BEHAVIOUR OF MECHANICAL PROPERTIES OF ULTRA-HIGH PERFORMANCE CONCRETE WITH STEEL FIBRES AND MINERAL ADMIXTURES

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Abstract

The present experimental work is taken to study the strength properties of UHP-FRC. The locally available materials are used for making UHPC with steel fibers from manufacturer and low water binder ratio is adopted with hyper-plasticizer as admixture. The effect of presence of coarse aggregates on strength of UHPFRC is evaluated in comparison with UHPFRC without coarse aggregates. The present work also studies the effect of using mineral admixtures namely GGBS – Ground Granulated Blast Furnace Slag and Silica fumes replacing the cement by weight. The fine aggregate content of the mix is replaced with Manufactured Sand (M-Sand) and Quartz sand. The steel fibers are used in both the mixes that are mix with without coarse aggregates. The strength characteristics of the mixes are studied, adopting particle packing density approach. The characteristic of the materials determined using the standard procedure as per relevant codes of practice. The design mix is arrived by taking a reference mix from the literature, revalidating its properties and modifying the mix suitably. The workability of mixes is evaluated as per EFNARC 2005. The compressive strength, flexural strength and spilt tensile strength of UHFRC with and without coarse aggregates are assessed.

Keywords *— Steel Fibers, Rheology of UHPC, High Strength, Mineral Admixtures*

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1. INTRODUCTION

Concrete is the premier construction material around the world and most widely used in all types of civil engineering works and it is a man made product, essentially consisting of cement, aggregates, water and admixtures.Concrete is the most popular and most economical construction material. The concrete technology has evolved significantly in recent years resulting in the development of Self Compacting Concrete, Fibre Reinforced Concrete, Geopolymer Concrete, Light weight concrete and so on. The main criteria for concrete to be used as a main construction material are strength characteristics, durability parameters and most importantly the performance of concrete. The rapid growth in construction industry is resulted in demand for new materials which satisfy the requirements of strength, durability and performance. The structures should be constructed at the faster rate, reducing self weight and making them earthquake resistant. The result is material like Ultra High Performance Concrete. Ultra High Performance Concrete – UHPC is the concrete, which is manufactured with low water cement ratio, which results in high strength. The materials of design mix are so proportioned that, there will be higher reduction in the porosity which not only enhances strength, but also increases durability by reducing permeability fluids. The materials used include cement, mineral admixtures like GGBS, Silica Fume and metakaolin, fine aggregates – Manufactured Sand and Quartz sand, coarse aggregates, super plasticizers and water.

2. MATERIALS AND PROPERTIES

2.1 Cement

The ordinary Portland cement 53 Grade with specific gravity of 3.15 is used.

2.2 Sand

The locally available M-sand having specific gravity of 2.65 conforming IS 383-1987 is used for this study.

2.3 Micro Silica Fume (MSF)

It is a byproduct of producing silicon metal or ferrosilicon alloys. Micro silica consists primarily of amorphous (crystalline) silicon dioxide (SiO_2). They have stable SiO_2 content and high Pozzolanic Strength Activity. According to SiO_2 content, Micro silica range from 90% to 97%.

2.4 Metakaolin

It is the most abundant natural minerals which is produced by heat- treating kaolin. Kaolin is a fine, the term kaolin is derived from metakaolin which is typically contains 50-55% SiO_2 and 40-45% of AL_2O_3. Metakaolin particles are generally one half to five microns in diameter, larger than silica fume particles, it is of white color.

2.5 Steel Fibers

A hooked end steel fiber length of 30mm and 0.2mm diameter and an aspect ratio of 60 were used throughout the experimental work study.

2.6 Super Plasticizer

It is a P C based new generation Hyper Plasticizer specially designed for Self Compacting Concrete. It is Suitable for precast concrete industry and high performance concrete production. There is a water reduction up to 40% at low dosages.

2.7 Quartz

The quartz sand was used from locally available source. The sizes of quartz are 60 meshes (250 microns), 100 meshes (150 microns), 200 meshes (75 microns).

