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COMPARATIVE STUDY ON ULTRA HIGH-PERFORMANCE CONCRETE WITH AND WITHOUT COARSE AGGREGATE BY PARTICLE PACKING METHOD.

The Study on Ultra High Performance Reactive Powdered Concrete

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Abstract: The present experiment aims the Comparative Study on Ultra High-Performance Concrete with and without Coarse Aggregate (RPC) by Particle Packing Method. The Present work is carried out on rheological and mechanical property of two design mixes of Ultra High-performance concrete in which one is without coarse aggregate (RPC) and the other is with coarse aggregates (Modified RPC) of 12.5mm down size. The behavior in the new state of each mix is studied by varying the water cement ratio by 0.3,0.28 & 0.26. The two mineral admixtures used in the mixes are 10% micro silica and 5% metakaolin replacing cement by weight, Manufactured Sand (M-Sand) and quartz sand are used as fine aggregates. Quartz sands consist of 60mesh, 100mesh, and 200mesh. 1% Steel fibers are used in both the mixes to resist shrinkage cracks in the concrete mix and to make the concrete ductile. Some properties of fresh UHPC were investigated with the experimental apparatus, which are usually used to determine the properties of self-compacting concrete the UHPC are tested by Slump flow test, L-box test, V-funnel test, and U-box test. The flowing ability, passing ability, filling ability of fresh UHPC are evaluated. Then the specimens are casted and tested for its Compressive strength. It has been observed that the compressive strength of the mix without coarse aggregate (RPC) is 5% to 10% higher than that with the coarse aggregate.

***Index Terms* -: Ultra High-performance concrete, Reactive Powdered Concrete, High strength concrete, Self-compacting concrete, Particle Packing Method.**

I. INTRODUCTION

1.1 GENERAL

In the preceding decade, concrete technology has advanced tremendously. Concrete is no longer a material made up of cement, aggregate, water, and admixtures; it is a designed material of a few additional constituents that function well under various situations. Concrete now comprises unique ingredients such as Metakaolin, micro silica, various folios, fillers, and Pozzolana compounds that can be completely designed for specific uses. The advancement of deciding a concrete based on its execution requirements rather than its constituents and fixes has offered a slew of new opportunities for manufacturers and clients to design concrete to meet their specific needs.

Reactive Powder Concrete (RPC) is defined as an Ultra-High-Strength and high ductility cementitious composite with improved mechanical and physical characteristics. It is a special concrete which is improved by microstructure through accurate gradients of all particles in the mix to produce maximum density. The pozzolanic properties of using very fine material (silica fume) and optimization of Portland cement chemical properties to create the highest strength hydrates. The RPC is a kind of technical revolution compared to the familiar concretes. Additionally, this material which is lately available demonstrates the high improved durability and strength characteristics compared to familiar or high-performance concrete and is categorized as Ultra High-performance concrete (UHPC).

1.2 NEED OF THE WORK

The need of the work is to bring up the concept of Reactive powdered concrete as very less work has been carried out in it and to compare with Modified reactive powdered concrete. The reactive powdered concrete necessitates very important applications in the field of concrete technology. Thus, It necessitates to study the rheological and mechanical properties of reactive and modified reactive powdered concrete by delving the procedure of particle packing method and its approach.

1.3 OBJECTIVE OF THE WORK

- To carry out the work on rheological and mechanical properties of two deign mixes.
- To evaluate the strength properties by performing compressive strength test.
- To determine paste content and volume of voids for different water-cement ratios.
- To study the behavior of fresh UHPC, i.e., Workability in terms of fill-ability, flowability, and resistance to segregation.

1.4 SCOPE OF THE WORK

The rheological property of RPC can't be determined with a direct method. since then, the Rheological properties of UHPC are assessed as of the Ultra high performance self-compacting concrete. The compressive test is carried out as per IS 516. the strength is assessed after 28days of curing. The paste content and volume of voids are determined by particle packing method approach.

