier and stronger aggregates. It was learnt that heavy mineral aggregates containing Chromite ore are quarried from northern areas of Pakistan. This stone is then transported to Karachi and crushed to powder form, and then exported abroad, as no extraction facilities are available. M/S Lasermed, the leading exporters of Chromium powder were requested to supply the stone. They very kindly accepted my request and provided me 500 Kg of required size aggregates. The properties of chromium aggregates are as follows. Aggregate passing 3/8" and retained on 3/16" is used for casting. Specific gravity is 3.61, water absorption 0.834 %, AIV 17.01 % and ACV 26.83 %. Chromite stone is about 40% heavier than Margalla crush so cubic content of aggregate was also increased from 1146 to 1500 kg/m^3. Concrete produced with Chromite aggregate is about 15 to 20 % heavier than that produced with Margalla crush.

RESULTS AND DISCUSSION

Cubes of 4 in size are casted and tested for different type of aggregates with varying water to binder ratios. These results are presented here in the form of bar charts in Fig: 1 to Fig: 3. These charts indicate the observed concrete strength development trends at different ages. Results regarding Margalla crush are tabulated in Fig: 1(a) to 1(f). Those of Havellian gravel crush are shown in Fig: 2 (a) to 2(d). Results pertaining to Chromite aggregates are presented in Fig: 3(a) to 3(f).

Fig: 1 shows that the concrete strength even after 56 days is less than the target strength. Though the 28 and 56 days strength with reduced water to binder content of 0.24 is more than that of 0.26, but for 7 and 14 days it shows somewhat lower values. Moreover concrete with 0.24 ratio is shows somewhat increasing trend for some, where as that of 0.26 start exhibiting a downward trend with age, and after 28 days the overall strength gaining trend is negative. This is actually due to weak nature of aggregates. Al-Harthi (2001) has given the following relationship between ACV and UCS (un-confined compressive strength).

$$ACV(\%) = e^{(3.71 - 0.005UCS)}.$$

From this equation the expected strength of Margalla crush should be in the range of 11,000 psi(76 MPa), and the maximum values of observed strength are very close to this value.

On the other hand the ACV of Havellian gravel crush was adequate for the purpose of concrete strength. As per Al-Harthi (2001) equation the expected strength of concrete with Havellian crush should approximately be 17,000 psi(118 MPa). But the results (Fig: 2) show that the observed strength is even less than the target strength 12,800 psi (90MPa). Though at the age of 56 days some samples crossed the targeted range and attain values even upto 14,700 psi (101 MPa), but for structural point of view and also for comparison purposes 28 days strength is more important. Though the ACV was adequate but the gravel aggregates has one smooth surface which create problem during bonding between paste and aggregate. Hand picking was done to reduce the smoothed surface particles, but their complete elimination was not possible. Hence this smooth surface was the source of weak transition zone which drastically reduced the concrete strength.

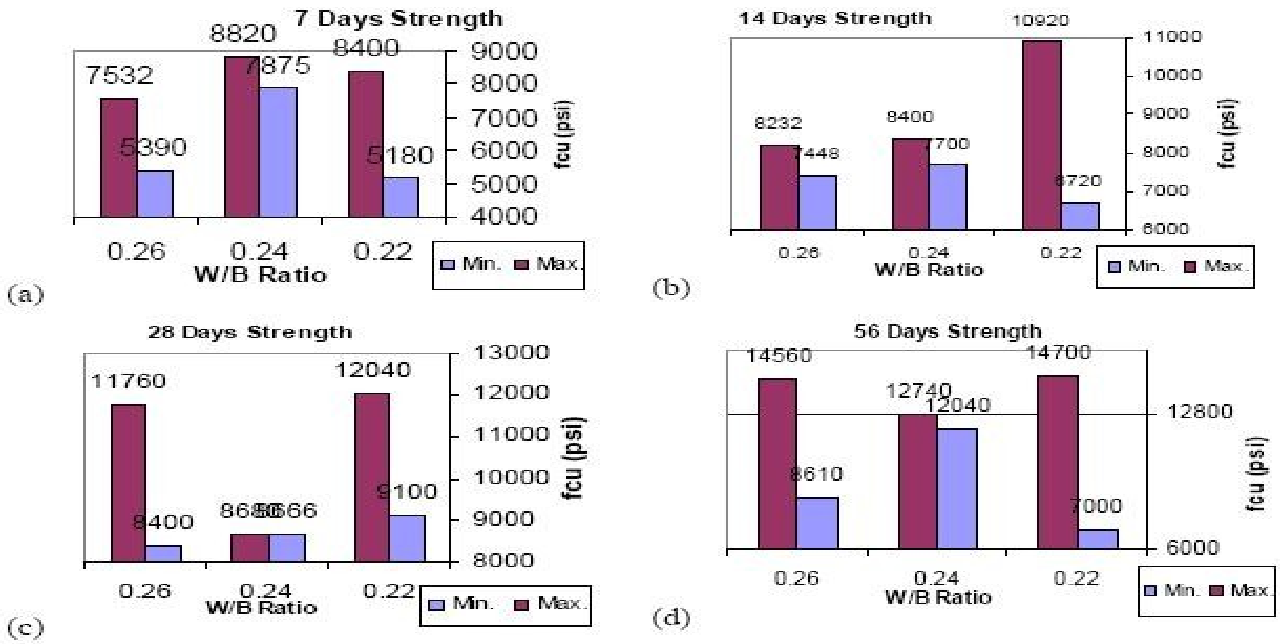

Figure: 2 Concrete Strength Development trends using Havellian Aggregates.

