EXPERIMENTAL INVESTIGATION OF UHPC USING ACID AND CHLORIDE PONDING TESTS

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Abstract

This paper presents the development of Ultra High Performance Fibre reinforced Concrete (UHPFRC) using mineral admixtures. UHPFRC mixture proportions were developed using local materials such as Micro silica and Metakaolin. The Ultra-High Performance Concrete (UHPC) used in this study is steel fibre reinforced concrete consisting of an optimized gradation of both fine and coarse agg along with different water/cement ratios. Experimental investigation was carried out for two different UHPFRC mixes Mix1 (without CA) and Mix2 (with CA) with different water cement ratio of 0.3, 0.28, 0.26 and 0.24 respectively. Both the UHPFRC mix had same values of steel fibre in terms of volume fraction (0.5%). It was found that Mix 1 with W/C ratio 0.24 has more compressive strength when compared to Mix 2 W/C ratio 0.24 and other W/C ratios.

Keywords *— Ultra-High Performance Concrete, Metakaolin, Micro silica, steel fibres, ACID Test, Chloride Ponding Test*

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1. INTRODUCTION

The term Ultra High Performance concrete is used to define a concrete having fibre reinforcement, superplasticizer, cementitious materials with very low w/c ratio characterized by the presence of Quartz sand instead of coarse aggregates for Mix1 and the other mix by using 12.5mm down size coarse aggregates along with Quartz sand for Mix2. The absence of coarse aggregates in Mix 1 is done mainly to obtain proper microstructure and the performance of Ultra high performance concrete in order to reduce the heterogeneity between the aggregates and the cement matrix. The work is carried out by using four different water to cement ratios of 0.24, 0.26, 0.28 and 0.3 for Mix1 (cement density 700kg/m3) and Mix2 (cement density 700kg/m3) including both fine aggregates and coarse aggregates in addition with mineral admixtures such as Micro Silica (10%) and Metakaolin (5%) and steel strands (0.5%). Different material tests are conducted on cement, M sand (FA), coarse aggregate to determine specific density, water absorption, etc. Workability tests such as slump test, L box, etc are conducted and durability test are also conducted such as RCPT, Sulphate attack test. The procedure for Mix design of UHPC is carried out by using particle packing density method since there are no proper mix design codes. The mix proportions arrived in this study is taken by referring from author H.J.H. Brouwers et.al, from Cement and Concrete Research journal published on November 2013.

2. MATERIALS

2.1 Cement

The Ordinary Portland cement of 53-grade was used in this study conforming to IS: 12269-1987.The specific gravity of cement is 3.15

2.2 Micro Silica

A white undensified Silica Fume (SF) with Blaine fineness about 200(m2/g) is a pozzolanic material which has a high content of amorphous silicon dioxide and consists of very fine spherical particles. It reacts with calcium hydroxide $Ca(OH)_2$, producing calcium silicate hydrate (secondary gel). It is added as partial replacement by weight of cement. The specific gravity of silica fume is 2.2

2.3 Metakaolin

It is the most foremost natural minerals that are made by heat-treating china clay. China clay could be a fine, the term china clay springs from metakaolin that is often contains 50-55 % SiO2 and 40-45% of AL_2O_3. Metakaolin particles are usually 1mm to 5 microns in diameter, bigger than micro Silica fume particles. In this study 5% of metakaolin is used as partial replacement of cement. Specific Gravity is found to be 2.56

2.4 Fine Aggregates

Manufactured sand is used as fine aggregate in this study conforming to the requirements of IS: 383-1970. Specific Gravity is found to be 2.65

2.5 Quartz Sand

The quartz sand was used from locally available source. Different sizes of Quartz sand such as 100mm mesh, 200mm mesh and 300mm mesh sizes are used in this study. Specific gravity of Quartz sand is 2.66

2.6 Coarse Aggregates

Coarse aggregate of 12.5mm down size is used conforming to the requirements of IS: 383-1970.The Specific Gravity is found to be 2.7

2.7 Water

Water used for the study was potable water conforming as per IS: 456-2000.

