Experimental Investigation on Ultra High Strength Concrete

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Abstract: **Concrete is one of the widely used construction material. However, its inherent poor tensile and flexural strengths make it prone to cracking and a gradual increase of brittleness with increase of compressive strength also brings numerous problems in its application. In developing countries, concrete is used in extent greater than that of the structural steel. And also maintenance and repair of concrete structure is a growing problem involving significant expenditure. In recent years cement based materials have been developed, with compressive strength greater than 200MPa; one such material is Ultra High Strength Concrete (UHSC). UHSC is a ductile material formulated by combining Portland cement, silica fume, quartz flour, fine silica, water reducing admixtures and steel or organic fibers with very low water cement ratio. Recent researches on UHSC revealed that it has high compressive strength and high tensile strength. Also large ductility continues to develop even after cracking in cooperation with fibers. The compressive strength ranging from 200 to 800MPa, flexural strength 30 to 50MPa and Young's modulus 50 to 60GPa have been achieved by using UHSC. The possibility of achieving high strength, durability, and improved ductility with the use of UHSC encourages researchers and engineers to use this modern material in many practical applications like nuclear waste containment structures, high rise structures, long span bridges, and walkways. Despite these potential, UHSC has not received wide attention in India. Its utility is nil in India, because of non availability of sufficient experimental data regarding the performance of UHSC. It is also still research stage which needs lot of experimental works. The basic objective of this research is to remove some of the barriers to the adoption of UHSC technology in India by developing a degree of experience with its production. Because the cement dosage of UHSC is generally as high as 800 to 1000 kg/m^3 to achieve ultra-high strength under very low w/c ratios, a high amount of cement not only affects the production costs, but also has negative effects on the environment due to the emission of carbon-di-oxide gas and heat of hydration which may cause shrinkage problems. Mineral admixtures can be a feasible solution to overcome these problems in UHSC. So an attempt has been made in this experimental work to produce UHSC using locally available sustainable materials like fly ash and rice husk ash to determine the effect of mineral admixtures on the mechanical properties of UHSC.**

Key Words**: Silica fume, Fly Ash, rice husk ash, Ultra High Strength Concrete**

I. INTRODUCTION

A. *Ultra high strength concrete*

UHSC was first developed by Bouygues in France in 1990s. Concrete having compressive strength more than 150 MPa is known is Ultra High Strength Concrete (UHSC). It is a high strength, ductile material formulated by combining portland cement, silica fume, quartz flour, fine silica sand, high-range water reducing admixture, steel or organic fibers and very low water-to-cementitious materials ratios. Absence of coarse aggregates is a key aspect for the microstructure and performance of UHSC. The steel fibers provide ductility to UHSC and in some cases can replace traditional mild steel reinforcement. This material differs from conventional concrete not only in terms of strength, but also in terms of durability. UHSC is more durable because the low water-to-cementitious materials ratio results in very low porosity. Due to the use of powder-like components and the fluidity, the material has the ability to replicate the macro and micro texture of the formwork. The possibility of achieving high strength, durability and improved ductility with the use of ultra high strength concrete encourages researchers and engineers to use this modern material in many practical applications like nuclear waste containment structures, high rise structures, long span bridges, and walkways.

B. *Principles of ultra high strength concrete*

1. Removal of coarse aggregate to enhance homogeneity of the concrete.
2. Use of silica fume for pozzolanic reaction.
3. Optimization of the granular mixture for enhancement of compacted density.
4. Application of presetting pressure for better compaction.
5. Post-setting heat treatment to enhance the mechanical properties of the microstructure.
6. Addition of steel fibers to achieve ductility.

The application of the first five principles produces a matrix with very high compressive strength, but with very low ductility than that of the conventional mortar. But the inclusion of fibers improves tensile strength, and also makes it possible to obtain the required level of ductility. The application of pressure and heat-curing are optional measures which are designed to enhance performance.