II. EXPERIMENTAL PROGRAM

2.1 ASSESSMENT OF PROPERTIES OF MATERIALS

The Materials as ingredients of concrete and their physical, chemical and morphological properties play very important role in workability, mechanical strength and durability of the concrete. The properties of materials assessed using the procedures as per the standard codes of practice and specifications of the properties of materials used namely cement, metakaolin and micro silica as cementitious materials, M-Sand and quartz sand as fine aggregate and also Mild Steel fibers. The relevant properties of materials as ingredients of UHPC are assessed.

2.1.1 CEMENTITIOUS MATERIAL

Two mineral admixtures namely metakaolin and micro silica are used along with cement as cementitious materials. The mineral admixtures are used as replacement by weight to cement in a concrete mass. The mineral admixtures react chemically with hydrating cement to form a modified paste to increase paste mass and to produce denser concrete. With the widespread use of cement in concrete, there have been some genuine concerns about the harm caused by crude material extraction and CO2 emissions during cement production. This has put pressure on the concrete sector to reduce its use of concrete. Meanwhile, there is a growing need to improve concrete durability to cope with a changing environment that is not the same as before. Supplementary cementing ingredients, also known as Admixtures, have been proposed as cement alternatives in concrete due to advancements in concrete technology. A few materials are similarly used, some of which are by-products of other industrial processes, and hence their use may be financially advantageous. The main reason for their use is that they can provide various useful improvements or changes to concrete qualities.

A. Cement

The 53 grade OPC cement is used in this experimental work, conforming to IS: 12269 – 1987. The specific gravity of cement is 3.15 and the specific surface area is 290 m2/kg.

B. Metakaolin

Metakaolin, often known as "calcined soil," is a reactive alumina-silicate pozzolana that forms when kaolinite is heated to a specific temperature. Calcining pure clays typically make Metakaolin at appropriate temperatures. Metakaolin is a chemical step that forms when kaolinite is heated to a certain temperature. Water escapes from Kaolinite (Al2O3:2SiO2. 2H2O) due to thermal treatment between 400°C and 500°C, forming an amorphous alumina silicate known as "Metakaolin."

Metakaolin has an average particle size of around 1.5µm, between silica fume (0.1 µm to 0.12 µm) and Portland cement (15 µm to 20 µm). It has specific gravity of 2.56 and surface area of 8000 to 25000 m2/kg. The average particle size is less than 2.5µm. Use of such type of minerals in the concrete helps to improve the surface finish and palpability of concrete. It is also providing cohesiveness to the concrete and there by helps to achieve the properties of self-consolidating concrete.

C. Silica Fume

The micro silica is also known as Silica fume. It is a waste product of silicon metal or ferrosilicon alloy industries. The silica fumes mainly consist of silicon dioxide (SiO2). The sizes of the individual particle are very small and are approximately equal to 1/100th of the average size of cement particles. The specific gravity of micro silica is 2.2. Specific surface of micro silica is about 15000 to 30000 m2/kg. It has a bulk density of 130 to 600 kg/m3. Average particle size of micro silica is less than 1µm. It is a very reactive mineral admixture because it consists very fine particle and high SiO2.

2.1.2 FINE AGGREGATES

The Fine aggregates used in the concrete mixes are Manufactured Sand and Quartz.

A. Manufactured Sand

The M-sand is used as a fine aggregate conforming to the requirements of IS: 383-1970. The M-Sand is artificially manufactured sand, consisting of particles of different sizes proportioned to suite the requirement of Fine Aggregates to be used in structural concrete. The M-sand shows higher rate of water absorption because of the higher content of finer particles. The shape of M-Sand particles is not spherical and hence there is reduction in workability of concrete with M-Sand with mix being more cohesive and viscous. The M-Sand used in the mix has specific gravity of 2.63, water absorption of 8.5%, Loose Bulk Density of 1356.16kg/m3 and Roded Bulk Density of 1469.39kg/m3.

B. Quartz Sand

The quartz sand is used as the filler material in the concrete. It is made up of a lattice of silica (SiO_2) tetrahedral. The hardness of the quartz sand is 7 as per Mohs scale of mineral hardness. The specific gravity is 2.65. There are three different sizes of quartz sand are used as fine aggregates in the present experiment work. They are 60mesh, 100mesh and 200mesh.