2.8Steel Fibers

The Fibers are used to increase tensile capacity and improve ductility. Hooked bar steel strands are used in this study having diameter of 0.2mm, length of 30mm and aspect ratio of 60.

2.9 Chemical Admixtures

Korean based M70 Dyn plasticizer is used. It is a PC based new generation Hyper Plasticizer specially designed for Self-Compacting Concrete. Suitable for precast concrete industry and high performance concrete production. Water reduction up to 40% at low dosages.

3. FRESH PROPERTIES TEST

The main aim of these tests is to understand the behavior of fresh UHP-Self Compacting Concrete i.e. Flow ability of SCC, Filling ability and Passing ability of SCC. The fresh properties of UHPFC are estimates using the procedure used for SCC as per EFNARC - standard code of reference. The tests results of Mix1 and Mix2 is as shown in Table 1 and Table 2.

4. MIX DESIGN

The Study includes the method or the approach used in arriving a proper dense concrete mix or the proportioning of various concrete materials. As we know that there is no proper mix design procedure for UHFRC in any code of references across the country. The proportioning of various materials in this work is taken by taking reference of H.J.H. Brouwers et.al journal. In this chapter particle packing density method is used for the mix design of concrete. The typical Mix proportion of Mix1 of w/c ratio 0.30 is shown in Table 3

Table 1 Results of Rheology of Mixes - UHPC Mix1

Test	w/b Ratio	0.3	0.28	0.26	0.24	Result
Slump Flow	Horizontal Dia.(mm)	720	700	670	650	600 - 800 mm
	T_{50} cm (sec)	3	3	4	4	2 Sec.
V -Funnel	(Tr) Flow (sec)	8	9	10	11	6 – 12 Sec.
	Flow at T_5 min (sec)	10	12	12	13	≤ Tr+3
J - Ring	T_{50} cm (sec)	4	4	6	8	< 10 Sec.
L - Box	Blocking ratio (H_2/H_1)	0.9	0.9	0.85	0.85	0.8 - 1
U - Box	Diff in height (left limb – right limb) in (mm)	5	1	0.5	1	Max 30mm

Table 2 Results of Rheology of Mixes - UHPC Mix2

Test	w/b Ratio	0.3	0.28	0.26	0.24	Results
Slump Flow	Horizontal (mm)	680	660	650	630	600 - 800 mm
	T_{50} cm (sec)	3	4	4	3	2 - 5 Sec.
V -Funnel	(Tr) Flow (sec)	11	12	10	10	6 - 12 Sec.
	Flow at T_5 min (sec)	13	14	12	11	≤ Tr+3
J - Ring	T_{50} cm (sec)	5	7	7	8	< 10 Sec.
L - Box	Blocking ratio (H_2/H_1)	0.9	0.85	0.9	0.85	0.8 – 1
U - Box	Diff in height (left limb – right limb) in (mm)	0	1	1	0	Max 30mm

Table 3 TYPICAL MIX FOR ONE BATCH OF W/C RATIO 0.30

Total volume = 0.006m^3		Weight in kg	Specific Gravity	Weight/ Sp. Gg.	Units
Cement	=	4.23	3.15	1.34285	
Micro Silica (10%)	=	0.42	2.4	0.175	
Metakaolin (5%)	=	0.21	2.56	0.08203	
M -Sand	=	7.2	2.65	2.73764	
Quartz Sand	=	1.35	2.66	0.50751	
SP (0.65%)	=	0.031	1.1	0.0281	
Fibers (0.5%)	=	0.024	7.6	0.0031	
Water	=	1.449	-	1.449	