II. MATERIALS USED

The materials used for this research are Ordinary Portland cement of 53 Grade, Quartz Sand, Silica Fume, Crushed quartz powder, Steel fibers, Super Plasticizer, Fly ash (FA) and Rice husk ash (RHA).

A. Ordinary Portland cement

Ordinary Portland cement of 53 Grade is used. Portland cement is the most common type of cement which is widely used in construction industry. Calcium, silicon, iron, and aluminum constitute Portland cement. Generally use of high grade cements offer many advantages for making stronger concrete.

B. Quartz Sand

Quartz is the second most abundant mineral in the Earth's continental crust, after feldspar. Quartz sand of size less than 600μm is used for making UHSC. Quartz sand is used in UHSC for giving volume and strength to the concrete.

C. Silica Fume

Silica fume is a byproduct in production of silicon and ferrosilicon alloys. Silica fume has very fine particles, approximately 100 times smaller than the average cement particle, and has a large surface area. Advantages of using silica fume in a concrete mix include enhancing compressive strength, bond strength, and abrasion resistance while reducing permeability and thus improving resistance against the corrosion of reinforcement. Possessing very small particle size, silica fume fills the voids remaining between cement and quartz powder particles. Silica fume of size less than 15μm is used.

D. Crushed quartz powder

Crushed crystalline quartz powder is an essential ingredient for heat-treated UHSC concretes. Maximum reactivity during heat-treating is obtained for a mean particle size of between 5 and 25μm. The mean particle size of the crushed quartz used for an UHSC is l0μm, and is therefore in the same granular class as the cement. Since quartz powder is a reactive material it acts as an excellent paste-aggregate interface.

E. Steel fibers

Steel fibers of size 0.4 mm dia. and length 16 mm are used in UHSC to replace the reinforcement and to achieve the tensile strength and ductility needed. However, fiber reinforcement is not the only means of addressing the tensile strength and ductility issue. Since High strength cementitious materials are more brittle than conventional cement based materials. The brittleness of high strength cementitious materials can be reduced by using fibers. The use of fibers in relatively high volume fractions not only reduces the brittle nature of high strength cementitious matrices, but also increases the maximum matrix strength.

F. Super Plasticizer

In order to obtain higher strength, the amount of water is decreased in RPC. Consequently, workability is reduced. To improve the workability of fresh UHSC concrete, high range water reducing poly carboxylate based super plasticizer is added to the mixture.

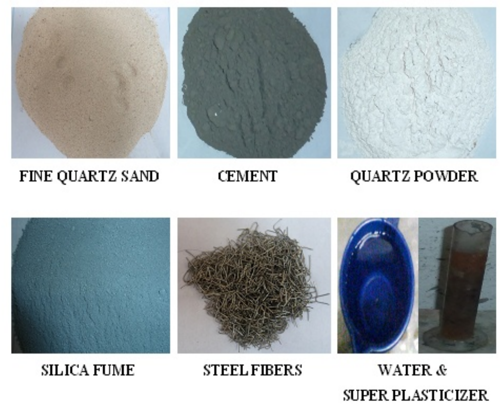

Fig.1 Materials Used

G. Fly ash (FA)

FA is a waste material obtained by firing coal from Thermal station at Tuticorin. Class F Fly ash is used for making UHSC.

Fig.2 Fly Ash

H. Rice husk ash (RHA)

RHA is an agricultural waste and it is obtained after complete combustion of the husk under controlled conditions contains 90-96% silica in amorphous forms. The average particle size of RHA ranges in general from 5 to 10μm, which is much larger than that of silica fume.

Fig.3 Rice Husk Ash

III. EXPERIMENTAL INVESTIGATION

The properties of the materials, Mix design, Preparation of specimens and the test procedures are discussed here.