2.1.3 COARSE AGGREGATE

The coarse aggregates of 12.5 mm down size, well graded, conforming to the requirements of IS: 383-1970 are used in this experimental work. The Coarse aggregates have rough texture and are cubical in shape, more suitable to gain the strength due to improved packing of particles. The coarse aggregates used have specific gravity of 2.65, 1% water absorption, with LBD of 1443.4 kg/m3 and RBD of 1563.3 kg/m3.

2.1.4 STEEL FIBRES

The steel fibers used are hooked type. The length of the steel fibers is 30mm and diameter is 0.5mm, aspect ratio is 60. The specific gravity of the hooked steel fibers is 7.86 and it has tensile strength of 1100MPa. A randomly distributed steel fiber reduces the drying and plastic shrinkage cracks in the concrete and also helps to fill the cracks in the composite.

2.1.5 WATER

The potable water available in the laboratory, satisfying the requirement of IS 456-2000 is used for mixing and also curing all the concrete specimens, PH of water used is almost neutral (7).

2.1.6 CHEMICAL ADMIXTURES

P C based new generation Hyper Plasticizer (Talrakplast PC) in Concrete is used as admixture. It is Suitable for precast concrete industry and high-performance concrete production. There is a water reduction up to 40% at low dosages. The PCE based super plasticizer has Specific Gravity of this admixture is 1.10.

2.2 PARTICLE PACKING METHOD

The packing density is the ratio of volume of solids to the total bulk volume. The Particle Packing gives indirect measurement of geometry of the concrete mix and also gives the cement paste to be required to fill the void content present in the concrete. To achieve the optimized particle packing density, particle is selected in such a way that, smaller size particles fill up the voids between the larger particles and so on. The voids between the aggregate particles are filled by the cement paste and excess of paste will form a thin coating around each aggregate present in the mix. For the optimized packing density of aggregate smaller amount of paste content is required to fill the voids.

In order to achieve optimized particle packing density well graded aggregates are to be used. The best graded aggregate consists of nano level particles (less than the size of cement particles), which helps to fill up the smaller voids in the mix. The Well graded aggregates are required to achieve the proper particle distribution in the concrete mass. To obtain the proper particle distribution, each size fraction is sieved and stored, and are mixed in the required proportion for obtaining the required zone of aggregates. Hence different sized particles are so adjusted to get best fit of S shaped curve for particle distribution curve.

In the present experimental work M-sand and Quartz sand are used as fine aggregates, which have well graded particles up to 150 microns. The M-Sand is sieved into different size particles, such as retaining on 2.36mm, 1.18mm, 0.6mm, 150mm sieves and particle passing through 150mm sieves. Total quantity of particle passing through 150mm sieve is less than 20%. Therefore, quartz sand of sizes 0.25mm (60 meshes), 0.15mm (100mesh) and 0.75mm (200mesh) are used to fill the requirements of very fine particles. The sieve analysis is carried out by varying the percentage of particle each time till S curve is obtained. The typical example of one sieve analysis and the final fractions obtained are as follows.

Particles of size > 3mm - 20 %
Particles of size > 0.6mm – 30%
Size Fraction of > 0.15mm – 40%
Quantity of particles with size < 0.15mm - 10%.

2.2.1 MIX DESIGN PROCEDURE

The mix design is carried out using Particle packing density approach. The loose bulk density of M- sand and coarse aggregates are evaluated separately. The following steps are adopted to calculate the design mix for further work to carry out.

- Determination of packing density.
- Estimation of voids content and voids ratio.
- Calculation of packing factor.
- Evaluate the mass of fine aggregate and coarse aggregate.
- Determining the mass of total aggregates.
- Finding out the required cement paste and by selected the W/C.
- Estimation of cement content and also the quantity of water required.