2.8 Water

Ordinary tap water is used for mixing and curing all the concrete specimens considered in this work.

The method used to produce mix proportion was done under particle packing density approach and achieving required quantity of weight of materials used in mix.

Table-1 Properties of Fine Aggregate (M-Sand), Coarse Aggregate, Quartz sand

Properties (M-sand)	Results
Specific gravity	2.65
Water absorption	3.5%
Loose Bulk Density	1356.16 kg/m^3
Rodded Bulk Density	1469.36 kg/m^3
Properties (Coarse Aggregate)	Results
Specific gravity	2.7
Water absorption	1.98 %
Loose Bulk Density	1443.4kg/m^3
Rodded Bulk Density	1563.3 kg/m^3
Properties (Quartz Sand)	Results
Specific gravity	2.66
Chemical Composition	Percentage
SiO_2	99.24
Fe_2O_3	0.04
Al_2O_3	0.27
CaO	0.39
Loss on Ignition	0.06
Physical Properties - Quartz sand	Results
Specific gravity	2.66

3. MIX DESIGN

The Particle Packing Density Approach is fairly a new concept for finding the proportion of mix required for experimental work. There is not a single method available as per standard code for designing the UHP-FRC mixes. Hence, for this experimental study, reference Design mix from author R. Yu, P. Spiesz, H.J.H. Brouwers, 2014, from paper titled "Mix design and properties assessment of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC)" is taken and validated twice. The design mix is modified suitably to use as design mix for present experimental work, freezing the final mix with numerous trials. The details of Design mix are provided as normalized values in terms of percentage of cement.

The comparison of standard concrete and well packed UHPC has been described in Fig. 4.6 to demonstrate that proper gradation and distribution of particle of different sizes size will make homogenious concret with minimum voids in the concrete. The floowing figure shows the concrete mass with fibers and admixtures, to fill the voidsbetween the agrregates with minimized cement paste with an objective of preventing corrotion of fibers and rducing pores to make dense concrete.