A. Materials properties

The material properties are shown in Tables 1 and 2

Table 1. Physical Properties of Constituent Materials

S.No	Materials	Specific Gravity
1.	Cement	3.00
2.	Fly Ash	2.03
3.	Rice Husk Ash	2.00
4.	Silica Fume	2.24
5.	Quartz Sand	2.21

Table 2. Chemical Composition of Constituent Materials

Chemicals	Chemical Composition (%)			
	Cement	Silica Fume	Fly Ash	Rice Husk Ash
SiO_2	20.10	92.26	65.43	20.83
Al_2O_3	5.62	0.89	20.67	2.8
Fe_2O_3	2.17	1.97	6.18	4.4
CaO	62.92	0.49	1.26	62.91
MgO	1.14	0.96	0.82	4.5
Na_2O	0.30	0.42	-	-
SO_3	2.92	0.33	-	2.9

B. Mix Proportion

There is no well defined mixture design procedure for UHSCs due to the significant influence of physical and chemical properties of available materials and the mixture processing, compacting and curing methodologies on the properties of the product. Therefore, the various mixture proportions reported in the available literature were examined and four mixtures were selected as a primary basis for further modifications by trial and error.

C. Reference Mixtures

Table 3. Reference Mixture

Composition, kg/m^3	**Mix Compositions**			
	Mix A	**Mix B**	**Mix C**	**Mix D**
Cement	994.81	1040	718.39	865.05
Silica-fume	250.63	310	179.59	198.96
Quartz flour	99.53	--	222.70	337.37
Quartz sand	1055	800	1116.66	951.55
Water, l/m^3	190.01	240	179.60	147.06
Sp, l/m^3	17.33	13.5	26.93	20.21
w/c ratio	0.21	0.23	0.25	0.17
Reference	Dugat et al	Reda et al	Dili et al	Richard et al

D. Trial Mix Proportion Result

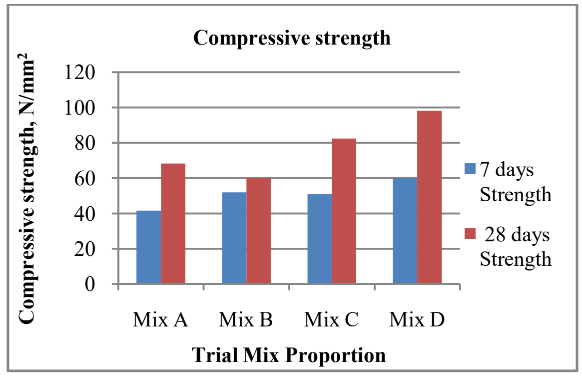

Fig.4 Trial mix Proportion result

From the test results, Mix proportion given by Richard et al (1995) has gained more strength than other.

Mix Proportion by replacing cement using Mineral admixtures fly ash (F) and Rice husk ash (R)

Table 4 % Replacement of cement with Fly ash and Rice Husk Ash

% Replacement	Mix Proportion Combination
No cement Replacement	F0R0
10% cement Replacement	F10R0
	F0R10
20% cement Replacement	F20R0
	F0R20
	F10R10

E. Specimen Preparation

The mixtures are combined in a high-speed mixer (470 rpm) and compacted by using table vibration. Dry powders and aggregates are mixed at low speed for about 1 min. After the water addition, the concrete is mixed at low and high speeds for about 2 min. Super Plasticizer is added to premixed material and mixed at high speed for about 5 min. Finally, steel fibers are added and mixed at high speed for about 2 min. The fresh concrete is then cast into the cube and cylinder moulds.

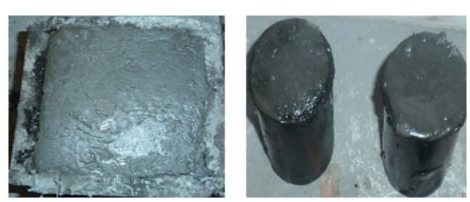

Fig. 5 Casted concrete cubes & cylinders

F. Curing

Concrete specimens are moist cured in two different conditions

- Standard curing: Curing at room temperature always at 20°C for 28 days
- Hot air oven curing: Curing at 100°C for 24 hours after a preliminary curing at 20°C for 24 hours

IV. RESULTS AND DISCUSSION

A. Compressive strength

For each mix of UHSC concrete, 12 numbers of cube specimens are prepared. These cubes are tested for its compressive strength at 7 days & 28 days standard & steam curing. The average 7 and 28 days compressive strength test results are presented in Figure 6.

