OPTIMIZATION OF CEMENT PASTE BY POLYCARBOXYLIC ETHER BASED SUPERPLASTICIZER TO ACHIEVE ULTRA HIGH PERFORMANCE CONCRETE

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BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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To

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DECLARATION

I hereby declare that the work reported in the B-Tech thesis entitled **"OPTIMIZATION OF CEMENT PASTE BY POLYCARBOXYLIC ETHER BASED SUPERPLASTICIZER TO ACHIEVE ULTRA HIGH PERFORMANCE CONCRETE"** submitted at **Jaypee University of Information Technology, Waknaghat, India,** is an authentic record of my work carried out under the supervision of **Assistant Prof. Abhilash Shukla**. I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the B-Tech. thesis entitled **"Optimization of Cement Paste by Polycarboxylic Ether Based Superplasticizer to Achieve Ultra High Performance Concrete"**, submitted by **Ashutosh Anand and Dhruv Gupta** at **Jaypee University of Information Technology, Waknaghat**, **India,** is a bonafide record of his / her original work carried out under my supervision. This work has not been submitted partially or wholly to any other university or institution for award of this or any other degree program.

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Thanking You.

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LIST OF ABBREVIATIONS & SYMBOLS

Abbreviations and Symbols	Description
UFS	Ultra-Fine Slag
UFA	Ultra-Fine Fly ash
QZ	Quartz Sand
CSQ-1	Cement+20% Silica Fume + Non-Fibred
CSQ-2	Cement+20% Silica Fume +Fibred (6mm)
CSQ-3	Cement+20% Silica Fume +Fibred (13mm)
CAQ-1	Cement+20% Ultra-fine Slag+ Non-Fibred
CAQ-2	Cement+20% Ultra-fine Slag + Fibred (6mm)
CAQ-3	Cement+20% Ultra-fine Slag + Fibred (13mm)
CSAQ-1	Cement + Silica Fume (20%) + Ultra-fine Slag (10%)
CSAQ-2	Cement + Silica Fume (20%) + Ultra-fine Slag (10%) + Fibred (6mm)
CSAQ-3	Cement + Silica Fume (20%) + Ultra-fine Slag (10%) + Fibred (13mm)
CASQ-1	Cement + Silica Fume (10%) + Ultra-fine Slag (20%)
CASQ-2	Cement + Silica Fume (10%) + Ultra-fine Slag (20%) + Fibred (6mm)
CASQ-3	Cement + Silica Fume (10%) + Ultra-Fine Slag (20%) + Fibred (13mm)
CASUQ-1	Cement+ Ultra-Fine Slag (15%) +Silica Fume (10%) + UFA (5%)
CASUQ-2	Cement+ Ultra-Fine Slag (15%) + Silica Fume (10%) + UFA (5%) + Fibred (6mm)
CASUQ-3	Cement+ Ultra-Fine Slag (15%) + Silica Fume (10%) + UFA (5%) + Fibred (13mm)
ASUQ-1	Cement+ Ultra-Fine Slag (20%) + Silica Fume (5%) + UFA (5%)
ASUQ-2	Cement+ Ultra-Fine Slag (20%) + Silica Fume (5%) + UFA (5%) + Fibred (6mm)
ASUQ-3	Cement+ Ultra-Fine Slag (20%) + Silica Fume (5%) + UFA (5%) + Fibred (13mm)

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ABSTRACT

Ultra High Performance Concrete is a recent and important advancement in composite material that will permit the concrete industry to grow and build structures that are economical, reinvigorate material use, and build structures that are tough, durable and resistant to continuous changing environment. Ultra High Performance Concrete has a number of important properties, especially its high strength shows that the material will be beneficial for things which require less dead load, large spans, and even in areas which are prone to seismic activity, and it surpasses normal concrete.

A very important and potential application for reactive powder concrete is that it can be used for defense structures like in underground bunkers. The underground bunkers should be blast resistant which is a very important aspect The blast of a high explosive material generates very hot gases under a high pressure of about 30 GPa and a high temperature of 3000 – 4000 ^{0}C. These gases generated continuously expands and forces out the volume it occupies which as a result leads to the formation of blast wave or compressed air ahead of the gas which has enormous energy which is released during the blast. This wave in no time reaches to a pressure which is higher than the ambient pressure and is called as peak pressure and then decreases as a shock wave bulging outwards from the blast source. During the decreasing phase a vacuum is created and the air is sucked in and this suction of air is accompanied by higher intensity suction of winds which carry debris for long distance away from blast source.

The main prerequisites of blast resistant structures are cost effective and simple implementation methods when compared to conventional methods. The materials should be ductile enough and able to absorb energy generated from a blast source and prevent the structures from collapsing. Also the reduction in debris and fragmentation reduces the injuries in a bomb blast. Ultra High Performance Concrete can be very useful in this aspect as it has high strength, high ductility and high fracture energy. A number of strategies are adopted for blast resistance like using a stud steel wall in the interior of existing walls, by using exterior bonded steel plates in RC elements, use of NSM technique (near surface mounted), use of glass fibre reinforced composites, carbon fibred reinforced polymeric composites and nano particle reinforced poly urea.

All the above techniques and composites were used because of the high ductility and energy absorption capacity. Ultra High Performance Concrete is more reliable in terms of the above properties as quoted in literature. Also reaction powder concrete has a very important use of blocking & stabilization of containment of nuclear waste. Taking into consideration the growing need for the use of reactive powder concrete, it is discussed and a detailed review has been conducted for highlighting mechanical properties, mix proportions, and its performance in tension and compression.

Trials were made by selecting different combinations (binary, ternary and quaternary) of cementitious materials and their mix designs were verified by the EMMA software to get the maximum packing density. Poly Carboxylate ether was used as a high range water reducer and accordingly optimization of PCE was done.

CHAPTER 1. INTRODUCTION

1.1. General Introduction

Reactive powder concrete is an emerging technology that gives a new dimension to the term “High performance concrete”. It has a lot of potential in construction due to its excellent mechanical and durability properties as compared to the conventional high performance concrete, and it can also substitute steel in some applications. Reactive powder concrete is based on the implementation of some basic principles to achieve increased uniformity, high workability, high packing density, improved microstructure and high ductility. Reactive powder concrete has a very packed microstructure, which provides an additional benefit of water resistance and durability features. It can be a good substitute for industrial and nuclear waste storage facilities. A comparison of the various mechanical and durability properties of Reactive powder concrete and high performance concrete indicates that Reactive powder concrete have good compressive and flexural strength and a decreased permeability. In High performance concrete the maximum compressive strength range is 120-150 MPa or so. However, at such a level of strength, the coarse aggregate becomes the weakest link in concrete. If we want to achieve a compressive strength more than high performance concrete the way is to eliminate the coarse aggregates and achieve uniformity in the mix. This theory has been in use in modern technology which is called as reactive powder concrete. It is a special concrete in which microstructure is optimized by precise gradation of all particles in the mix to get maximum packing density. It uses the pozzolanic properties of highly refined silica fume to obtain highest strength hydrates. Reactive powder concrete includes cement, sand, quartz powder, steel aggregates and silica fume, steel fibres and a superplasticizer. The superplasticizers, used at its optimal dosage, decrease the water to cement ratio and improves the workability of the concrete. A packed matrix is achieved by modifying the granular packing of the dry fine powders. This compactness gives reactive powder concrete, ultra-high strength and durability. Reactive powder concretes have compressive strengths from 200 MPa to 810 Mpa. Reactive powder concrete with trade name ‘DUCTAL’ was first developed in France by researchers in the early 1990s at Bouygues, laboratory in France. The world’s first Reactive powder concrete structure, the Sherbrooke Bridge in Canada, was constructed in July 1997.

Its low and discontinuous porosity decreases mass transfer and hence making penetration of liquid/gas or radioactive elements is very difficult. Caesium diffusion is almost nil and Tritium diffusion is 45 times lower than conventional containment materials. Recent applications of Reactive powder concrete can are the famous Pedestrian Bridge which is 197 m long, 3.3m in width, 3.0m depth, and only 30mm thick slab, in Sherbrooke, Quebec, Canada. Seonyu foot Bridge, which is 120m long, 4.4m in width, 1.3m depth, 30mm thick slab, in Seoul, Korea, Sakata Mirai footbridge, in Japan and Canopy at Shawnessy Light Rail Transit Station, Calgary, Canada.

Reactive powder concrete has also been used for isolation and containment of nuclear waste of several projects in Europe and also for Producing Sewer, Culvert and Pressure Pipes in Army engineer waterways experiment station, Vicksburg MS., This product was nominated for the 1999 Nova Awards from the Construction Innovation Forum. In this paper research from year 1995-2013 has been taken into account.