Total	=	14.91		6.33	
Total Cementitious Material	=	4.86			kg/m^3
Total in m^3	=		0.00633		m^3
W/C ratio	=	wt of water/ total cement material	0.298		
Cement	=	cement/total in m3	668.73		kg/m^3
Micro Silica	=	66.87			kg/m^3
Metakaolin	=	33.2			kg/m^3
M -Sand	=	1200			kg/m^3
FA (55%)	=	660			kg/m^3
CA (45%)	=	540			kg/m^3
Quartz Sand	=	225			kg/m^3
Fibers	=	4.025			kg/m^3
Water	=	230.61			kg/m^3
Total Concrete Density	=	2428.43			kg/m^3

5. DURABILITY TEST ON HARDENED CONCRETE

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

5.1 Acid Test

As per ASTM 642 This test is done to determine the loss of weight and loss of compressive strength after 28 days of curing in Hydrochloric acid. But weight of the concrete specimens sometimes increases due to the pores present in the specimen as in this case. 5% of HCl is mixed with 95ml of water in order to obtain 100ml of solution. The results of the test for Mix 1 and Mix 2 are shown in Table 4 and Table 5. Graphical representation is shown for this test in Fig1, Fig 2, Fig 3 and Fig 4.

Table 4 Compressive Strength of UHPC Mix 1 Specimens Immersed In HCl Solution

SL NO	W/C ratio	Avg Weight of Specimen before immersion in solution (Kg)	Avg 28 Days Weight of Specimen after immersion in HCl solution (Kg)	Normalised Compressive Strength before immersion (MPa)	Avg. Compressive Strength after immersion (MPa)
1	0.3	2.27	2.26	99.95	75.23
2	0.28	2.2	2.19	105.73	79
3	0.26	2.05	2.03	111.73	91.37
4	0.24	2.01	2.0	115.83	97