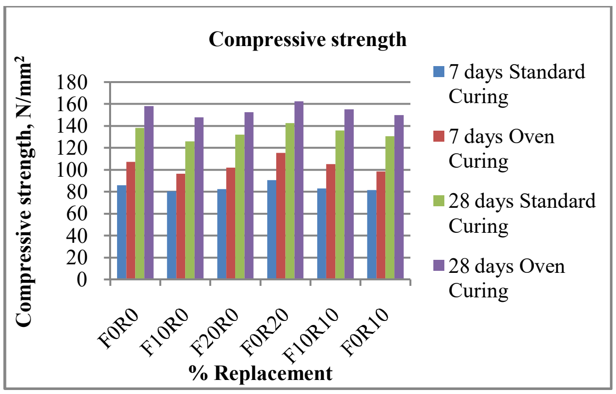

Fig.6 Compressive strength test results

B. Split Tensile Strength

For each mix of UHSC concrete, 12 numbers of cylinder specimens are prepared. These cylinders are tested for tensile strength at 7 days & 28 days standard & steam curing. The average 7 and 28 days tensile strength test results are plotted in Figure 7.

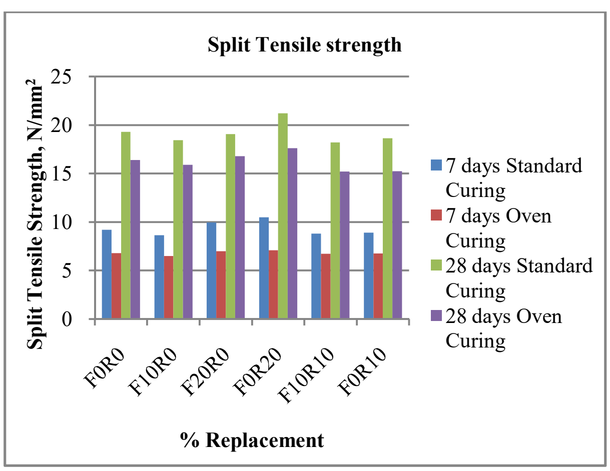

Fig.7 Split Tensile strength test results

V. CONCLUSION

The following are the major conclusions that are drawn from our experimental study

- Test results showed that UHSC containing mineral admixtures have satisfactory mechanical performance.
- Although the cement content of these mixtures importantly lowers than conventional UHSC, compressive strength exceeded 143MPa (F0R20) after standard water curing.
- Hot air oven curing seems very effective ways to increase the compressive strength of UHSC. This can be attributed to the improvement of hydration process under these curing regimes. In this case compressive strength is over 162MPa (F0R20) after oven curing.
- On the other hand, hot air oven curing caused slight reduction in Tensile strength compared to the 28-day standard curing. This is probably due to the decreasing bond strength between matrix and fibers.
- Incorporating steel fibers is essential in changing the brittle failure mode of UHSC into a more ductile one.
- Mechanical properties are improved by the incorporation of steel fibers in UHSC especially splitting tensile strength.
- RHA is an effective pozzolan, even at lower water-binder ratios as the addition of RHA into matrices maintained or increased compressive strength.
- Furthermore, these mixtures have also important environmental benefits. Decreasing cement content reduces heat of hydration and shrinkage which are normally important problems for conventional UHSC.
- Nowadays, the environmental pollution is one of the most important world wide issues. FA and RHA is a promising material because of its widespread availability, its effectiveness as a pozzolanic material, and its potential for creating more environmentally sustainable building materials.
- The results show that RHA and FA can be suitable for use as a supplementary cementitious material to produce UHSC.
- The combination of RHA and FA can improve the properties of UHSC. The total cement replacement percentage by this blend can reach up to 20%.

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