1.2. Composition of Reactive Powder Concrete

Reactive powder concrete is composed of cement, sand, quartz powder and silica fume, steel fibres and superplasticizer. The superplasticizer, used at its optimal dosage, decreases the water to cement ratio while improving the workability of the concrete. A very dense matrix is attained by optimizing the granular packing of the dry fine powders. This compactness gives Reactive powder concrete ultra-high strength and durability. Reactive Powder Concretes have compressive strengths ranging from 200 MPa to 800 MPa.

The mixture design of Reactive powder concrete primarily involves the creation of a dense granular skeleton. Optimization of the granular mixture can be achieved either by the use of packing models or by open source software, such as LISA8 [developed by Elkem ASA Materials]. In this proposal the review is done according to the different properties which will give a clear idea about the development in technology and then the objectives and work plan are specified.

CHAPTER 2. LITERATURE REVIEW

2.1. Mix Proportions

Richard and Cheyrezy (1995) indicated the principles for developing reactive powder concrete i.e. Increase in uniformity of the mix, Increase in packing density by modifying the mix, Improving the microstructure by giving heat treatment after setting, Improving the ductility by adding steel fibres, Use of pozzolans like silica fume and use of superplasticizers to reduce water to cement ratio and improve workability. These were the major recommendations which proved to be the cutting edge in the development of reactive powder concrete.

Stephanie Staquet and Bernard Espion (2002) studied the mechanical properties of Reactive Powder Concrete which was developed with the materials available in Belgium. Also, it was suggested CEM152.5 which was used in Reactive powder concrete applications can be replaced by VEM 42.5 so as to obtain a compressive strength of 180MPa without heat treatment. The workability of the concrete made with the white silica fume from the Zirconium industry and the light grey silica fume from the silicium industry was better than the Reactive powder concrete made by white and black silica fume from silicium industry.

Plawsky.J. (2002) proposed a new method so that cement can be dispersed in sand to obtain a dry premix which had better mechanical and physical properties. The problems in blending the dry materials and the dispersion of water were identified. In addition, the understanding of mixing process resulted in designing the future generation equipment's to produce dense-mortar.

Masami Uzawa, (2005) improved the Reactive Powder Concrete which existed earlier and thus a new material was proposed with simple curing process. This reactive powder composite material (RPCM) has high compressive strength and toughness in spite of simple curing techniques unlike Reactive powder concrete. This RPCM premix is composed of (steel fibre reinforced ultra-high strength mortar) cement, siliceous material quartz sand, special water reducer and high strength steel fibre (0.2mm diameter and 15mm length). The results concluded that the RPCM has an extremely high fluidity and hence excellent self-compactability when it is fresh mortar and when it is hardened; it had high levels of strength and toughness with a compressive strength of about 200 N/mm^2.

Dili and Manu Santhanam (2005) developed two Reactive powder concrete mixes of 200MPa and 800MPa strength, which could be applicable for nuclear waste containment structures. The workability and durability properties were examined for the designed Reactive powder concrete mix. Also characterization of mechanical properties was carried out.

Dattatreya. J.K., (2007) examined several particle packing models so as to develop a mix proportion for the reactive powder concrete. The optimization of granular packing of the ingredients was a necessary factor to get enhanced mechanical and durability properties. The granular packing of materials like silica fume, quartz powder, standard sand with cement were optimized and the experimental results were correlated with the theoretical packing models.

2.2. Non Destructive Test

Glenn Waher (2004) performed non-destructive tests on reactive powder concrete (RPC) with traditional piezoelectric transducers which had centre frequencies of 500 kHz and 1 MHz Also longitudinal wave and shear wave velocities were found. These data combined with mass density were used for determining the modulus of Elasticity of Reactive powder concrete material. The results were correlated with the static moduli measurements conducted according to ASTM469. This comparison gives a correlation coefficient of 0.94 which indicates a high correlation by these two different of the dynamic and static moduli of elasticity.

2.3. Mechanical Properties

Aftab.A.Mufti, (1992) examined the suitability of fibre-reinforced concrete deck slabs without steel reinforcement. Four half-scale models were formed for slab-girder bridges with polypropylene fibres which completely avoid steel reinforcement and corrosion problems related to it. The upper flange of girders should be connected with steel straps in transverse directions to avoid the deck slab arching on the upper surface. This has been simulated by introduction of stiffeners along the edges using unconventional edge beams. The tested results showed that slab had major flexural rigidities in horizontal plane and it was recommended to introduce shear connectors to ensure an effective transfer of in-plane forces from the deck slab to the girders.

Luigi Bioizi, Gian Luca Guerrini and Rosati (1997) examined the effect of high tensile steel micro fibre on high strength concrete on compression and tension under controlled strain through closed-loop system. The maximum size of aggregate used was 3 mm with water to binder ratio was 0.2 mm and aggregate binder ratio of 2. The effect of different dosages of fibre on concrete was evaluated. Also it was concluded that polyacrylic base super plasticizer gives materials with lower porosity.

Olivier Bonneau and Mohamed Lachemi, (1997) produced two Reactive powder concretes (RPC) at a precast plant in Sherbrooke University. One was a ready mix Reactive powder concrete and the other was used in precast plant. In ready mix Reactive powder concrete samples were prepared both with and without fibres. All these Reactive Powder Concrete samples were tested for modulus of elasticity, compressive strength, freezing and thawing cycling resistance, scaling resistance to dicing salts and resistance to chloride ion penetration. He concluded that the Reactive Powder concrete mix were found to be freeze-thaw resistance and loss of very low mass under the scaling test. Chloride ion penetration was below 10 coulombs for Reactive Powder Concrete impregnated with steel fibres.

Surendra P.Shah (1998) Studied existing procedures for preparation of specimen in general and examined testing, workability, flexural strength, toughness and energy absorption. He also presented newly developed test methods for the first time for impact strength and flexural toughness. The applicability of the these tests on fibre reinforced concrete (FRC) are reviewed: air content, yield, unit weight, compressive strength, splitting tensile strength, freeze – thaw resistance, shrinkage, creep, modulus of elasticity, cavitation's, erosion and abrasion resistance. This report is based on conventionally mixed and placed fibre reinforced concrete (FRC) or fibre reinforced shotcrete (FRS) using steel, glass, polymeric and natural fibres.

Ashish Dubey (1998) examined the post-peak energy dissipation mechanism across a crack. It was reported that the energy dissipation is because of pull-out of fibres across the crack. Pozzolanic materials like silica fume when added increase the brittleness of the matrices. Due to increase in load results in crushing and splitting of matrix, the ability of fibres to transfer the stresses is curtailed. It was also suggested that the toughness of Reactive Powder Concrete can be increased by addition of high-reactivity metakaolin to the mix which will in turn improve the durability properties of Reactive Powder Concrete.

Karl-Heinz (2004) Performed direct tension tests, and noticed only a slight increase of the load after first cracking. Mainly a decrease of the load occurred, and in some cases, it was so abrupt that it was a specimen with a weak cross section where the fibres were mainly orientated perpendicular to the load direction during concreting. Therefore, utmost care should be taken on concreting and the quality assurance. The flexural tensile strength of 25 to 40 MPa were noticed. The flexural tensile strength decreases with increasing depths of the prisms, and this shows that there was a distinct "size effect". This implies that the size of the prism must always be mentioned when such values are reported. One of the main reason for this size effect was the orientation of the fibres, which leads to a preferred orientation of the fibres parallel to the surface respectively to the formwork, and therefore it has greater influence for small dimensions.

Behloul and Lee (2004) revealed a characteristic tensile strength of 8 MPa and a post-peak strength of 5 MPa for the Reactive powder concrete mix (Ductal) that was used for the Seonyu Bridge in Seoul. The axial tensile tests were performed with flat bone-shaped specimen which had cross section of 30 × 90 mm. This shape is better than prisms or cylinders so as to determine this important material characteristic for ultra-high strength performance reinforced fibre concrete that used for shells and tanks.

Reineck and Greiner (2004) performed tensile tests on a commercially available formulation of Reactive powder concrete (RPC) namely, Ductal using steel fibres of 2% volume. The compressive strength values that were obtained were about 180 MPa and axial tensile strength of about 9 to 10 MPa for reactive powder concrete.

Jorg Jungwirth (2004) conducted material tests and tests on structural members of reactive powder concrete using reinforcement bars. Large-scale tests simulating the condition in actual structures were performed to understand the behaviour of structural members in ultra-high strength performance concrete. The test was done with three specimens with different reinforcement ratios between 1% and 4.8 % (ribbed steel, f_y = 556 MPa). The dimensions of the specimens used were 160 × 160 × 1500 mm. The strain was noted over a gauge length of 1000 mm. The behaviour in tension in Ultra high strength performance concrete due to the presence of fibres and their contribution shows a drastic difference when compared to that of ordinary concrete. This has a critical influence on the design of structures in ultra-high strength performance concrete.

