EXPERIMENTAL INVESTIGATIONS ON ULTRA HIGH STRENGTH CONCRETE

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***ABSTRACT*: The construction of high-rise buildings and mega projects around the world, and the increasing demands of owners and designers have led to the increasing demand on Ultra-High Strength Concrete (UHSC). Progress in concrete materials science and technology during the last 30 years has far exceeded that made during the previous 150 years. The technology development of concrete and demand for high strength construction materials give momentum to the development of Ultra-High Strength Concrete (UHSC). This new type of concrete is characterized with very high compressive strength i.e., strength higher than 100 MPa. Current UHSC preparation methods require costly materials and relatively sophisticated technology. In this project, study on Ultra-High Strength Concrete has been made. Concrete mix design and experimentation on Ultra-High Strength concrete have been carried out. The mechanical properties such as compressive strength, split tensile strength and Young's modulus of elasticity of ultra-high strength concrete have been researched.**

I.INTRODUCTION

1.1 General

New types of concrete such as High Strength Concrete (HSC), High Performance Concrete (HPC), Self-Compacting Concrete (SCC), Ultra High Performance Concrete (UHPC) and Ultra-High Strength Concrete (UHSC) are being constantly developed in order to meet the increasing demand for improved mechanical properties and durability. The properties of such concrete show a substantial improvement over conventional concrete of low or medium strength.

Normal Strength Concrete (NSC)

Normal Strength Concrete (NSC) has cube strength in the range 20 – 40 MPa.

High Strength Concrete (HSC)

High strength concrete has a compressive strength greater than 40 MPa. High- strength concrete is made by lowering the water-cement (w/c) ratio to 0.35 or lower. Often silica is added to prevent the formation of free calcium hydroxide crystals in the cement matrix, which might reduce the strength as the cement-aggregate bond. Low w/c ratios and the use of silica fume make concrete mixes significantly less workable, which is particularly likely to be a problem in high strength concrete applications where dense rebar cages are likely to be used. To compensate for the reduced workability, super plasticizers are commonly added in high-strength concrete. Aggregates must be selected carefully for high strength mixes, as weaker aggregates may not be strong enough to resist the loads imposed on the concrete and cause failure to start in the aggregate rather than in the matrix or at a void, as normally occurs in conventional concrete.

Ultra High Strength Concrete (UHSC)

The concrete which has compressive strength greater than 100MPa is called as Ultra-High Strength Concrete (UHSC). Ultra-High Strength Concrete is a concrete which has an extremely low water to cement ratio (i.e. less than 0.26), higher binder content, optimum packing density to eliminate capillary pore and provide an extremely dense matrix. It is a high strength material formulated from a special combination of combination of constituent materials which include Portland cement, silica fume, fine aggregate, coarse aggregate, high-range water reducer and water. The material has the capability to sustain deformation and resists flexural and tensile forces, even after initial cracking.

Evolution of Ultra-High Strength Concrete (UHSC)

The construction of high-rise buildings and mega projects around the world, and the increasing demands of owners and designers have led to the increasing demand on high-strength concrete (HSC). It should be noted that the definition of HSC has changed over the years and will no doubt continue to change. Progress in concrete materials science and technology during the last 30 years has far exceeded that made during the previous 150 years. Ultra-high-strength concrete (UHSC) is a new class of concrete that has been the result of such development. This new type of concrete is characterized with very high compressive strength; higher than 100 MPa. Even though UHSC features high compressive strength, it shows very brittle failure behavior and therefore a limited post- crack behavior. UHSC fails explosively without any omen. By the addition of fibers the load-displacement behavior and consequently the ductility and fracture toughness can be improved.