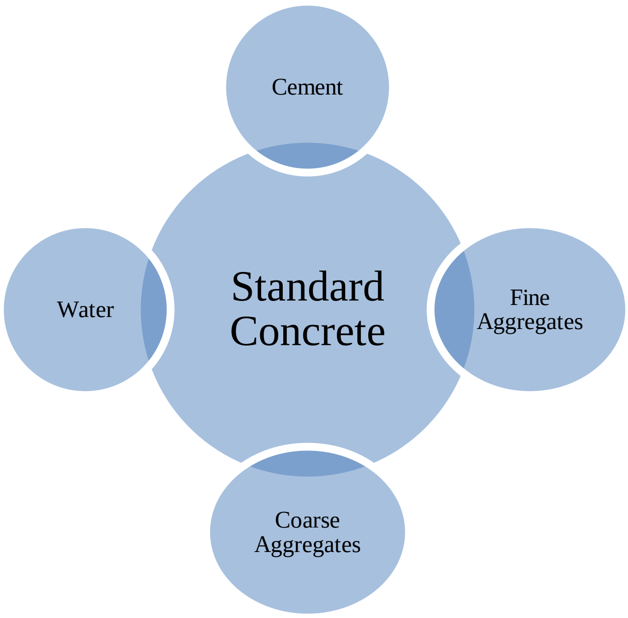

Fig. 1 Concept of Standard Concrete

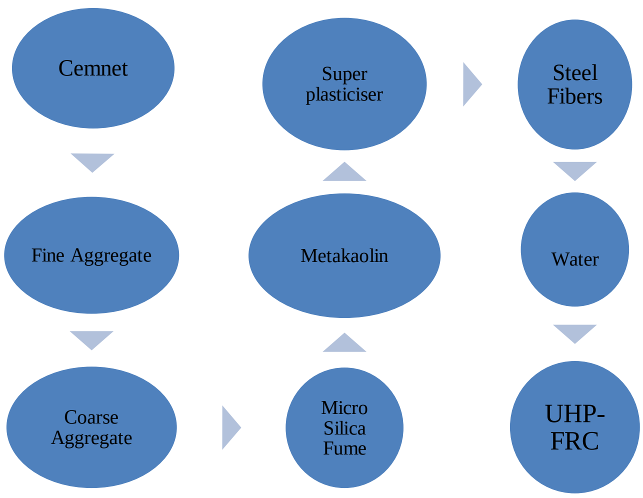

Fig. 2 Concept of UHPFRC

The Gradation of Fine agrregate is carried out to achive the S curve by selecting the percentages of materials mentioned below for the mix design it is illustrated with paticle Size Distribution curve in Fig.4.10.

Above 3mm size- 20 %
Above 600 microns - 30%
Above 150 microns - 40%
Below 150 microns - 10%
After Garadation the graph achieved has been noticed and plotted below,

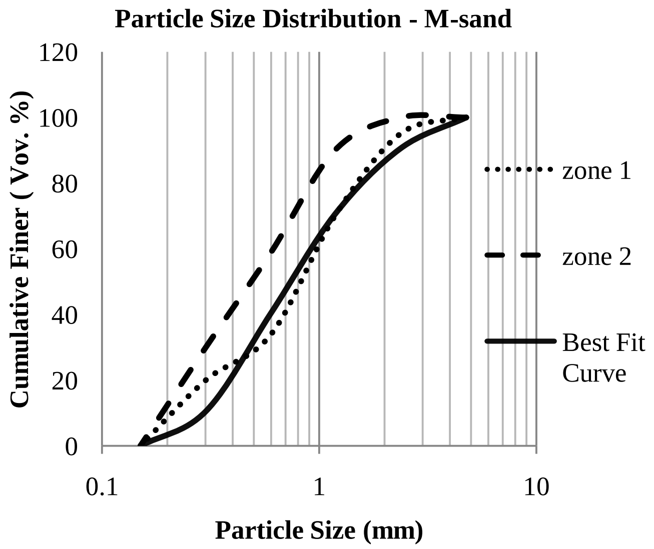

Fig. 3 Concept of Standard Concrete

Table- 2 Mix Proportion Details for UHP-FRC-Mix1

Materials	kg/m³	% by Weight	W/C Ratio
Cement	700	1	0.30, 0.28, 0.26, 0.24, 0.22
Micro Silica Fume	70	0.1	
High Reactivity Metakaolin	35	0.05	
M-Sand	1200	1.72	
Coarse Aggregate	-	-	
Quartz Sand	225	0.32	
Steel Fibers	4.025	0.00575	

Table- 3 Mix Proportion Details for UHP-FRC-Mix2

Materials	Kg/m³	% by Weight	W/c Ratio
Cement	650	1	0.30, 0.28, 0.26, 0.24, 0.22
Micro Silica Fume	65	0.1	
High Reactivity Metakaolin	32.5	0.05	
M-Sand	1200	1.72	
Coarse Aggregate	-	-	
Quartz Sand	225	0.32	
Steel Fibers	4.025	0.0062	

4. ASSESSMENT OF BEHAVIOUR OF UHPC

Fresh properties test are conducted on UHPC to satisfy the standards of EFNARC 2005. The properties are,

1. Slump Flow-Test
2. L-Box-Test
3. V-Funnel Test
4. U-Box-Test
5. J-Ring-Test

UHP-FRC 1

Table- 4 Final Results of Trials for Different W/C Ratio -UHP-FRC 1

Trial No	W/C Ratio	Slump Flow		J-Ring	L- Box	V- funnel		U box
		Horizontal (mm)	T_{50} cm (sec)	T_{50}cm (sec)	Blocking ratio (H_2/H_1)	(Tr) Flow (sec)	Flow at T_5 min (sec)	Diff in height (mm)
2	0.30	720	3	4	0.9	8	10	0.5
2	0.28	700	3	4	0.9	9	12	1
3	0.26	670	4	6	0.85	10	12	0.5
3	0.24	650	4	8	0.85	11	13	1
6	0.22	630	5	9	0.85	12	13	1
values		600-800mm	2-5 sec	<10 sec	0.8-1	6-12 sec	≤ Tr+3	Max 30 mm