Dean Bierwagen (2005) tested 71 ft. (21.64m) long reactive powder concrete test beam for shear and flexural capacities. In phase II, 111 ft. (33.83m) long beams were used for casting and testing. Based on the test results that were obtained the section of web was reduced in top flange by one inch (25 mm) and in bottom flange by two inches (50 mm). The design guidelines were taken from the sources available from the reports available and the construction was finished in 2005.

Dili and Manu Santhanam (2005) Two Reactive powder concrete mixes and designated as RPC 200 and RPC 800 were developed which could be used for nuclear waste containment structures. The mixes were examined for its workability, mechanical and durability properties. The flow table test as per ASTM C 10916 was in the range of 120%-140% and the water and chloride ion permeability is extremely low which shows that the suitability of nuclear waste containment structures.

Katrin Habel, (2006) examined the improved performance of ultra-high performance fibre-reinforced (UHPFRC) concretes with fibre cocktail. This study concluded that small fibres contribute to strain hardening resulting in bridging of micro cracks and long fibres were responsible for transferring of forces in localized cracks and govern the softening part. So the improved UHPFRC resulted in higher stiffness and higher resistance to cracking with a hardening modulus of more than 45 GPa preventing softening behaviour.

Toshiyuki Kanakubo (2006) analysed the findings of JCI technical committee sponsored round robin test program on tensile characteristics of ductile fibre reinforced concrete (DFRCs) in which four types of uniaxial direct tension tests were examined with different types /dimensions of specimen and loading jigs. In addition, flexural and split tension tests were also studied. Differences observed in the results were reported according to testing method, shape and dimensions, specimen parameters, boundary conditions and specimen preparation.

2.4. Durability Properties

Helene Zanni (1996) examined the hydration and pozzolanic reaction by two Reactive Powder Concrete specimens using two different heat treatment at 20ºC and 250ºC. The experiment was done to study the effect of temperature on hydration and pozzolanic activity. At 250ºC micro structural changes leads to the appearance of Q3 peak which attributed to the formation of Xonolite.The heat treatment resulted in increase in the C-S-H chain length due to the pozzolanic activity of silica fume and quartz powder .It was concluded that leaching greatly affects the microstructure especially that of the unhydrous cement grains that remained in the paste.

Feylessoufi.A (1996) investigated a Reactive Powder Concrete (RPC) with compressive strength of 230 MPa using low temperature nitrogen adsorption – desorption volumetry by DRIFTS (Diffuse Reflectance infrared Fourier Transformed Spectroscopy). The experiments concluded that Reactive powder Concrete had an open network of pores of various diameters which have high level durability characteristics.

Feylessoufi.A. (1997) studied results of specimens which were cured using three different heating modes. The results concluded the formation of Xonolite when it was heat-treated and the data showed that the kinetically controlled thermal curing had control on hydration and crystallization.

Vodak.E (1997) performed experiments to study the thermal characteristics of Reactive powder concrete like thermal conductivity, thermal diffusivity and linear thermal expansion coefficient of RPC. The concrete that was used in French nuclear power plant were examined for a temperature Range of 20ºC to 200ºC, specific heat of -30ºC to 100ºC, moisture diffusivity from 0 to 75% of maximum water saturation at room temperature and water vapour diffusivity at room temperature. The results were compared with the measurements of other authors for concretes which had similar composition and concluded a reasonable agreement for most of the parameters.

The durability properties of a new cement based materials with excellent micro structural properties were investigated. The durability properties were studied for concrete. Study of the C-S-H (behaviour of hydrates) gel was studied on a pure cement and silica fume paste. The advantage of silica fume addition on calcium leaching was studied by XRD analysis from SEM observations and from the tritium diffusion and pore distribution analysis. It was concluded that leaching greatly affects the microstructure especially that of the anhydrous cement grains that remained in the paste.

Matte.V., Moranville.M.,(2000) conducted experiments to predict the long – term durability of Reactive Powder Concrete, the hydration rate of cement minerals, pore structure and mechanism of chemical reactions, pozzolanic reactivity of silica fume,. First, the microstructure of Reactive Powder Concrete matrix was simulated using the NIST micro structural model. Then the transfer of Ca ions through percolating water was noted using DIFFU-Ca, a model that is based on the local chemical equilibrium. This double modelling validates the damage process related to an instantaneous dissolution of anhydrous cement silicates at the degradation from which results in a higher connected pore, space and is in good agreement with experimental results. The investigation reveals that the Reactive Powder Concrete matrix is durable as long as a sound zone persists. So, taking only the calcium concentration, the degraded depth was 14-15 mm at 300 years for the Reactive Powder Concrete matrix, in experimental conditions of leaching. This value can be used to determine the thickness of high integrity containers which in turn can be used in the storage of type B nuclear waste without cementation.

Saremi.M. and Mahallati.E. (2002) investigated the chloride ion passivity through simulated concrete pore (SCP) solution using electrochemical techniques. The sensitivity of impedance parameters and cyclic potential dynamic parameters were studied. The aim of the present study was to study the effect C1- ion concentration on the stability of passive file on mild steel in simulated concrete pore (SPC) solution. This study was done to know the effects on anodic inhibitors on passive film performance.

Cwirzen.A. (2007) examined the influence of remedying regime on the mechanical properties of ultra-high performance concrete. Nine different remedying methods were endeavoured with variation in heat treatment, variation in dihydrogen monoxide to binder ratio, with variation of filler materials like silica fume and fine quartz. The microstructure of the specimens was examined by electron microscope and mercury intrusion porosimeter scan. Results revealed that increase in heat treatment periods decreases the hydration processes and refine the microstructure. This results in higher compressive vigour. The scanning electron microscope investigation showed the formation of one hydration rim around anhydrous cement particles and the presence of a hollow shell in all investigated specimens.

Dattatreya.J.K. (2008) developed a mix proportion for Reactive powder concrete and sundry durability test procedures suggested by other scientists for Reactive Powder Concrete were discussed in this paper. Also, the sundry testing procedures for finding the mechanical and durability properties of Reactive Powder Concrete have been identified. It is found that Reactive Powder Concrete is very sensitive to heat treatment and a remote vicissitude in curing regime affects the vigour of Reactive Powder Concrete.

2.5. Design Considerations

Rossi.P. and Parant.E. (2001) developed a new Ultra high performance (UHPC) material and until the peak strength was reached, he characterized the same by the gradual and continuous activation of the multiscale fibres. In addition, the studied material is modelled as an elasto-plastic specimen with strain hardening in tension. The results revealed that the material is very sensitive to the rate of loading and modulus of rupture shoots by 25% in the range of quasi-static loading.

Jungwith.J. and Muttoni.A. (2004) examined the tensile behaviour of Ultra high strength members. The behaviour was different because of the presence of high strength steel fibres. It was noted that the stiffness of the element was very high because of very high bond and tensile strength. It was recommended that ultra-high strength performance concrete with pre-stressing cables or reinforcement to carry major tensile stresses.

Marko Orgass and Yuette Klug (2004) studied the effect of short and a cocktail of short and long fibres on the mechanical properties especially on the ductility and size effect of ultra-high performance concrete. The experiments were performed with specimens of various fibres ranging from 0, 1 and 2 % and varying the grain size from 0.8 mm for reactive powder concrete to 5.0 mm for ultra-high strength performance concrete. The flexural strength and crack behaviour revealed that there is an increase in strength with increase in volume of steel fibre and ductile post fracture behaviour was noted for 2 % volume of the fibre.

Kim Huy Hoang (2008) examined the mechanical properties of ultra-high strength performance concrete with two types of steel fibres (Lf/df=17/0.235/0.5) the combination of fibres resulted in good flowability, flexural strength and compressive strength of over 150 MPa. It was noticed that higher strength was achieved due to micro steel fibres and not less than 1% was used. The ratio of silica fume and other filling powders should be approximately 0.2 – 0.25 for manufacturing self-compacting ultra-high strength concrete with water-binder ratio of 0.2.

Almansour.H. and Lounis.Z. (2008) made an ultra-high strength performance concrete with high strength and very low permeability that could be used for construction of durable bridges. The existing design recommendation for ultra-high strength performance concrete was used and was designed according to the Canadian Highway Bridge Design Code. Results showed that there is a significant reduction in concrete volume by 49 % - 65 %.

Lai.J and Sun.W. (2010) performed experiments to find the spalling strength of Reactive Powder Concrete (RPC) with Hopkinson bars. Reactive powder concrete samples with different values of steel fibres were subjected to impact of projectile at the free end. The compressive waves and reflected tensile waves were measured. A finite element analysis was carried out by simulation using the material model JHC (JOHNSON HOLMQUIST CONCRETE) (LSTC 2003) and was found to be suitable.