Satisfactory long-term performance of structures has become vital to the economies of all nations. Concrete has been the major instrument for providing stable and reliable infrastructure since the days of the Greek and roman civilization. At the turn of the 20th century, concrete compressive strength was in the range of 13.8MPa, by the 1960s it was in the range of 27.6-41.4MPa. Deterioration, long term poor performance, and inadequate resistance to hostile environment coupled with greater demands for more sophisticated architecture, led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards. As a result, new materials and composites have been developed and improved cements evolved. Today, concrete structures with a compressive strength exceeding 138MPa are being built world over. In research laboratories, concrete strengths of even as high as 800 MPa are being produced. One major remarkable quality in the making of Ultra-high Strength Concrete (UHSC) is the virtual elimination of voids in the concrete matrix, which are mainly the cause of most of the ills that generate deterioration. Such concretes can be either normal strength or high

strength. Normal strength concrete, by ACI definition, is a concrete that has a cylinder compressive strengths not exceeding 42 MPa. UHSC's with 140 MPa are currently being used in High rise structures in USA and Europe. Important governing factors for UHSC's are strength, long term durability, serviceability as determined by crack and deflection control, as well as response to long term environmental effects. Ultra-High Strength Concrete (UHSC) is a concrete with properties or attributes which satisfy the performance criteria. Generally, concretes with high strengths and attributes superior to Conventional concretes are desirable in the Construction Industry. UHSC is defined in terms of Strength and Durability. Therefore, UHSC can be considered as a logical development of cement concretes in which the ingredients are proportioned and selected to contribute efficiently to the various properties of cement concrete in fresh as well as in hardened states.

Based on a wide experimental programed on ultra-high strength concrete, the hardened concrete properties were investigated extensively. The primary findings are that the used materials influence especially the time development of the mechanical behavior of the concrete. Ultra-High Strength Concrete (UHSC) is characterized by extraordinary mechanical properties (high compressive and tensile strength, large E-modulus) and has excellent durability properties regarding corrosion of concrete and reinforcement (low permeability against liquids and gases, thus high resistance against the penetration of ions, very good freeze-thaw-resistance with or without de-icing salts and a high abrasion resistance). Nevertheless, the deformation behavior of the UHSC-Matrix in comparison to normal strength concrete is a contrary matter. Until the peak load, the behavior is predominantly linear-elastic, large deformations at peak cannot be observed, and the reached post-peak strain is nearly zero. These facts point out the very brittle material behavior. The mentioned changes influence certainly design – relevant properties like bending, shear, torsion and punching, bearing capacity as well as the bond of reinforcement and the behavior under concentrated loading.

II. LITRATURE REVIEW

1. Chong Wang; Changhui Yang; Fang Liu; Chaojun Wan; Xincheng Pu; "Preparation of Ultra-High Performance Concrete with common technology and materials"; Cement & Concrete research, Vol.34,00.538-544,2012.

This journal was regarded on the technology development of concrete and demand for high strength construction materials has given the momentum to the development of Ultra-High Performance Concrete (UHPC). Current UHPC preparation methods require costly materials and relatively sophisticated technology. To overcome these weaknesses, this paper focused on the preparation of UHPC with common technology and ordinary raw materials. Influence of binder content, water/binder ratio, Ground Granulated Blast furnace Slag (GGBS) content, and Limestone Powder (LP) replacement on fluidity and compressive strength of concrete were researched, respectively. The test results show that the addition of super plasticizer and fine mineral additives enabled the UHPC to be produced at an extremely low water/binder ratio of 0.14–0.18, achieving excellent workability with a maximum slump of 268 mm and compressive strengths of 175.8 MPa at 90 d and 182.9 MPa at 365 days.

2. Andrew Logan; Wonchang Choi; Amir Mirmiran; Sami Rizkalla; and Paul Zia; "Short-Term Mechanical Properties of High-Strength Concrete", ACI Materials Journal, Vol. 106, No. 5, September-October 2009.

A comprehensive experimental program was undertaken to determine the short- term mechanical properties of high-strength concrete (HSC). Modulus of rupture beams and two different sizes of concrete cylinders with three different target compressive strengths ranging from 10 to 18 ksi (69 to 124 MPa) were subjected to three different curing methods and durations. Test results were combined with data from the literature to improve predictive equations for the elastic modulus and modulus of rupture of HSC. Of the three different curing methods, cylinders moist-cured for 7 days exhibited the highest compressive strengths at ages of 28 and 56 days. In contrast, 1-day heat curing generally resulted in the lowest compressive strength.