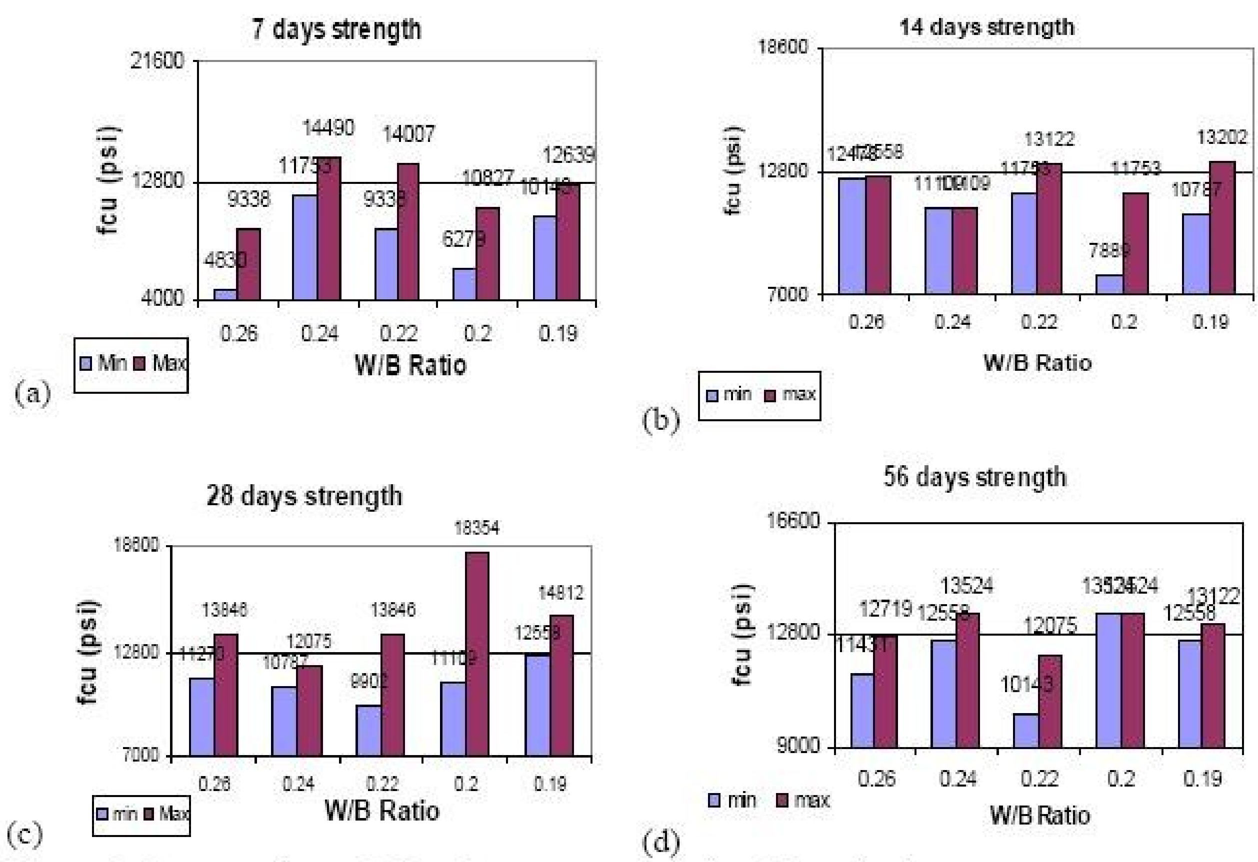

Figure: 3 Concrete Strength Development trends using Chromite Aggregates.

Next phase of experimentation was using Chromite ore as aggregates. This aggregate was specially transported from Karachi. Though the expected strength calculated from Al-Harthi equation was approximately 12,200 psi (84 MPa), but the results obtained (Fig : 3) are very excellent.

The other supporting factor was the density of these aggregates. These aggregates were about 40% heavier than the conventional aggregates and the concrete produced was 15 to 20% denser. As we know denser concrete is also stronger, hence the observed strength was more than the targeted strength. Some samples attain the required values even at the age of only 7 days. At the ages of 28 and 56 days, a sizeable proportion of samples show strength more than 12,800 psi (90 MPa).

Conclusions: Margalla crush is not suitable for ultra high strength concrete. It is best for concrete upto 6000 psi (42 MPa).

- Havellian gravel crush is also not suitable for ultra high strength concrete, but this aggregate can be used for production of concrete strength in the range of 8000 to 9000 psi (55 to 62 MPa).
- Chromite aggregates are suitable for ultra high strength concrete. Its cost is much more than conventional aggregates hence careful economic feasibility study must be conducted before using these aggregates.
- With 3.5% dosage of super plasticizer, water to binder ratio should not be less than 0.2, otherwise workability problem may reduce the strength.

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