2.6. Applications

Donnaes and Phillippe (1998) developed Reactive powder concrete (RPC) which included extremely fine powders of sand, cement, quartz, and silica fume. A new pedestrian walkway bridge was constructed in Sherbrooke, Quebec on November 27, 1997. This prefabricated 197 ft. walk way was constructed with prefabricated Reactive Powder Concrete structural elements. In the assemblages which allowed in each cable a single strand and anchorage head was simplified by elimination of support plates since Reactive powder concrete can directly take the compressive stress developed during prestressing. Also a 2,150 sq.ft, facade for a Paris school was constructed using Reactive powder concrete. The façade demonstrated the materials aesthetic qualities creating plates with an untreated surface similar to polished concrete.

Ming-Gen Lee, (2005) examined the usage of Reactive powder concrete as repair material and evaluated its bond and durability properties with existing High strength (HSM) and reinforced concrete (RC).The compressive strength, bond strength, steel pull out strength and relative dynamic modulus of elasticity (NDT) tests were carried out. The test result proved the superiority of RPC with respect to other concretes. The mechanical properties are 200% more when compared to the normal strength concrete. The results of slant shear tests show that the bond strength of RC/RC, HSM/RC and RPC/RC decreased significantly more with freeze – thaw cycles as compared with that of RPC/RPC.

Masami Uzawa.M.(2005) explored the practical applications of the reactive powder concrete with steel fibres with a high compressive strength of 200 MPa Masami Uzama improved the already existing Reactive Powder Concrete (RPC) and a new material was proposed with simple curing process. This reactive powder composite material (RPCM) has high compressive strength and toughness in spite of simple curing techniques unlike Reactive Powder Concrete. This RPCM premix consists of (steel fibre reinforced ultra-high strength mortar) cement, siliceous material, quartz sand, special water reducer and high strength steel fibre (0.2 mm diameter and 15 mm length). The results showed that the RPCM has an extremely high fluidity and thus excellent self-compactability in the state of fresh mortar and when it is hardened, it had high levels of strength and toughness with a compressive strength of about 200 N/mm^2.

Zhang.M.H. (2006) developed a new engineered cementitious composites (ECC) impregnated with poly vinyl alcohol. This had a high ductility feature which can be used in repair and retrofit of existing structures. The specimens were tested for high early strength gain rate with various combinations of binder system. The micromechanical model revealed that the quick deterioration in strain capacity which was due to rapid drop of complementary energy and continuous rise of crack tip toughness. Initial flexural strength was 10 MPa (4 hours) and improved to 16 MPa at a later stage.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Introduction

As we have already understood from the literature that reactive powder concrete is prepared by using ultra-fine materials. So reactive powder concrete was prepared by using binary, ternary and quaternary blends of materials. To achieve a strength of 200 MPa the following principles were followed in our study:

- Elimination of coarse aggregates for increasing the homogeneity of concrete.
- Selection of proportion of materials to obtain maximum packing density (Particle packing was analysed by EMMA (Elkem Materials Mix Analyser).
- Hot water curing of concrete for three days at 90°C was done to increase the rate of hydration reaction and to achieve the hydrated products at an early age.

3.2 Materials Used

- Ordinary Portland Cement 53 grade conforming to IS: 12269:1987.
- Densified Silica Fume.
- Ultra-fine fly ash (Pozzocrete 100).
- Ultra-fine slag.
- Quartz Sand.
- Micro Steel Fibres: two types of steel fibres were used. Both the steel fibres had the same diameter of 0.18-0.22 mm but then length was varied one was of 6 mm and the second one was 13 mm.

3.3 Specific gravity of Materials

Table 1: Specific Gravity of Materials

Materials Used	Specific gravity
OPC cement	3.15
Densified Silica fume	2.25
Ultra-fine fly ash	2.3
Ultra-fine slag	2.9
Quartz sand	2.59
Manufactured Sand	2.7
Quartz Powder	2.65

3.4 Particle size distribution of Materials

Particle size distribution was carried out by Laser Diffractometer with static light scattering technique. Since Quartz sand was having a particle size ranging from 600 micron to 150 micron so Laser Diffractometer cannot be used as the particles do not remain in suspension. For quartz sand we performed sieve analysis. The following are the results of particle size distribution of different materials.

Table 2: Particle Size distribution of OPC 53 grade Cement

Volume %	Particle Diameter µm (Trial 1)	Particle Diameter µm (Trial 2)	Particle Diameter µm (Trial 3)	Average Particle diameter µm
10	1.077	0.914	0.86	0.950
25	6.598	6.205	6.047	6.283
50	14.17	13.75	13.59	13.837
75	29.35	29.09	29.27	29.237
90	50.01	50.33	50.62	50.32

Table 3: Particle Size distribution of Silica Fume

Volume %	Particle Diameter µm (Trial 1)	Particle Diameter µm (Trial 2)	Particle Diameter µm (Trial 3)	Average Particle diameter µm
10	40.29	38.03	37.01	38.443
25	106.8	104.6	103.7	105.03
50	173.8	172.2	173	173
75	266.8	265.9	265	265.9
90	373.6	371.8	370.7	372.033

Table 4: Particle Size distribution of Ultra-fine fly Ash

Volume %	Particle Diameter µm (Trial 1)	Particle Diameter µm (Trial 2)	Particle Diameter µm (Trial 3)	Average Particle diameter µm
10	0.898	0.662	0.578	0.713
25	5.13	4.142	3.726	4.333
50	9.585	7.806	7.107	8.166
75	16.87	11.95	10.6	13.14
90	411.1	18.16	14.22	147.826

Table 5: Particle Size distribution of Ultra-fine Slag

Volume %	Particle Diameter µm (Trial 1)	Particle Diameter µm (Trial 2)	Particle Diameter µm (Trial 3)	Average Particle diameter µm
10	1.441	1.345	1.288	1.358
25	6.701	6.55	6.483	6.578
50	16.09	15.6	15.45	15.713
75	32.95	32.35	32.11	32.47
90	53.85	53.01	52.33	53.063

Table 6: Particle Size distribution of Quartz Sand

Sieve Sizes (mm)	Amount of Sample Passing (Total From 500 gms)	Amount of Sample retained	Cumulative Percentage Passing
2.36	500	0	100
1.18	500	0	100
0.6	267.8	232.2	53.56
0.3	2.8	265	0.01
0.15	0.4	2.4	0.0008
0.09	0	0	0

3.5 Design of Mix Proportions

Selection of the mix proportions is a very important phase for getting the optimum materials which are expected to give the desired strength. So we selected the combinations which were binary mix, ternary mix and quaternary mix of cementitious materials. Accordingly the combinations were checked in EMMA software with the standardized graph that how close the curve matches to the standard one. In EMMA we have used Modified Andreassen Model. The close the curve is to the standard one higher is the packing density which is one of our main principle to achieve high strength concrete.

In Binary mix we have taken two combinations which are

- Ordinary Portland cement 53 (OPC 53) grade and Ultra-Fine Slag (UFS)
- Ordinary Portland cement 53 grade and Silica Fume (SF)

The reason for selecting these two mixes is the silica fume and Ultra-Fine Slag are very fine materials so the packing density will be higher when compared with other binary mixes.

In ternary mix we have taken the combination of Ordinary Portland cement 53 grade, Silica Fume and Ultra-Fine Slag.

In Quaternary mix we have taken the combination of Ordinary Portland cement 53 grade, Silica Fume, Ultra-Fine Slag and Ultra-fine fly ash (UFA).

The proportions of silica fume and OPC53 taken for analysis in EMMA are

Silica Fume (20%) + OPC53 (80%)

Silica Fume (15%) + OPC53 (85%)

Silica Fume (10%) + OPC53 (90%)

Silica Fume (5%) + OPC53 (95%)

Similarly for also Ultra-fine slag and Ordinary Portland cement 53 grade are:

UFS (20%) +OPC53 (80%)

UFS (15%) +OPC53 (85%)

UFS (10%) +OPC53 (90%)

UFS (5%) +OPC53 (95%)

For Ternary mixes the proportions taken are Ultra-fine slag, Silica fume and ordinary Portland cement are:

UFS (5%) +SF (5%) +OPC53 (90%)

UFS (10%) +SF (10%) +OPC53 (80%)

UFS (10%) +SF (20%) +OPC53 (70%)

UFS (20%) +SF (10%) +OPC53 (70%)

For Quaternary mixes the proportions are

UFS (5%) +SF (5%) +UFA (5%) +OPC 53(85%)

UFS (10%) +SF (10%) +UFA (10%) +OPC 53(70%)

UFS (10%) +SF (15%) +UFA (5%) +OPC 53(70%)

UFS (5%) +SF (20%) +UFA (5%) +OPC 53(70%)

UFS (15%) +SF (10%) +UFA (5%) +OPC 53(70%)

For all these different proportions the cement was taken to be a constant amount of 900kg and all other materials are calculated according to their percentages compared with cement for one cubic metres.