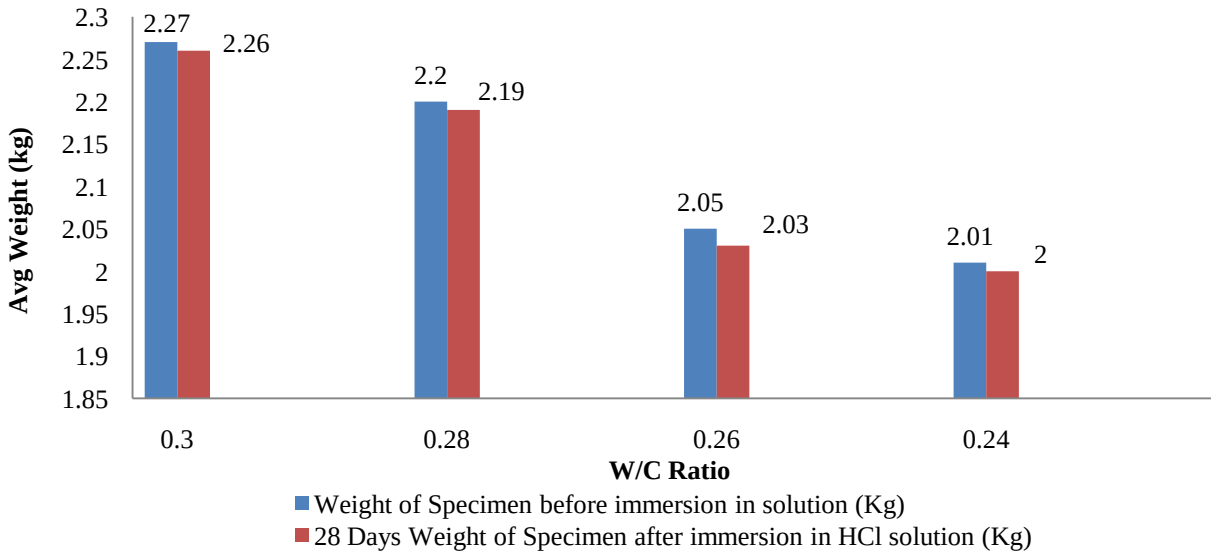

Fig. 1 UHPC Mix 1- Effect of HCl on Weight of UHPC Mixes

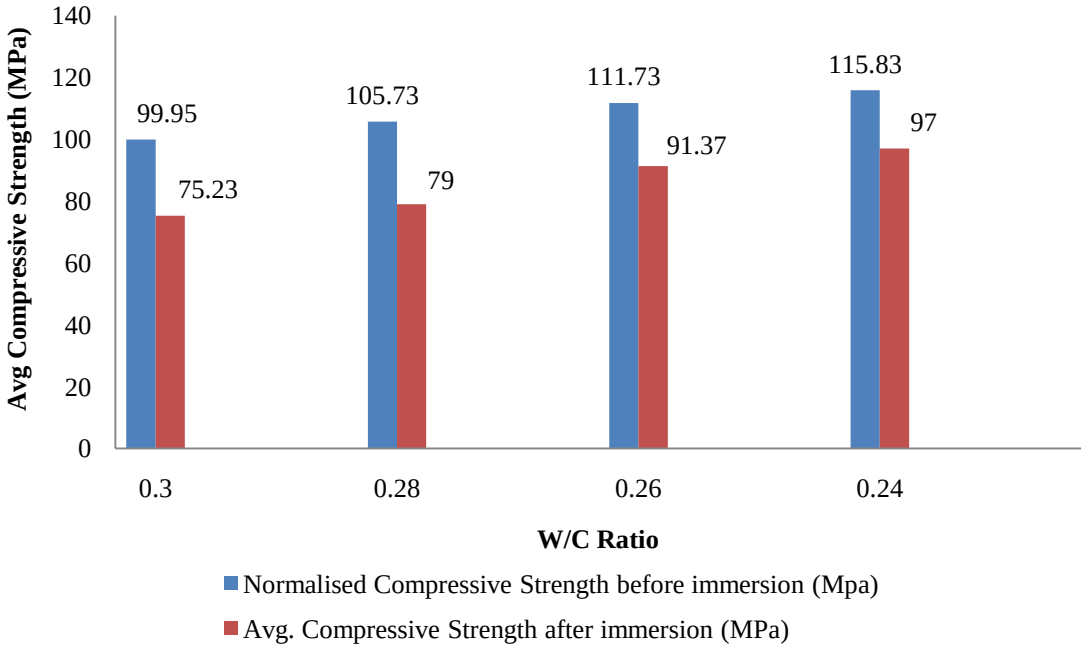

Fig. 2 UHPC Mix 1- Effect of HCl on Strength of UHPC Mixes

Table 5 Compressive Strength of UHPC Mix 2 specimens immersed in HCl solution

SL NO	W/C ratio	Avg Weight of Specimen before immersion in solution (Kg)	Avg 28 Days Weight of Specimen after immersion in HCl solution (Kg)	Normalised Compressive Strength before immersion (MPa)	Avg. Compressive Strength (MPa)
1	0.3	2.32	2.31	89.48	73.83
2	0.28	2.29	2.27	95.31	78.23
3	0.26	2.25	2.24	97.22	90.13
4	0.24	2.22	2.21	98.48	96.97