UHP-FRC – Mix2

Table- 5 Final Results of Trials for Different W/C Ratio -UHP-FRC 2

Trial No	W/C Ratio	Slump Flow		J- Ring	L - Box	V- funnel		U- Box		
		Horizontal (mm)	T_{50} cm (sec)	T_{50} cm (sec)	Blocking ratio (H_2/H_1)	(Tr) Flow (sec)	F low at T_5 min (sec)	Left Limb (cm)	Right Limb (cm)	Diff in Ht (mm)
2	0.30	750	3	5	0.85	11	12	30.5	30	0.5
3	0.28	710	4	5	0.85	11	13	35	34	0
3	0.26	690	4	6	0.9	10	13	30	30	1
3	0.24	670	5	8	0.85	9	11	31	30	0
4	0.22	620	5	8	0.85	10	13	30	30	0
values		600-800 mm	2-5 Sec	< 10 Sec	0.8-1	6-12 sec	≤ Tr+3			Max 30 mm

5. RESULTS

The experimental work is carried out on UHPC mixes with cementitious contents of 700 kg/m^{3}and 650 kg/m^3. The two mixes without coarse aggregates are used with 5 different water binder ratios to make 10 mixes of UHPC. The study is carried out on 240 Cubes of 100x100x100mm for compressive strength and 60 Cylinders of diameter 100mm and height 200mm for Split Tensile Strength Test and 60. The volume fraction of 0.5% hooked end steel fibers is used in all the mixes. The results are recorded tabulated below under each properties of test and graphs have been plotted.

5.1 Compressive Strength Results

Table-6 Result of Compression Test –UHP-FRC 1

The Compressive Strength of Mix UHP-FRC 1 for Different Curing Periods (MPa)					
Mix without Coarse aggregates with Cementitious Content of 650 kg/m^3					
W/C Ratio	1Days	3Days	7Days	28 Day	56 Days
0.30	28.4	40.6	50.5	75.5	77.89
0.28	26.9	43.6	59.7	78.3	82.5
0.26	24.9	48.6	62.3	83.5	87.11
0.24	21.4	55.6	68.4	89.7	92.5
0.22	17.4	59.6	73.5	100.3	103

Table-7 Result of Compression Test -UHP- FRC 2

Results of Compressive Strength Test UHP-FRC 2 - Compressive Strength in MPa UHPC Mixes (with Coarse Aggregates) with 650kg/m^3 of Cementitious Content					
W/C Ratio	1.Days	3.Days	7.Days	28.Days	56.Days
0.30	27.6	39.5	54.5	79.3	81
0.28	26.7	42.6	58.6	81.2	83.1
0.26	22.9	45.6	60.7	83.5	85.5
0.24	20.7	50.3	65.3	89.27	92.6
0.22	15.4	54.6	69.5	93.5	97