For each of these proportions, various w/c ratios were chosen and the corresponding amount of water is calculated for every mix. Once the mix proportions were decided, they were fed into EMMA software for analysis.

In EMMA, the materials have to be fed into the library. The basic properties of materials that EMMA take to analyse the mix proportions are the specific gravity and the particle size distribution of the materials which were already found experimentally. For each of the proportions, five different w/c ratios have been chosen which are 0.17, 0.19, 0.21, 0.23, and 0.25.

Among these various combinations the six combinations which gives the graph almost matching the standard graph were chosen to perform the casting.

The following some figures that shows the graphs of the various combinations selected for casting.

Figure 1: EMMA Analysis Cement 95% + Silica fume 5%, w/c ratio=0.17

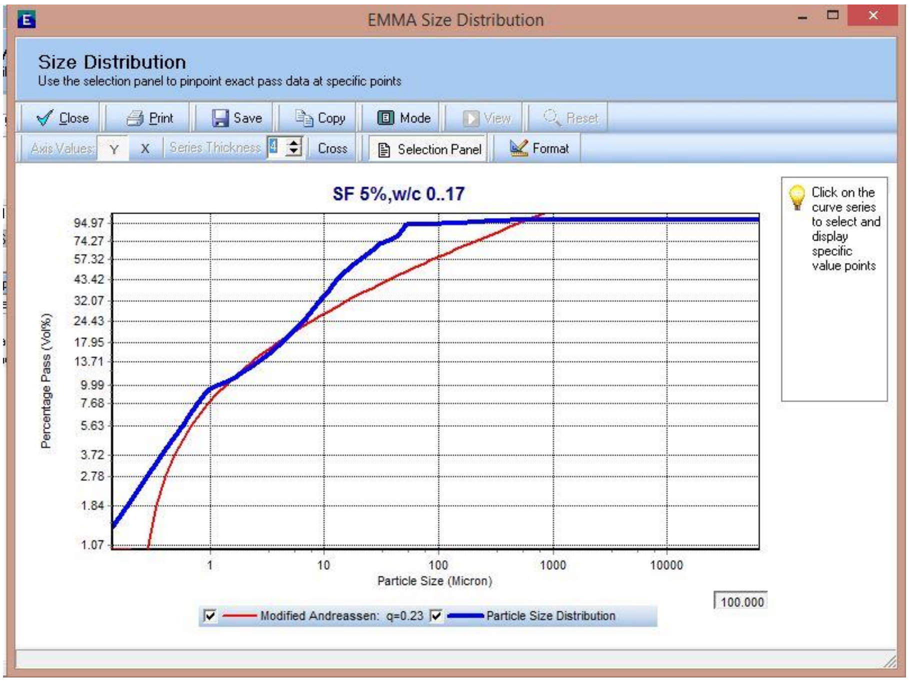


Figure 2: EMMA Analysis OPC 53 (80%) + Ultrafine slag (20%), w/c ratio=0.25

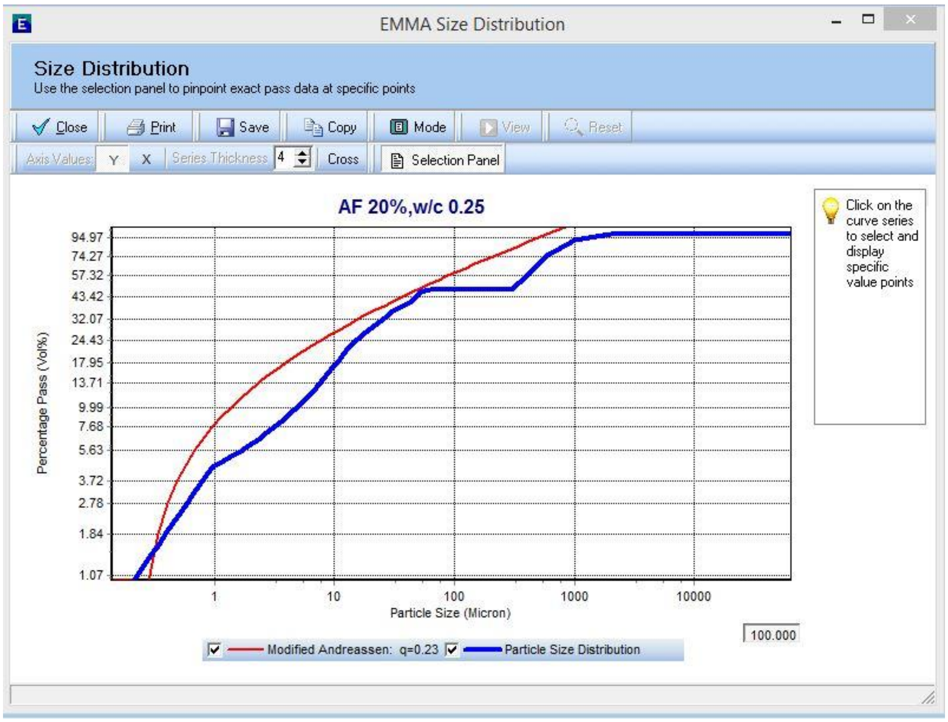
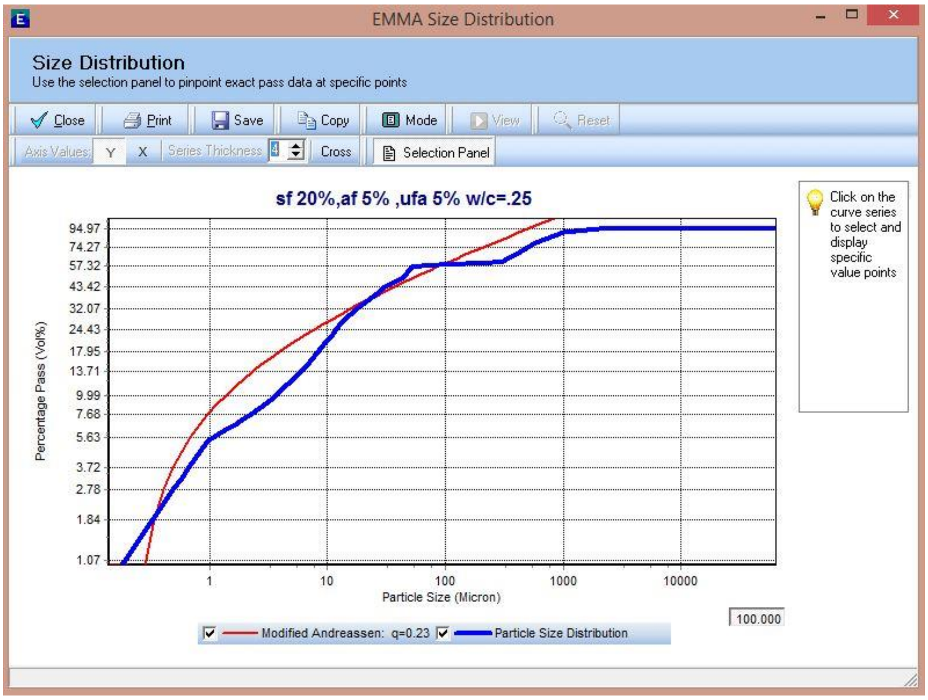


Figure 3: EMMA Analysis OPC 53 (70%) + Silica fume (10%) + Ultra-fine Slag (20%) w/c ratio=0.25

Figure 4: EMMA Analysis OPC 53 (70%) + Silica fume (10%) + Ultra-fine Slag (20%), w/c ratio=0.25

Figure 5: EMMA Analysis OPC 53 (70%) + Silica fume (10%) + Ultra-fine slag (15%) + Ultra-fine fly ash (5%), w/c ratio =0.25

Figure 6: EMMA Analysis OPC 53 (70%) + Silica fume (20%) + Alcofine (5%) + Ultra-fine fly ash (5%), w/c ratio =0.25



3.6 Super Plasticizer Optimization

The superplastizer used is 100% Poly Carboxylate Ether with Solid content of 36%.

The Marsh cone test and the Mini Slump test are performed to understand the behaviour of the mixture in different proportions of the superplastizers. The marsh cone test gives an idea about the viscosity of the mixture under different proportions of the superplastizers. The time taken for the flow of 800ml of cement paste is noted for each mix under different proportions of SP and the less the time, the more the workability of the mix in that SP proportion. The mini slump test is also to find the workability of the mix. The more the diameter of the spread in the Mini Slump test, the more the workability of the mix.