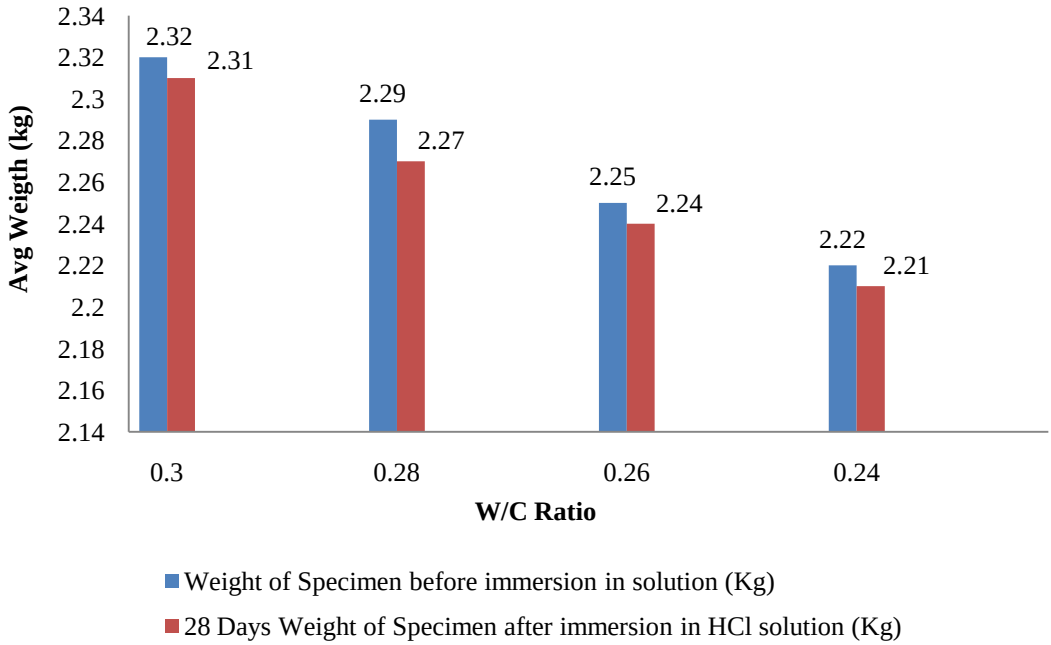

Fig.3 UHPC Mix 2- Effect of HCl Solution on Weight of Mixes

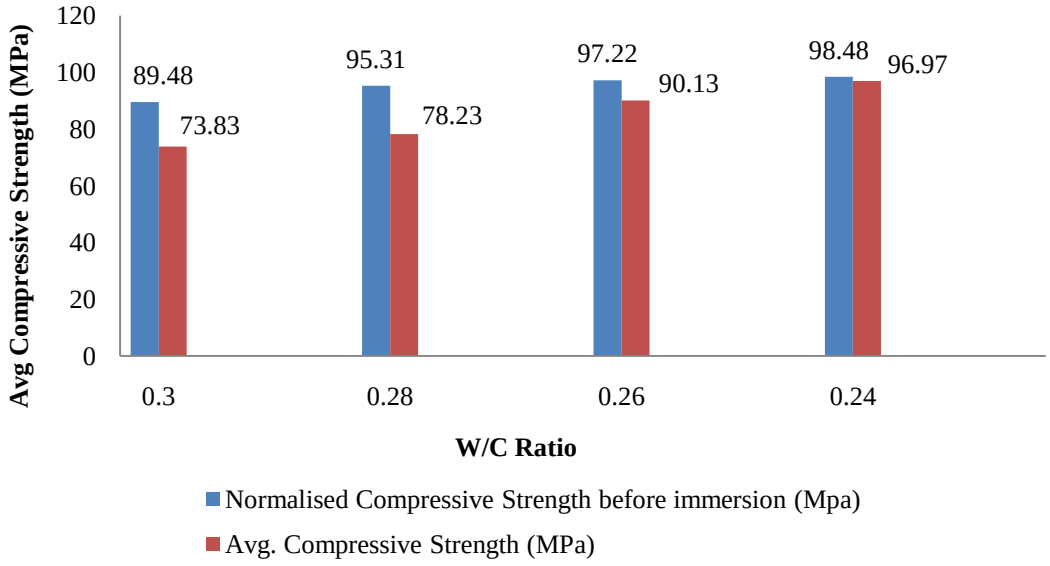

Fig.4 UHPC Mix 2- Effect of HCl Solution on Strength of Mixes

5.2 Chloride Ponding Test

This test is done to determine the loss of weight and loss of compressive strength after 28 days of curing in Sodium Chloride solution. But weight of the concrete specimens sometimes increases due to the pores or the voids present inside the specimen.