DESIGN OF MODIFIED REACTIVE POWDERED CONCRETE

- **Determination of packing density.**

Manufactured Sand conforms to Zone-II as per specifications of IS: 383-1970

Specific gravity =2.63
Loose Bulk Density =1356.16 kg/m3
Roded Bulk Density =1469.36kg/m3

Coarse Aggregates of 12.5 mm maximum size Confirms to graded requirements as per specifications of IS: 383-1970

Specific gravity =2.65
Loose Bulk Density =1443.4 kg/m3
Roded Bulk Density =1563.3 kg/m3

Optimum Combined bulk density of total (Coarse and fine combined in the ratio of 45:55 respectively) aggregates:

Packing density for fine aggregates

(Bulk density x weight fraction)/ specific gravity = (1356.16*0.55)/ 2.63 = 281.47 kg/ m3
Volume = 0.281 m3

Packing density for Coarse aggregates

(Bulk density x weight fraction)/ specific gravity = (1443.4*0.45)/ 2.65=245.763 kg/ m3
Volume = 0.246 m3
Total packing density = 0.282+0.246 = 0.53

- **Estimation of voids content and voids ratio.**

Void Content (1-Total packing density) = 0.47
10% excess in void content = 0.47 x 1.1
Paste content = 0.517
Total volume of aggregate (1-Paste Content) = 0.483

- **Calculation of packing factor.**

Packing factor: Aggregate packing factor (PF) is defined as the ratio of roded bulk density to lose bulk density

PF = R B D / L B D = 1.1

Vfa = Volume of fine aggregates,
Vca = Volume of coarse aggregates
Pfa= Density of fine aggregate,
Pca= Density of coarse aggregate
Substituting the values ρfa = 1356.16kg/m3,
ρca = 1443.4 kg/m3 and Rfa/ca = 1
Vfa = 0.55 and Vca = 0.45
we get Rfa/ta = 1

- **Evaluate the mass of fine aggregate and coarse aggregate.**

Loose Mass of fine aggregates mfa = Vfa x ρfa = 745.80kg
Loose Mass of coarse aggregates mca=Vca x ρca = 649.35 kg
Mass of total aggregate = PF (mfa + mca) =1.1 (745.8 + 649.35) = 1534.52kg

- **Determining the mass of total aggregates.**

Final mass of fine aggregates PF x mfa = 1.1 x 745.8 = 810.17 kg
Final mass of coarse aggregates PF x mca = 1.1 x 649.60 = 713.87 kg

- **Finding out the required cement paste and by selected the W/C.**

Water cement ratio= w/c = 0.3
Total paste C+W = C/3.15 +0.30C/1 = 0.6174C

- **Estimation of cement content and also the quantity of water required.**

Cement content (0.517/0.6174) *1000 = 833.6 kg
Quantity of water (cement*0.3) = 249.9L.

III. RESULTS AND DISCUSSION

3.0 GENERAL

The Tests to be conducted on fresh and hardened UHPC, procedure are not available hence it can be checked as for SCC as per relevant codes of practice are discussed in this chapter. The rheology of UHPC mixes evaluated using Slump Flow Test, L-box Test, V-Funnel Test, and U Box Test are presented followed by discussions on the results of compressive strength test.

3.1 PASTE CONTENT

The Paste content is the summation of amount of paste required to fill the voids in the concrete mass and 10% paste extra to coat the aggregate. The paste content of different mixes for different water cement ratio is tabulated in table 3.1

Table 3.1 Paste Contents of the Mixes

w/c	Paste Content in %	
	Mix 1	Mix 2
0.3	49.5	51.7
0.28	48	49.7
0.26	46.4	48

3.1.2 DISCUSSIONS ON VOLUME OF PASTE

- The paste content of the mixes decreases with reduction in the water cement ratio.
- The Mix2 with coarse aggregates shows higher paste content than the mixes without coarse aggregates, indicating the presence of higher void content of mix2 created due to the presence of coarse aggregates. This shows that, the concrete mixes with coarse aggregates need more volume of paste (higher paste content) than that without aggregates.
- From the discussions on the volume of paste in the mixes, it may be concluded that the higher the cementitious content in a concrete mix, higher is the paste volume available. The presence of coarse aggregates in concrete increases the void content and hence requirement of paste also increases.