The following are the results obtained in the SP optimization.

Table 7: SP optimisation for OPC (80%) +Alcofine (20%), w/c Ratio=0.25

Total Cementitious Material (g)	Cement (g)	Ultra-fine slag (20%) (g)	Water(g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content(g)	Marsh cone test (sec)	Mini slump (mm)
1745.4	1396.32	349.08	436.35	1	0.36	17.454	6.28344	425.1794	90	200
1745.4	1396.32	349.08	436.35	1.25	0.45	21.8175	7.8543	422.3868	80	225
1745.4	1396.32	349.08	436.35	1.5	0.54	26.181	9.42516	419.5942	83	226
1745.4	1396.32	349.08	436.35	1.75	0.63	30.5445	10.99602	416.8015	83	217
1745.4	1396.32	349.08	436.35	2	0.72	34.908	12.56688	414.0089	79	217
1745.4	1396.32	349.08	436.35	3	1.08	52.362	18.85032	402.8383	109	214
1745.4	1396.32	349.08	436.35	4	1.44	69.816	25.13376	391.6678	114	207

Figure 7: Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

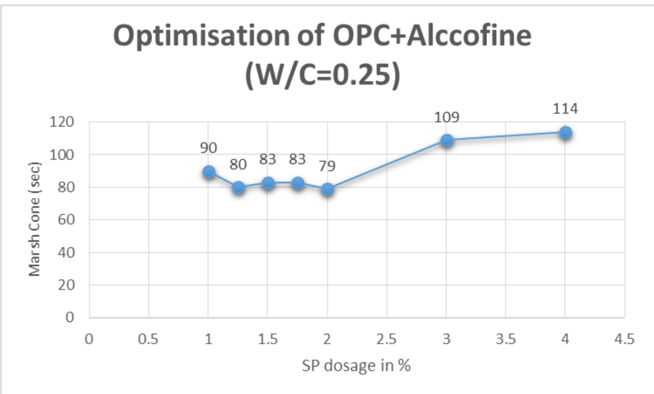


Figure 8: Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

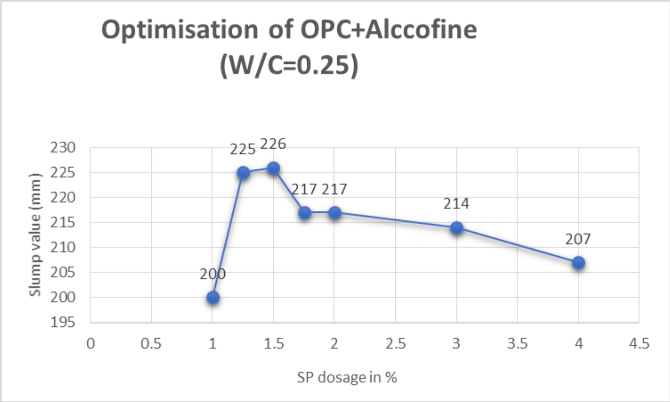


Table 8: SP optimisation for OPC (70%) +Alcofine (20%) +Silica fume (10%), w/c =0.25

Total cementitious material (g)	Cement (g)	Silica fume (10%) (g)	Alcofine (20%)	Water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Mini slump (mm)
1678.996	1175.298	167.8996	335.79929	419.7491	1	16.78996	409.0035	125	193
1678.996	1175.298	167.8996	335.79929	419.7491	1.5	25.18495	403.6307	116	197
1678.996	1175.298	167.8996	335.79929	419.7491	2	33.57993	398.258	135	198
1678.996	1175.298	167.8996	335.79929	419.7491	2.5	41.97491	392.8852	151	191
1678.996	1175.298	167.8996	335.79929	419.7491	3	50.36989	387.5124	127	203
1678.996	1175.298	167.8996	335.79929	419.7491	3.5	58.76488	382.1396	137	200
1678.996	1175.298	167.8996	335.79929	419.7491	4	67.15986	376.7668	139	198

Figure 9: Marsh Cone values graph for SP Optimization of OPC (70%) +Alcofine (20%) +Silica fume (10%), w/c =0.25

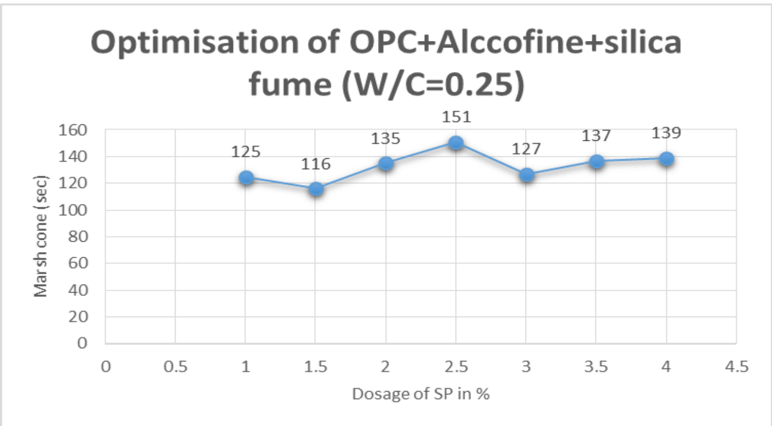


Table 9: SP optimisation for OPC (70%) +Silica fume (20%) +Alcofine (10%) w/c Ratio=0.25

Total cementitious material (g)	Cement (g)	Silica Fume (20%) (g)	Alcofine (10%)	Water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1707.556	1195.289	341.5113	170.75564	426.8891	1	17.07556	415.9607	No flow	117
1707.556	1195.289	341.5113	170.75564	426.8891	2	34.15113	405.0324	209	175
1707.556	1195.289	341.5113	170.75564	426.8891	2.5	42.68891	399.5682	182	180
1707.556	1195.289	341.5113	170.75564	426.8891	3	51.22669	394.104	181	185
1707.556	1195.289	341.5113	170.75564	426.8891	3.5	59.76447	388.6398	215	175
1707.556	1195.289	341.5113	170.75564	426.8891	4	68.30226	383.1757	212	187
1707.556	1195.289	341.5113	170.75564	426.8891	4.5	76.84004	377.7115	204	182

Figure 10: Mini Slump values graph for SP Optimization of OPC (70%) +Silica Fume (20%) +Alcofine (10%), w/c Ratio=0.25

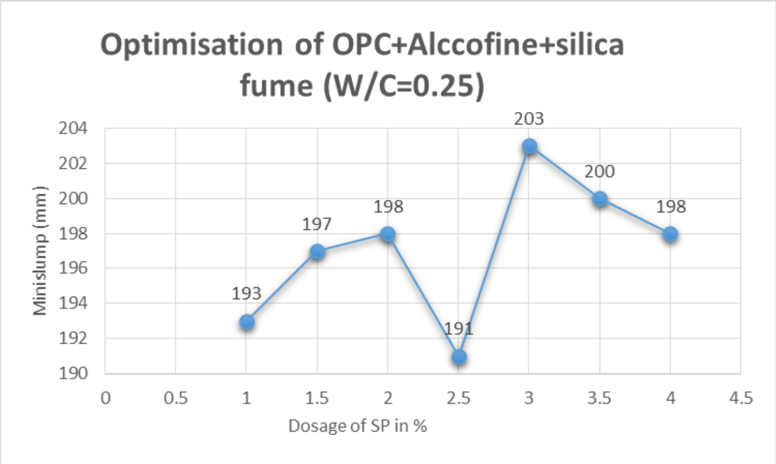


Figure 11: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (20%) +Alcofine (10%), w/c Ratio=0.25

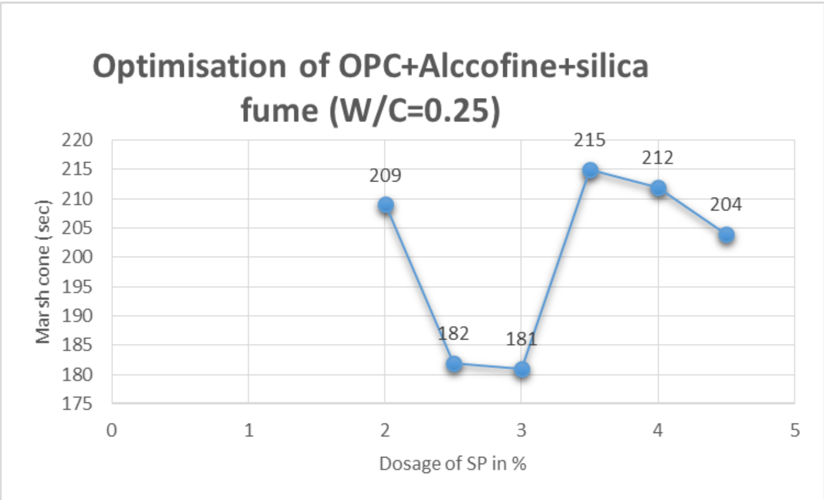


Table 10: SP optimisation for OPC (70%) +Silica fume (10%) +Alcofine (15%) + Ultrafine fly ash (5%), w/c =0.25