5% of NaCl is mixed with 95ml of water in order to obtain 100ml of solution. The results of the test for Mix 1 and Mix 2 are shown in Table 6 and Table 7. Graphical representation is shown for this test in Fig5, Fig 6, Fig 7 and Fig 8.

Table 6 Compressive Strength Of UHPC Mix 1 Specimens Immersed In Nacl Solution

SL NO	W/C ratio	Avg Weight of Specimen before immersion in solution (Kg)	Avg 28 Days Weight of Specimen after immersion in NaCl solution (Kg)	Normalised Compressive Strength before immersion (MPa)	Avg. Compressive Strength after immersion (MPa)
1	0.3	2.28	2.26	99.95	76.6
2	0.28	2.22	2.2	105.73	85.37
3	0.26	2.18	2.16	111.73	93.1
4	0.24	2.13	2.1	115.83	95.9

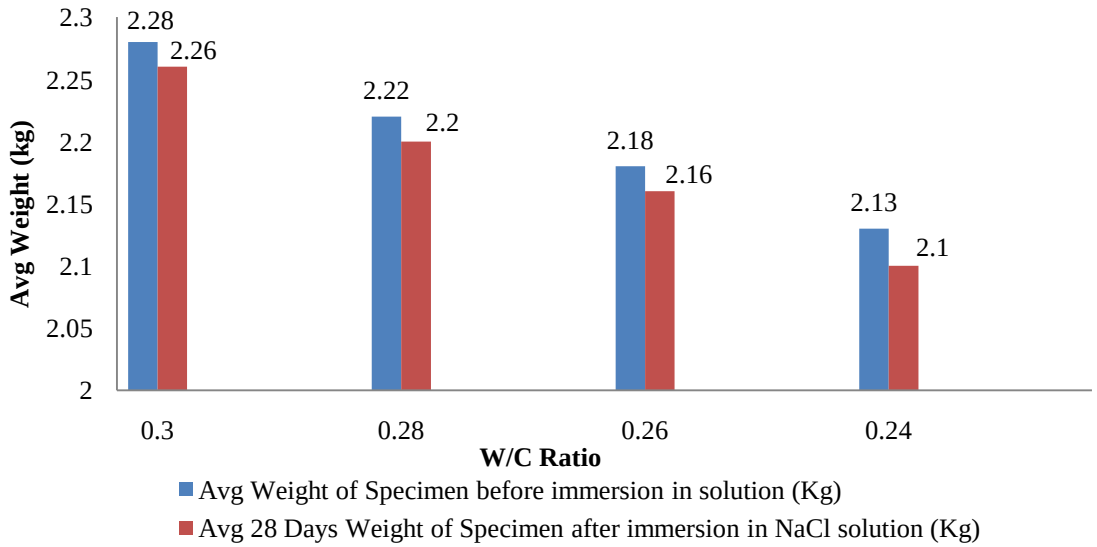

Fig. 5 UHPC Mix1 - NaCl Immersed Specimen on Weight

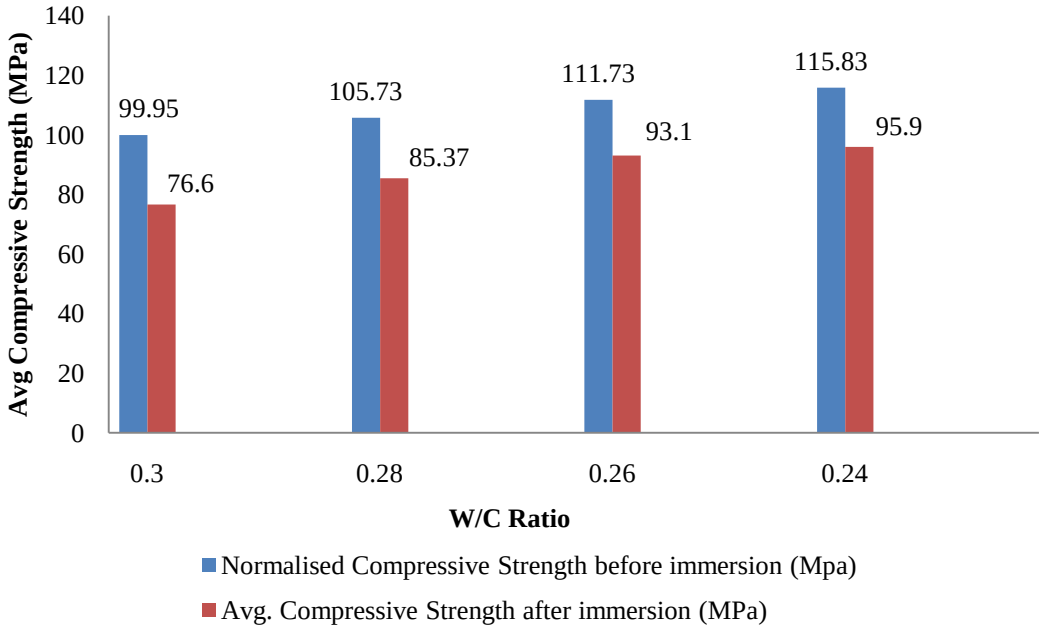

Fig.6 UHPC Mix1 - NaCl Immersed Specimen on Strength

Table 7 Compressive Strength Of UHPC Mix 2 Specimens Immersed In Nacl Solution

SL NO	W/C ratio	Avg Weight of Specimen before immersion in solution (Kg)	Avg 28 Days Weight of Specimen after immersion in NaCl solution (Kg)	Normalised Compressive Strength before immersion (MPa)	Avg. Compressive Strength after immersion (MPa)
1	0.3	2.25	2.23	89.48	72.3
2	0.28	2.2	2.19	95.31	81.97
3	0.26	2.18	2.16	97.22	87.6
4	0.24	2.15	2.14	98.48	91.37