The study shows that a Poisson's ratio of 0.2 can be adequately used for HSC.The development of high-strength concrete (HSC) has led to more efficient design of buildings and bridges, with shallower members and longer spans. Although some design specifications have addressed the use of HSC, many have implicitly or explicitly placed restrictions on its use, primarily because of limited research data.

3. Mohammad Abdur Rashid; Mohammad Abul Mansur; "Considerations in producing high strength concrete", Journal of Civil Engineering (IEB), Vol. 37(1) pp. 53-63, 2009.

This paper was regarded on the requirements of ingredient-materials for producing high strength concrete (HSC) along with the results of an experimental study on achieving HSC has been reported in this paper. Use of quality materials, smaller water-binder ratio, larger ratio of coarse aggregate (CA) to fine aggregate (FA), smaller size of coarse aggregate, and suitable admixtures with their optimum dosages are found necessary to produce HSC. In the experimental study, the targeted strengths of concretes were from 60 MPa to 130 MPa. A larger ratio of CA to FA (1.81 except one mix of 1.60) was considered in the study. While the variables considered were the water-binder ratio (from 0.34 to as low as 0.20) and the superplasticizer-binder ratio (from 0.73% to 2.95%). Test results are found to support the reviewed information on HSC production. Also the water-binder ratio and the suitable admixtures with their optimum dosages are found to be the most important parameters for producing HSC.

4. Amr S. El-Dieb; "Mechanical, durability and microstructural characteristics of ultra-high-strength self-compacting concrete incorporating steel fibers", Materials and design, Vol.30, pp.4286-4292, 2009.

Few researches were carried out in the Gulf area to study the feasibility of producing UHSC using available local materials with the inclusion of steel fibers, and investigate its properties and durability. Local available materials and the inclusion of steel fibers with different volume fractions are investigated to produce UHSC. Different mechanical properties are evaluated (compressive strength and splitting tensile strength). Durability of the concrete in high sulfate and high temperature condition (i.e. resembling Gulf environment) is evaluated. Also, chloride permeability, bulk chloride diffusion and electrical resistivity are evaluated. Test results indicate that local material can produce UHS–FRC. The ductility of the concrete is greatly improved by the incorporation of steel fibers and increases as the fiber volume increases. Chloride permeability, bulk chloride diffusion and electrical resistivity are affected by the volume fraction of steel fibers. The inclusion of steel fibers did not have significant effect on the durability of the concrete in the sulfate environment. Micro structural investigations of UHS–FRC concrete were also performed. The micro structural investigations shed some light on the nature of interfacial bond of fibers and the cement paste and its effect on its mechanical and fracture properties.

5. M. Elices; C.G. Rocco; "Effect of aggregate size on the fracture and mechanical properties of a simple concrete", Vol.75, pp. 3839–3851,2008.

This journal was regarded on the influence of the aggregate size on the fracture energy, tensile strength and elasticity modulus in different types of concrete are analyzed. For this purpose, nine simple cement-based composites have been designed, manufactured and tested, with one objective to provide experimental results that can be used as a benchmark for checking numerical models of concrete fracture, as this simple composite (a matrix, spherical aggregates of the same radius, and two types of matrix–aggregate interface) is amenable to modeling. All in all, 44 specimens were tested. From notched beam tests, values of the fracture energy and modulus of elasticity were obtained. The tensile stress was deduced from indirect standard tensile test. Data for bilinear softening functions extracted from the experimental measurements are also provided. Comparison with available experimental data is also included and discussed.

6. Jyotsna Devi; Dr. K. Srinivasa Rao; "A Study on the Flexural and Split Tensile Strengths of Steel Fibre Reinforced Concrete at High Temperatures", ISSN, Vol.4, pp.49–53, 2014.

This journal was regarded at investigating the performance of steel fiber reinforced concrete at high temperatures. It also aims at comparing the flexural and split tensile strengths of normal (M30) and high strength concrete (M60) when mixed with 1% volume fractions of steel fibers . To study flexural strengths prisms of size 100x100x500mm were casted and to study splitting tensile strength cylinders of 150mm diameter and 300mm length were casted. The samples are cured for 7, 28 and 91 days. After specified period of curing, the specimens were air dried and then exposed to 100, 200, 300, 400 and 500oC (apart from 27oC), for duration of one hour and then allowed to cool. The prisms are tested in Universal Testing machine for flexure and cylinders are tested for split in compression testing machine. The use of fibers in high strength concrete is of good advantage than using in normal strength concrete. By adding steel fibers fracture resistance of concrete can be increased. All the results and observations are presented in the paper.