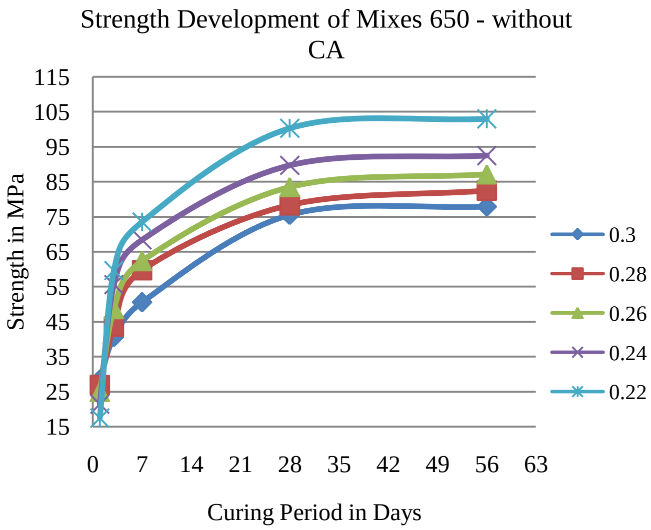

Fig. 4 Compressive Strength of UHPC Mixes with CA at Different Curing Periods

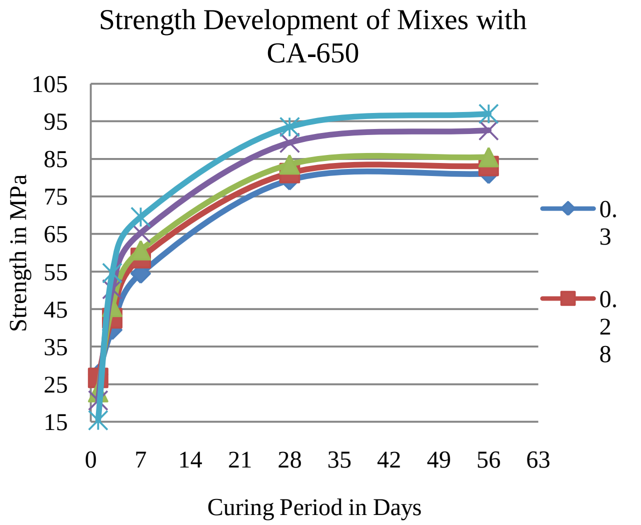

Fig. 5 Strength Development of UHPC Mixes without CA at Different Curing Periods

5.2 Split Tensile Test

Table – 8 Results of Test – Split Tensile Strength-UHP-FRC 1(Mix1)

UHP-FRC 1 - Split Tensile Strength in MPa		Cement: 700 kg/m^3 without Coarse Aggregates
W/C Ratio	7 Days	28 Days
0.30	2.6	3.57
0.28	3.2	4.3
0.26	3.8	4.6
0.24	4.1	5.67
0.22	4.6	6.8

Table – 9 Results of Test – Split Tensile Strength-UHP-FRC 2(Mix2)

UHP-FRC 2 - Split Tensile Strength in MPa		Cement: 650 kg/m^3 with Coarse Aggregates
W/C Ratio	7 Days	28 Days
0.30	2.4	3.7
0.28	2.7	4.5
0.26	3.6	5.4
0.24	4.8	5.8
0.22	5.0	6.1