3.2 TESTS ON FRESH PROPERTIES

The fresh properties of the UHPC assessed are presented in this part of the report. The test procedures for determination of fresh properties of UHPC such as fallibility, passing ability and resistance to segregation are explained first, followed by the results and discussions on each test. No single test is available, which determines all the fresh properties UHPC, a RPC. Therefore, Slump Flow test, V funnel test, L- Box test and U box tests are conducted to assess the behavior of UHPC in fresh state. The typical values, which should be satisfied by Self compacting concrete.

3.2.1 SLUMP FLOW TEST

This test is carried out to assess the filling ability and resistance to segregation of SCC. In The slump test the concrete starts flowing freely after the cone is lifted the diameter at three different places is to be measured, average is recorded as slump diameter of the mix.

A stop watch is simultaneously switched on while lifting the slump cone and time required for the fresh mix to reach 500mm circle is recorded as T50 time.

A. OBSERVATIONS OF SLUMP FLOW:

As the water cement ratio increases the demand for dosage of admixture of the mix decreases and vice versa. The requirement of admixture of UHPC mixes without coarse aggregate having different cementitious content is similar. It may be concluded that flow properties of UHPC mixes can be improved with increasing the paste volume of the mixes.

Table 3.2 Specifications and Results of Slump Flow Test - Summary

Water Cement Ratio		0.3	0.28	0.26	Specifications
Mix 1	Paste Content in %	49.5	48	46.4	
	Admixture Dosage in %	0.65	0.7	0.85	
	Horizontal Flow in mm	780	750	710	600to 800
	T50 cm Flow Time in sec	2	3	3	5
Mix 2	Paste content in %	51.7	49.7	48	
	Admixture Dosage in %	0.55	0.65	0.75	
	Horizontal Flow in mm	760	720	680	600to 800
	T50 cm flow Time in sec	3	3	4	5

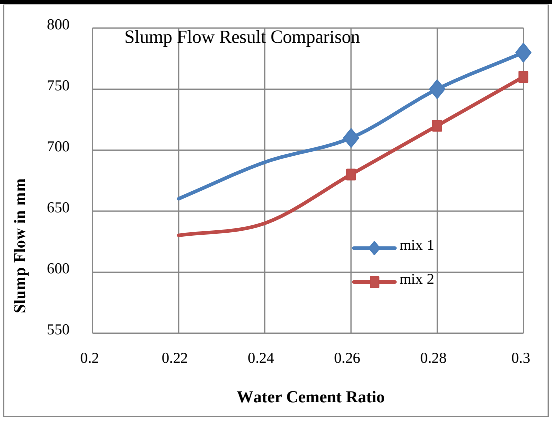

Fig 3.1 Slump Flow of Mixes - Mix 1 and Mix 2 - Comparison

3.2.2 L-BOX TEST

This method is used to access the passing ability of concrete. The time required for the UHPC mixes to reach the 200mm and 400 mm marks is measured and the blocking ratio is calculated. The mixes with higher volume of paste have blocking ratio very close to 1, showing the better flowability of mixes. At lower paste content of UHPC mixes higher admixture dosage is required to achieve the required range.

Table 3.3 Confirmation Results of L Box

Water Cement Ratio		0.3	0.28	0.26	
Mix 1	Paste Content in %	49.5	48	46.4	
	Admixture Dosage in %	0.65	0.7	0.85	
	Blocking Ratio (H_2/H_1)	0.95	0.95	0.9	0.8- 1
Mix 2	Paste Content in %	51.7	49.7	48	
	Admixture Dosage in %	0.55	0.65	0.75	
	Blocking Ratio (H_2/H_1)	0.9	0.9	0.85	0.8- 1

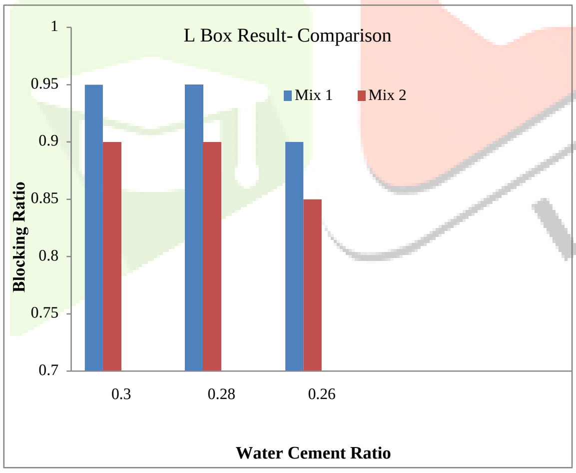

Fig 3.2 Comparison of L Box Blocking Ratio with Water Cement Ratio

3.2.3 U-BOX TEST

This test method is used to access the passing ability of the concrete. The dosage of admixture required at lower w/c ratio is high and vice versa. The variation in the response of U-box test of the mixes with coarse aggregates and without coarse aggregate is less.