7. R.Yu; P. Spiesz; H.J.H. Brouwers; "Mix design and properties assessment of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC)", Vol.56, p.p.29-39,2014.

This paper was presented the mix design and properties assessment of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC). The design of the concrete mixtures is based on the aim to achieve a densely compacted cementations matrix, employing the modified Andresen & Andersen particle packing model. One simple and efficient method for producing the UHPFRC is utilized in this study. The workability, air content, porosity, flexural and compressive strengths of the designed UHPFRC are measured and analyzed. The results show that by utilizing the improved packing model, it is possible to design UHPFRC with a relatively low binder amount. Additionally, the cement hydration degree of UHPFRC is calculated. The results show that, after 28 day of curing, there is still a large amount of anhydrate cement in the UHPFRC matrix, which could be further replaced by fillers to improve the workability and cost efficiency of UHPFRC.

8. Adel A. Al-Azzawi, Ahmed Sultan Ali and Husam K. Risan; "Behavior of ultra high performance concrete structures", ARPN Journal of Engineering and Applied Sciences , Vol.6, ISSN 1819-6608, 2011.

A study has been made through this investigation to understand the behavior of UHPC members with steel fibers by using two approaches: experimental investigation of concrete mixes and simulation of the problem studied by other researchers using finite elements. Experimental investigation is carried out to obtain the mechanical properties for two types of UHPC mixes, namely, the type of pozzolanic admixture (Silica Fume and High Reactivity Metakaolin) in addition to use three different values of steel fibers volume fraction (1%, 1.5% and 2%). The finite element method through the ANSYS computer program is used. The eight node brick element is used to model the UHPC beams with embedded steel fibers. The stress-strain curve in compression for the UHPC with steel fibers is simulated by a nonlinear elasto-plastic model which is terminated at the onset the crushing. In tension, a smeared crack model with fix orthogonal cracks has been used. The experimental data obtained from other researchers is compared with the finite element solution and good agreement between the results is obtained. Parametric studies are carried out to investigate the effects of type of pozzolanic admixture, volume fraction of steel fibers and other solution parameters. Higher values of compressive strength have been achieved using UHPC mixes with Silica Fume in comparison with UHPC mix with High Reactivity Metakaolin.

9. Prabhat Ranjan Prem; B.H.Bharathkumar; Nagesh R Iyer; "Mechanical Properties of Ultra High Performance Concrete", Vol. 6, p.p.8-23, 2012.

A research program was conducted to evaluate the mechanical properties of Ultra High Performance Concrete, target compressive strength at the age of 28 days being more than 150 MPa. The methodology to develop such mix has been explained. The material properties, mix design and curing regime were determined. The material attributes were understood by studying the stress strain behavior of UHPC cylinders under uniaxial compressive loading. The load –crack mouth opening displacement (cmod) of UHPC beams, flexural strength and fracture energy was evaluated using third point loading test. Compressive strength and Split tensile strength results were determined to find out the compressive and tensile behavior. Residual strength parameters were presented vividly explaining the flexural performance, toughness of concrete. Durability studies were also done to compare the effect of fiber to that of a control mix For all the studies the Mechanical properties were evaluated by varying the percentage and aspect ratio of steel fibers. The results reflected that higher aspect ratio and fiber volume produced drastic changes in the cube strength, cylinder strength, post peak response, load-cmod, fracture energy flexural strength, split tensile strength, residual strength and durability. In regards to null application of UHPC in India, an initiative is undertaken to comprehend the mechanical behavior of UHPC, which will be vital for longer run in commercialization for structural applications.

10. M.Yaqub; Imran Bukhari; "Development of mix design for high strength concrete", Our world in concrete & structures, 16 - 17 August 2006.