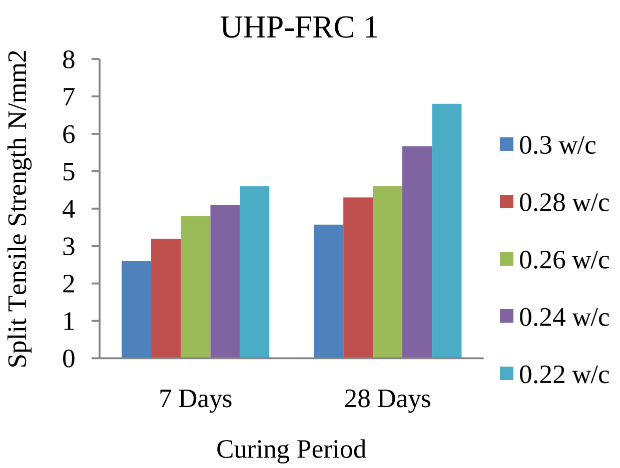

Fig. 6 Split Tensile Strength vs. Curing Period for Mix 1

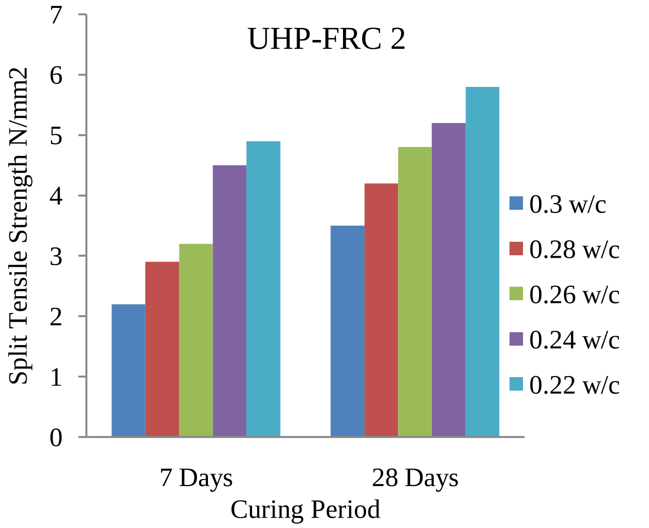

Fig. 7 Split Tensile Strength vs. Curing Period for Mix 2

5.3 Flexural Strength Test

Table 6.11 Results-of-Flexural-Strength-Test --UHP- FRC 1-Mix1

UHP-FRC 1- Flexural Strength in MPa		Cement: 700 kg/m3 without Coarse Aggregates
W/C Ratio	7 Days	28 Days
0.30	1.9	4.3
0.28	2.3	4.5
0.26	3.1	5.4
0.24	4.8	6.2
0.22	5.6	8.5

Table 6.12-Flexural-Strength Test Results-UHP- FRC 2-Mix2

UHP-FRC 2 - Flexural Strength in MPa		Cement: 700 kg/m^3 with Coarse Aggregates
W/C Ratio	7 Days	28 Days
0.30	2.1	4.0
0.28	2.5	4.2
0.26	3.6	5.5
0.24	4.8	5.8
0.22	5.7	7.1

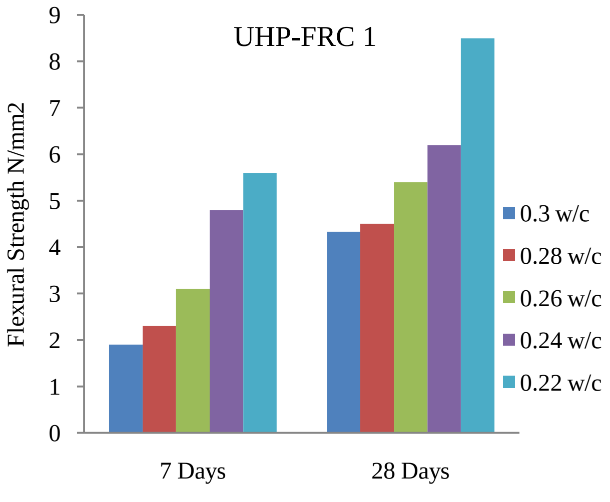

Fig. 8 Flexural Strength of UHPC Mixes at Curing Period of 7 & and 28 days- Mix 1

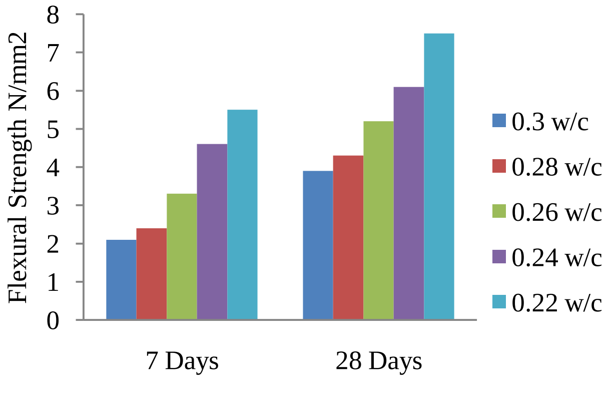

Fig. 9 Comparison of Flexural Strength of Mix 2 at Different Curing Period

6. CONCLUSION

a. The Rheology of mixes measured in using tests on Slump, L-Box, V-Funnel Test and U Box can be achieved by varying the admixture.
b. The mixes without coarse aggregates show better behaviour in fresh state than that with coarse aggregates.
c. It is concluded from the above discussion that the w/c ratio 0.22 has achieved compressive strength of 118.5 Mpa at 28 days test.
d. The addition of steel fibers content improves the compressive strength, split tensile strength and flexural strength at the age of 28 days. It can be recommended to use of steel fibers in to the concrete material to UHPC.
e. Hence by conducting proper gradation of aggregates and with careful design and mixing further strength can be achieved more than 150 Mpa.
f. By adding more volume fraction of steel fibers in UHPC mechanical properties can be achieved more than 30 % of what we have achieved in this study.
g. Hence UHPC using locally available materials can be used in order to manufacture ultra performance concrete in economical manner.