Table 3.4 Confirmation Results of U-Box

Water cement ratio		0.3	0.28	0.26	Max. value
Mix-1	Paste Content in %	49.5	48	46.4	
	Admixture Dosage in %	0.65	0.7	0.85	
	Difference in Height in mm	0.5	0.5	1	30
Mix-2	Paste content in %	51.7	49.7	48	
	Admixture Dosage in %	0.55	0.65	0.75	
	Difference in Height in mm	0.5	0.5	1	30

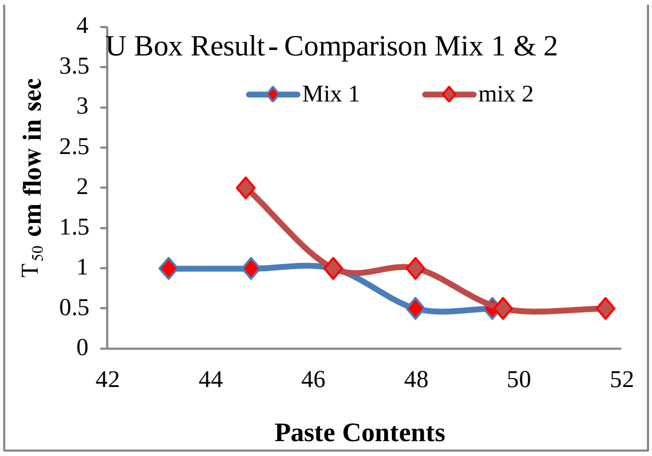

Fig 3.3 Comparison of U Box Height – Mix 1 and Mix2

3.2.4 V-FUNNEL TEST

This test is used to access the filling ability. At higher w/c ratio, dosage of admixture required is less and time of emptying is less. The mixes with higher volume of paste may make the mixes cohesive and may reduce the flowability of mixes.

Table 4.13 Summary of Results Final Dosage of Admixture

Water Cement Ratio		0.3	0.28	0.26	
Mix 1	Paste Content in %	49.5	48	46.4	
	Admixture Dosage in %	0.65	0.7	0.85	
	Tr - Flow Time in sec	8	9	10	12
	Flow at T5 min in sec	11	13	13	≤ Tr+3
Mix 2	Paste Content in %	51.7	49.7	48	
	Admixture Dosage in %	0.55	0.65	0.75	
	Tr Flow Time in sec	9	10	11	12
	Flow at T5 min in sec	10	12	13	≤ Tr+3

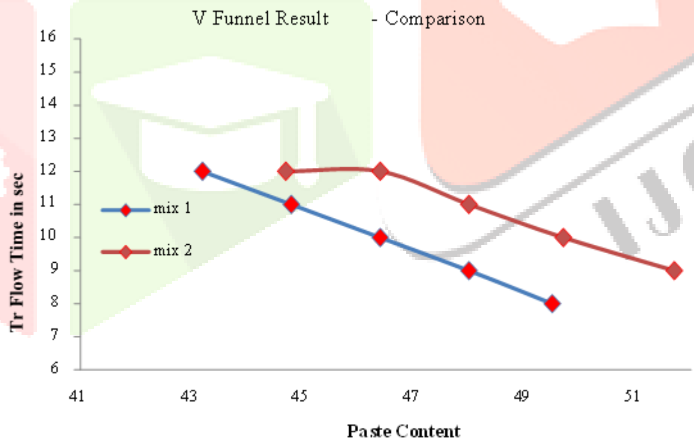

Fig 3.4 Variation of V Funnel flow with Paste Content Mix1

3.3 TEST ON HARDENED PROPERTY

The mixes which have satisfied the rheological requirements, then the specimens of compressive strength test of 100 x100 x 100 mm are casted. The specimens are demoulded after 24 hour and immersed in water for curing as per the requirements of codes.