This paper was determined the result of mix design developed for high strength concrete. Development of mix design method plays a key not in concrete technology. It involves the process of determining experimentally the most suitable concrete mixes in order to achieve maximum strength with at least economic expenditures. In this research work the locally available constituents of concrete were selected for the purpose of determining their relative quantities and proportions for best results. As the trend of high strength increase in all over the world it is strong need to investigate the factor enhancing the compressive strength of concrete at least economical expenditure. To make economical use of high strength concrete in Pakistan a mix design for high strength concrete was developed. In this research work four mix were selected to achieve a compressive strength up to 162 Mpa. The variables were aggregate sizes and mix ratio. Four mix ratios by weight were selected with 0.3 water cement ratio. Ultra727 super plasticizer was used to improve the workability of concrete mix. Locally available coarse and fine aggregates were used with ordinary Portland cement. It was concluded that the compressive strength depends on mix ratio, size and texture of aggregates and method of compaction. It is further concluded that 1:0.75:1.5 showed higher strength than other three mix ratios.

III. MATERIAL USED AND OTHER PROPERTIES

3.1 Cement

- Specific gravity of cement is 3.15
- Fineness of cement is 4%
- Consistency of cement is 30%
- Initial setting time of cement is 35%

3.2 Silica-fume

- Specific gravity of silica fume is 1.3

3.3 River-sand

- Specific gravity of fine aggregate is 2.71
- Fineness of fine aggregate is 3.37
- Loose bulk density is 1520 kg/m^3
- Rodded bulk density is 1632 kg/m^3

3.4 Coarse-aggregate

- Specific gravity of coarse aggregate is 3.10
- 12mm Coarse aggregate loose bulk density is 1323kg/m^3
- 12mm Coarse aggregate rodden bulk density is 1538kg/m^3
- 6mm Coarse aggregate loose bulk density is 1300kg/m^3
- 6mm Coarse aggregate rodden bulk density is 1600kg/m^3
- Crushing value of coarse aggregate is 27%
- 12mm fineness coarse aggregate is 4.72
- 6mm fineness of coarse aggregate is 3.41
- 12mm coarse aggregate % of water absorption is 2%
- 6mm coarse aggregate % of water absorption is 2%

IV. METHODOLOGY

3.1 Mix Design

3.1.1 Indian Standard Method of Mix Design

The design of concrete mix will be based on the following factors, using physical properties of materials.

(a) Grade of concrete: This gives the characteristic strength requirements of concrete. Depending upon the level of quality control available at the site, the concrete mix has to be designed for a target mean strength which is higher than the characteristic strength.

(b) Type of cement: The type of cement is important mainly through its influence on the rate of development of compressive strength of concrete as well as durability under aggressive environments ordinary Portland cement (OPC) and Portland Pozzolona cement (PPC) are permitted to use in reinforced concrete construction.

(c) Maximum nominal size of aggregate: It is found that larger the size of aggregate, smaller is the cement requirement for a particular water cement ratio. Aggregates having a maximum nominal size of 20mm or smaller are generally considered satisfactory.

(d) Minimum water cement ratio: The minimum w/c ratio for a specified strength depends on the type of cement.

(e) Workability: The workability of concrete for satisfactory placing and compaction is related to the size and shape of the section to be concreted.

3.1.2 Mix Design for M30 Concrete by IS Method

Characteristic compressive strength for M30 grade is 30N/mm^2

Target Strength for Mix Proportion:

$f'_{ck} = f_{ck} + 1.65s$

$= 30 + 1.65 \times 6$

$= 39.9$ N/mm2

Selection of Water Content:

Max water content for 20mm aggregate = 186 litres
From table 2

= 186+ 0.6/100*186
= 187.116 lit

Calculation of Cement Content:

w/c ratio = 0.43
Cement ratio = 187.116/0.43
= 432.55 kg/m^3

Table 5; minimum cement content for several exposure condition =320kg/m3
432.55 > 320 kg/m^3
Hence ok.