REFERENCES

[1] Adel A. Al-Azzawi, Ahmed Sultan Ali and Husam K Risan, Behavior of Ultra High Performance Concrete Structures: ARPN Journal of Enginnering and Applied Science, Vol 6, No 5, May 2011, ISSN 1819-6608.

[2] Asma K C, Meera C M, Preetha Prabhakaran, Effect of Mineral Admixtures on Durability Properties of High Performance Concrete: International Journal of Engineering Research and Applications (IJERA), pp-33-37, ISSN: 2249-6645, (TRACE-24TH -25TH January 2014).

[3] B B Patil, P D Kumbhar, Strength and Durability Properties of High Performance Concrete Incorporating High Reactivity Metakaolin: International Journal of Modern Engineering Research (IJMER), Vol 2, Issue 3, May- June 2012 pp- 1099-1104, ISSN: 2249-6645.

[4] Doo-Yeol Yoo a, Su-Tae Kang b , Young-Soo Yoon c, Enhancing the flexural performance of ultra-high-performance concrete using long steel fibers, Composite Structures 147 (2016) 220–230, Science Direct,17 March 2016.

[5] Dr. S Sundararaman, S Azhagarsamy; Performance of Ultra High Performance Concrete Containing Mineral Admixtures: SSRG International journal of Civil Engineering Vol: 2, Issue 10, October 2015.

[6] M. Al -Hassani, 2. W. I. Khalil, 3. L. S. Danha, Acta Tehnica Corviniensis, Mechanical Properties of Reactive Powder Concrete with Various Steel Fiber and Silica Fume Contents: – Bulletin of Engineering, Tome VII [2014], Fascicule 1 [January – March] ISSN: 2067 – 3809.

[7] Jianxin Ma, Marko Orgass, Comparative Investigations on Ultra-High Performance Concrete with and without Coarse Aggregates: Kassel, Germany September 2004.

[8] M. Dayanand1 , K.Rajasekhar, A Study Of High Strength Fibre Reinforced Concrete By Partial Replacement Of Cement With Silica Fume And Metakaolin: International Journal of Advanced Technology in Engineering and Science www.ijates.com Volume No.03, Issue No. 05, May 2015 ISSN (online): 2348 – 7550.

[9] Nagesh N Meleka, Alaa A Bashandy, Mohamed A Arab, Ultra High Strength Concrete Using Economical Materials: International Journal Of Current Engineering And Technology (IJCET) , ISSN 2277-4106,Volume 3, No 2, June 2013.

[10] Narasimha Raj, Suresh G Patil and B. Bhattacharjee, Concrete Mix Design By Packing Density Method: IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 2 Ver. I (Mar- Apr. 2014), PP 34-46.

[11] Prabhat Rajan Prem, B H Bharatkumar, Nagesh R Iyer, Mechanical Properties of Ultra High Performance Concrete: International journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol: 6, No 8, 2012.

[12] R R Yu, P Spiesz, H J H Brouwers, Mix design and properties assessment of Ultra High Performance Fiber Reinforced Concrete: Cement and Concrete Research, 56(2014) 29-39.

[13] R. Yu ⇑ , P. Tang, P. Spiesz, H.J.H. Brouwers**,** A study of multiple effects of nano-silica and hybrid fibres on the properties of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) incorporating waste bottom ash (WBA), Construction and Building Materials 60 (2014) 98–110, 17 February 2014.

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