Total cementitious material (g)	Cement (g)	Silica Fume (10%) (g)	Alcofine (15%)	UFA (5%)	Water (g)	SP (%)	SP in ml	Modified water content (g)	Marsh cone test (sec)	Mini Slump (mm)
1680.359	1176.25	168.035	252.053	84.0179	420.089	1	16.8035	409.335	108	197
1680.359	1176.25	168.035	252.053	84.0179	420.089	2	33.6071	398.581	107	200
1680.359	1176.25	168.035	252.053	84.0179	420.089	2.5	42.0089	393.204	125	197
1680.359	1176.25	168.035	252.053	84.0179	420.089	3	50.4107	387.827	126	202
1680.359	1176.25	168.035	252.053	84.0179	420.089	3.5	58.8125	382.448	116	203
1680.359	1176.25	168.035	252.053	84.0179	420.089	4	67.2143	377.072	145	205
1680.359	1176.25	168.035	252.053	84.0179	420.089	4.5	75.6161	371.695	167	201

Figure 12: Mini Slump values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c =0.25

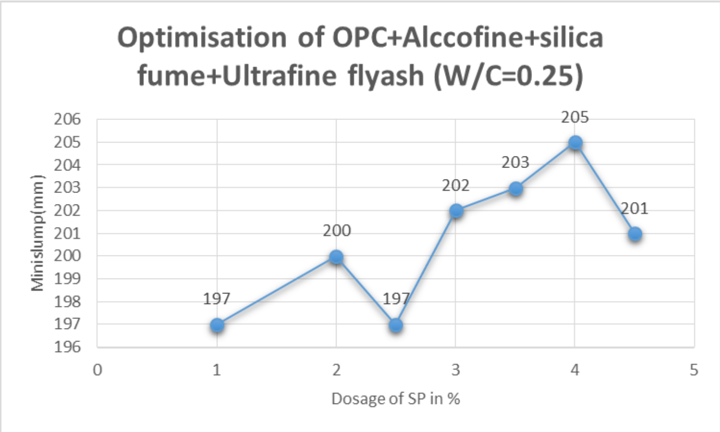


Figure 13: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c =0.25

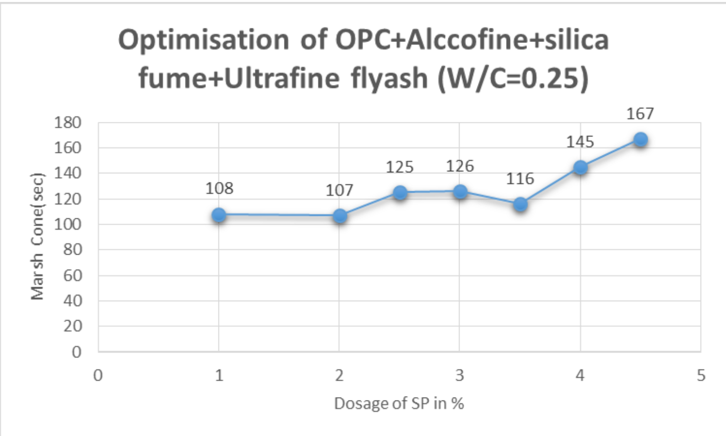


Table 11: SP optimisation for OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.25

Total cementitious material (g)	Cement (g)	Silica fume (5%) (g)	Alcofine (20%)	UFA (5%)	water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1666.412	1166.4	83.320	333.282	83.320	416.60	1	16.664	405.938	77	229
1666.412	1166.4	83.320	333.282	83.320	416.60	1.5	24.996	400.6055	89	217
1666.412	1166.4	83.320	333.282	83.320	416.60	2	33.328	395.273	66	232
1666.412	1166.4	83.320	333.282	83.320	416.60	2.5	41.660	389.9405	103	215
1666.412	1166.4	83.320	333.282	83.320	416.60	3	49.992	384.6079	102	218
1666.412	1166.4	83.320	333.282	83.320	416.60	3.5	58.323	379.2754	103	215
1666.412	1166.4	83.320	333.282	83.320	416.60	4	66.656	373.9429	117	187

Figure 14: Mini Slump values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.25

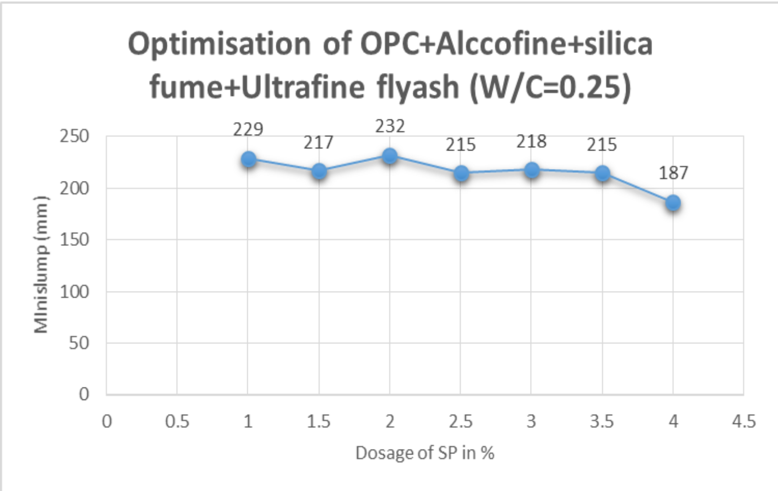
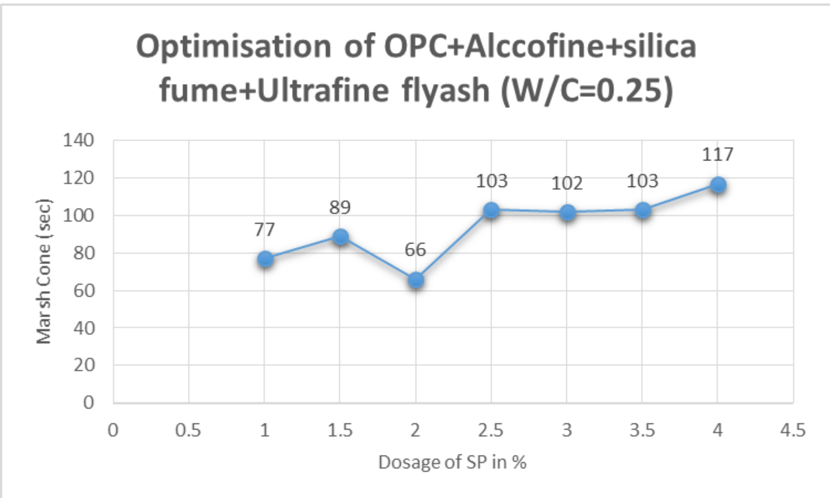


Figure 15: Marsh Cone values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.25



From the above graphs, the optimum SP values were found for each of the mix proportions and they are

OPC 53(80%) + Ultra-fine slag(20%) ,w/c ratio=0.25	1.5%
OPC 53 (70%)+ Ultra-fine slag (20%)+silica fume(10%) , w/c ratio=0.25	3%
OPC 53 (70%)+ Ultra-fine slag (10%)+silica fume(20%) , w/c ratio=0.25	4%
OPC53(70%)+ Ultra-fine slag (10%)+silica fume(15%)+Ultra-fine fly ash (5%),w/c=0.25	1%
OPC53(70%)+ Ultra-fine slag (20%)+silica fume(5%)+ Ultra-fine fly ash (5%),w/c=0.25	1.5%

Table 12: SP optimisation for OPC (80%) +Alcofine (20%), W/c Ratio=0.19

Total Cementitious material (g)	Cement (g)	Alcofine (20%) (g)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini slump (mm)
1949.5694	1559.656	389.91	370.42	.75	.27	14.62	5.2638	361.06	DISCONT. FLOW	158.4
1949.5694	1559.656	389.91	370.42	1	.36	19.5	7.0184	357.94	DISCONT. FLOW	179.7
1949.5694	1559.656	389.91	370.42	1.25	.45	24.37	8.77331	354.82	200.6	194.1
1949.5694	1559.656	389.91	370.42	1.5	.54	29.24	10.528	351.70	184.2	215.4
1949.5694	1559.656	389.91	370.42	1.75	.63	34.12	12.282	348.58	161.4	230.5