Determination of Fine Aggregate:

M-30 mix for fine aggregate

0.98 = [187.116+ (432.55/3.14) + (fa/0.31*2.64)*(1/1000)]
Fa = 536.55kg/m^3

Determination of Coarse Aggregate:

0.98 = [187.116+ (432.55/3.14)+ (Ca/(1-0.31)*2.64)*(1/1000)]
Ca = 1195.49kg/m^3

Mix:

Cement: Fine aggregate: Coarse aggregate: Water
1: 1.24: 2.76:0.43

Quantity per m^3

Cement	=	432.55 kg/m^3
FA	=	536.55 kg/m^3
CA	=	1195.49 kg/m^3
W/c ratio	=	187.12 litter

3.2 Mix Proportion

Materials	Mix - 1	Mix - 2	Mix - 3
	% of material added in concrete	**% of material added in concrete**	**% of material added in concrete**
Cement(kg/m^3)	100	100	100
Fine aggregate((kg/m^3)	100	100	100
Coarse Aggregate (kg/m^3) use dry coarse aggregate two size separately for each mix (6mm,12mm) and saturated coarse aggregate two size separately for each mix (6mm,12mm)	100	100	100
Silica fume add as a admixture (% taken from weight of cement)	0%	5%	10%
Super plasticizer	1%	1%	1%

4.2 Quantity of specimens for concrete test

Mix	Test	Number of specimens			
		Cube			Cylinder
		3 days	7 days	28 days	28 days
1	Compressive strength	3	3	3	-
	Split tensile strength	-	-	-	3
	Young's modulus of elasticity	-	-	-	1
	Flexural strength	-	-	-	-
2	Compressive strength	3	3	3	-
	Split tensile strength	-	-	-	3
	Young's modulus of elasticity	-	-	-	1
	Flexural strength	-	-	-	-
3	Compressive strength	3	3	3	-
	Split tensile strength	-	-	-	3
	Young's modulus of elasticity	-	-	-	1
	Flexural strength	-	-	-	-

V. TEST FOR CONCRETE

5.1 Test results for hardened concrete

5.1.1 Dry Coarse aggregate

5.1.1.1 6mm Coarse aggregate

S.NO	Mix Design	Compressive strength			Split-tensile strength	Young's modulus of elasticity
		3 days	7 days	28 days	28 days	28 days
1	MIX-I	23.96	45.17	69.17	4.76	33,211
2	MIX-II	30.15	49.02	76.82	5.01	37,111
3	MIX-III	32.17	55.51	82.17	5.67	39,482

5.1.1.2 12mm Coarse aggregate

S.NO	Mix Design	Compressive strength			Split-tensile strength	Young's modulus of elasticity
		3 days	7 days	28 days	28 days	28 days
1	MIX-I	18.966	34.008	58.86	3.981	31,321
2	MIX-II	22.236	38.586	65.4	4.280	33,230
3	MIX-III	24.198	41.856	70.632	4.814	34,429

5.1.2 Saturated Coarse aggregate

5.1.2.1 6mm Coarse aggregate

S.NO	Mix Design	Compressive strength			Split-tensile strength	Young's modulus of elasticity
		3 days	7 days	28 days	28 days	28 days
1	MIX-I	48.396	71.94	98.1	6.29	49,516
2	MIX-II	53.628	77.172	104.64	6.85	51,143
3	MIX-III	57.552	83.712	116.412	7.22	53,945

5.1.2.2 12mm Coarse aggregate

S.NO	Mix Design	Compressive strength			Split-tensile strength	Young's modulus of elasticity
		3 days	7 days	28 days	28 days	28 days
1	MIX-I	44.472	64.092	87.636	5.739	46,256
2	MIX-II	47.088	69.324	94.176	6.294	49,115
3	MIX-III	53.320	75.864	104.64	6.850	51,550

VI. RESULT AND DISCUSSION

The percentage of silica-fume increased. The strength of the concrete also increased. Compared to dry coarse aggregate saturated coarse aggregate given maximum strength in all the three mix. In this compared to 12mm coarse aggregate 6mm coarse aggregate given maximum strength in all the three mix. So in this project 6mm saturated coarse aggregate with adding 10% silica fume and 1% super-plasticizer given maximum compressive strength compared to all other mix proportion.

VII. CONCLUSION

Using 6mm saturated coarse aggregate with admixtures silica fume and super plasticizer given maximum compressive, young's modulus and tensile strength. So use this can able to provide high strength concrete in construction. By use this can able to prevent cracks. So it can able to increase the strength and durability of the concrete

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