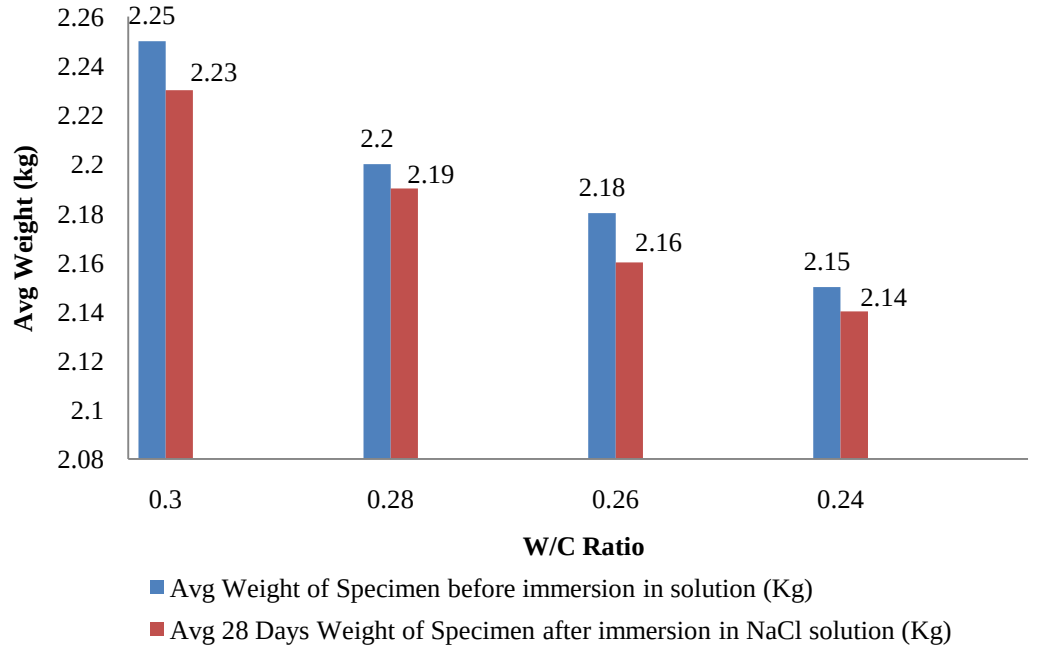

Fig.7- UHPC Mix 2 – Effect of Immersion of Specimens in NaCl solution on Weight

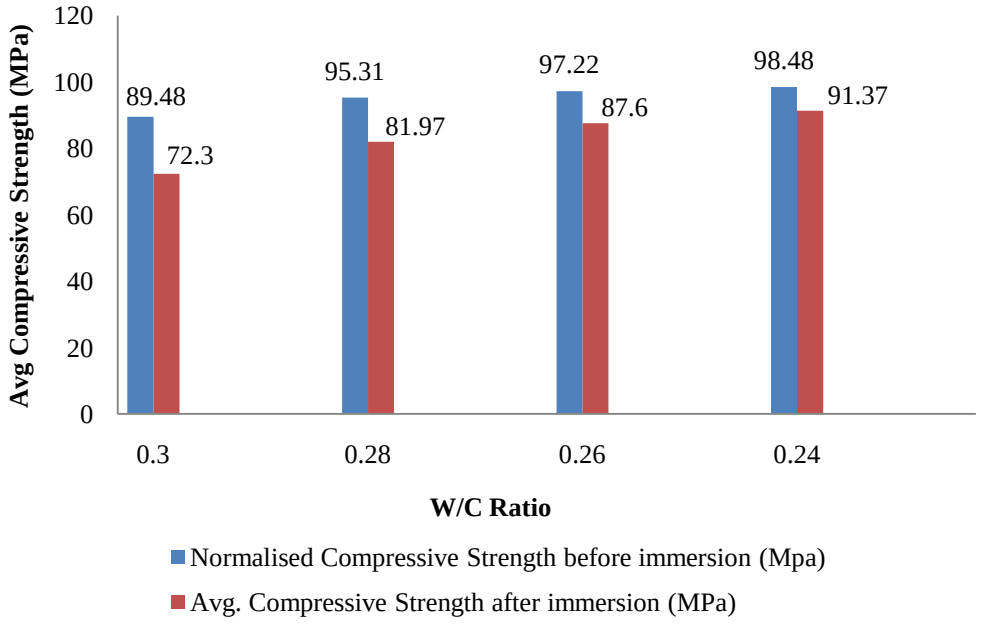

Fig. 8 - UHPC Mix 2 – Effect of Immersion of Specimens in NaCl solution on Strength

6. CONCLUSION

This chapter includes summary of all the test results of durability property of concrete by using various cementitious materials and mineral admixtures, etc. The Discussion is as follows

1. The purpose of this study is to understand the durability behavior of UHPC subjected to various tests.
2. Micro Silica (10%) and Metakaolin (5%) was used as mineral admixture as partial replacement of cement and steel strands (0.5%) is used as reinforcement.
3. Superplasticizer having 40% water reduction (M70 Dyn) is used for the study.
4. Since there is no proper procedure and guidelines for Mix design of UHPC, the design is carried out by Particle packing density method.
5. In Acid attack test Mix 1 gives more strength compared to Mix 2 since mix 1 specimens are compacted with more fine particles. Max Strength of Mix 1 was found to be 97 MPa for W/C ratio of 0.24, for W/C 0.24 of Mix 96 MPa.
6. In Chloride attack test Mix 1 gives more strength compared to Mix 2 since mix 1 specimens are compacted with more fine particles. Max Strength of Mix 1 was found to be 95.9 MPa for W/C ratio of 0.24, for W/C 0.24 of Mix 91.3 MPa.
7. From the discussions on the results of UHPC mixes, it may be concluded that the strength of UHPC mixes is more without coarse aggregates than with coarse aggregates at higher cementitious content than with lower cementitious content.

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