3.3.1 Compressive Strength Test

The compressive strength of the Ultra high-performance concrete is evaluated as per IS516.The strength is assessed after 3 days and 28 days of curing.

Table 4.14 Compressive Strength Test Results

Water Cement Ratio		0.3	0.28	0.26
Mix 1	Paste Content %	49.5	48	46.4
	3days Strength in MPa	38.04	42.49	45.80
	28 days	80.80	84.66	89.47
Mix 2	Paste Content %	51.7	49.7	48
	3days Strength in MPa	35.69	40.25	43.69
	28 days	71.60	76.25	77.78

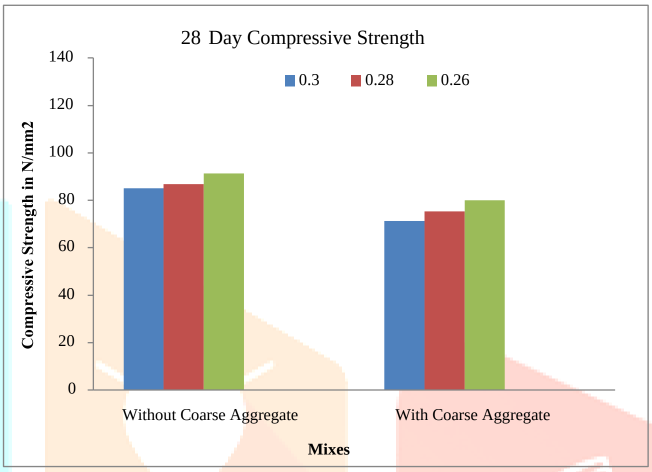

Fig 3.5 Strength of Mix 1 and 2 with and without Coarse Aggregates at Different w/c ratio

IV. CONCLUSIONS

4.0 CONCLUSIONS

- The 28 days compressive strength of M80 is achieved for mix-1 and M-70 for mix-2 at w/c ratio of 0.3, this shows that the higher strength is exhibited by the mixes without coarse aggregate by 10% than with coarse aggregate due to the powdered form in it thus the role of coarse aggregate is done by finer particles as the concrete powdered is very densely packed into minute silt sized particle thus increasing the surface area for binder and in-turn increase the strength of concrete, the ductility is taken care by the steel fibres to gain the matrix of the concrete.
- The paste content of the mixes decreases by 3.25% with reduction in w/c ratio from 0.3,0.28, & 0.26 this explains us that the less w/c ratio will form less paste content and will give more strength. the mix-2(with coarse aggregate) showed higher paste content of 51.7% for w/c of 0.3 and minimum paste content was for mix-1 with w/c ratio of 0.26.
- The dosage of admixture required at lower w/c ratio is high which is 1.3%. The variation in the response of U-Box test of the mixes with coarse aggregates and without coarse aggregates is less.
- At lower paste content of 41.4% UHPC mixes, higher admixture dosage is required to achieve the required range of blocking ratio of 0.8 to 1.0. The behaviour is similar with lower w/c ratio of 0.26 and 0.28.
- As the dosage of admixture is increased by 5.8%, time required for the emptying the V funnel is reduced. As the w/c ratio is increased, the time of flow is reduced. This shows that at higher w/c ratio, dosage of admixture required in more and time of emptying is less.

4.1 SCOPE FOR FUTURE STUDY

- RPC is not environmentally friendly. So, studies are required to replace the high cement ratio.
- There is no enough work on the behaviour of RPC when replacing the quartz powder with different granite percentage.
- There is a shortage in data about cracking and its evaluation method for RPC.
- Several potential areas for future research work can be carried out on the behaviour of RPC structural members.

4.2 CRITICAL CONCLUSION

- The Compressive strength is more in lesser w/c ratio in Reactive powdered concrete than in the Modified RPC (With coarse aggregate).
- More dosage of admixture is required for less w/c ratio and less paste content is formed with less w/c ratio.

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