Figure 16: Marsh Cone values graph for SP Optimization of

OPC (80%) + Ultra-fine slag (20%)

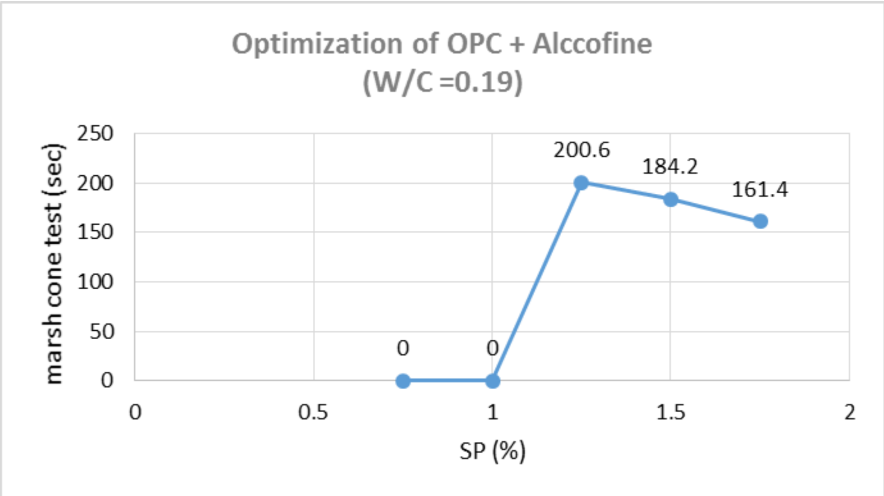


Figure 17: Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

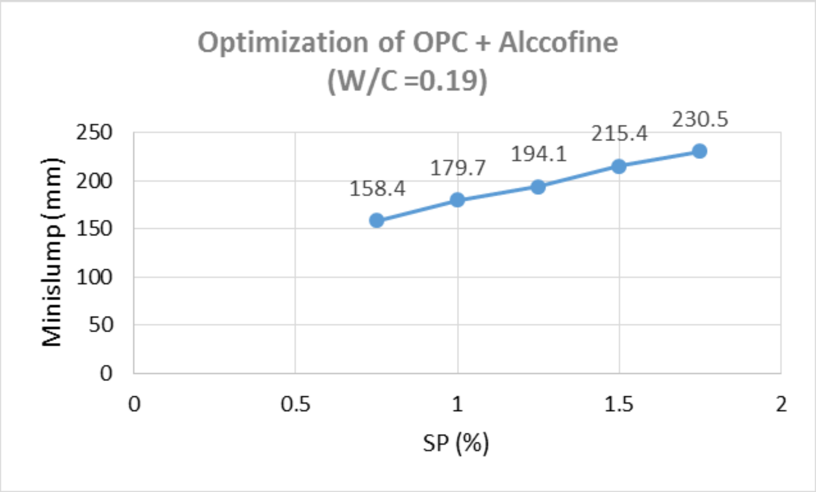


Table 13: SP optimisation for OPC (80%) +Silica Fume (20%), w/c Ratio=0.19

Total cementitious material (g)	Cement (g)	Silica fume (20%) (g)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini Slump (mm)
1876.676	1501.34	375.34	356.57	4.75	1.71	89.142	32.09115	299.52	DISCONT. FLOW	136
1876.676	1501.34	375.34	356.57	5	1.8	93.833	33.78016	296.51	DISCONT. FLOW	145.6
1876.676	1501.34	375.34	356.57	5.25	1.89	98.525	35.46917	293.51	308.52	165.95
1876.676	1501.34	375.34	356.57	6	2.16	112.60	40.53619	284.50	307.2	165.1

Figure18: Mini Slump values graph for SP Optimization of OPC (80%) + Silica Fume (20%)

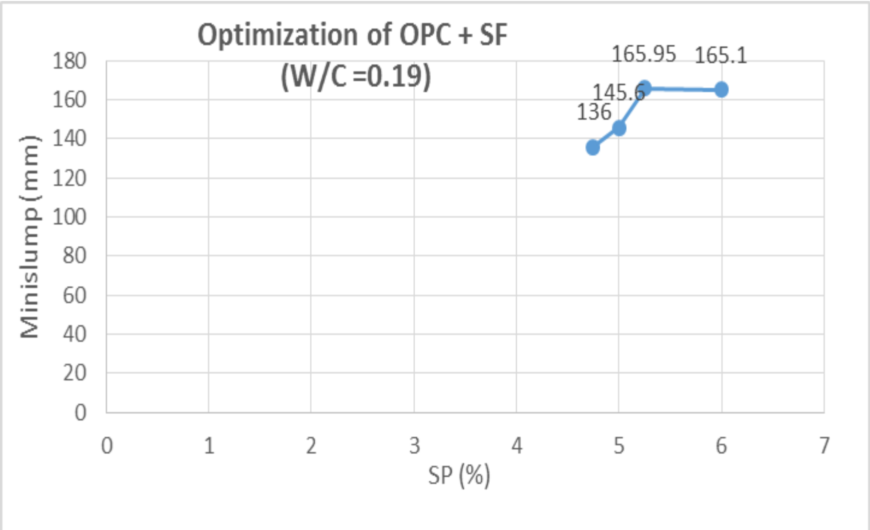


Table 14: SP optimisation for OPC (70%) +Alcofine (20%) +Silica fume (10%), w/c =0.19

Total Cementitious material (g)	Cement (g)	Alcofine (20%) (g)	Silica Fume (10%)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini slump (mm)
1902.471	1332	380.494	190.2	361.47	1	0.36	19.02	6.8489	349.29	NO FLOW	160
1902.471	1332	380.494	190.2	361.47	1.5	0.54	28.53	10.273	343.21	NO FLOW	167
1902.471	1332	380.494	190.2	361.47	1.75	0.63	33.29	11.986	340.16	229.09	171
1902.471	1332	380.494	190.2	361.47	2	0.72	38.04	13.698	337.12	245.29	175
1902.471	1332	380.494	190.2	361.47	2.25	0.81	42.80	15.41	334.07	207	182.5

Figure 19: Mini Slump values graph for SP Optimization of OPC (70%) +Alcofine (20%) +Silica fume (10%), w/c =0.19

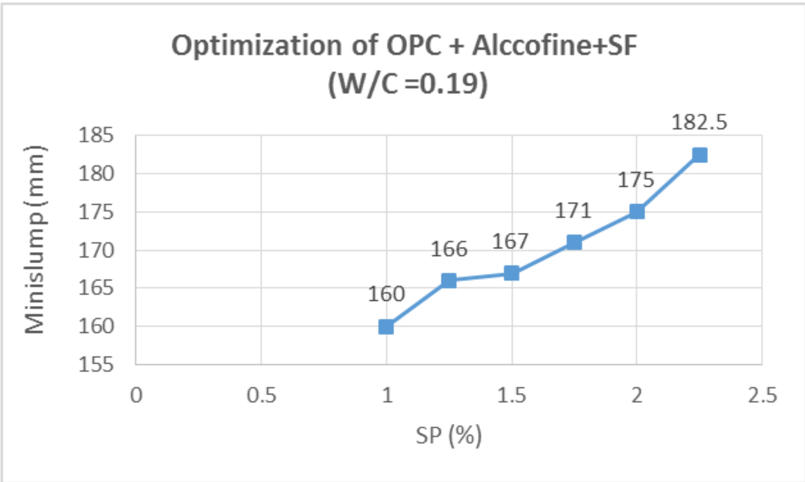


Table 15: SP optimisation for OPC (70%) +Silica fume (20%) +Alcofine (10%) w/c Ratio=0.19

Total cementitious material (g)	Cement (g)	Silica fume (20%) (g)	Alcofine (10%)	Water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1867.086	1306.960	373.42	186.7086344	354.75	1	18.671	342.8	NO FLOW	NO SLUMP
1867.086	1306.960	373.42	186.7086344	354.75	2	37.342	330.85	NO FLOW	148
1867.086	1306.960	373.42	186.7086344	354.75	2.5	46.677	324.87	DISCONT. FLOW	152
1867.086	1306.960	373.42	186.7086344	354.75	2.75	51.345	321.89	DISCONT. FLOW	157.5
1867.086	1306.960	373.42	186.7086344	354.75	3	56.013	318.90	DISCONT. FLOW	155
1867.086	1306.960	373.42	186.7086344	354.75	3.25	60.68	315.91	360	158.2
1867.086	1306.960	373.42	186.7086344	354.75	3.5	65.348	312.92	438	157.3

Figure 20: Mini Slump values graph for SP Optimization of OPC (70%) +Silica Fume (20%) +Alcofine (10%), w/c Ratio=0.19

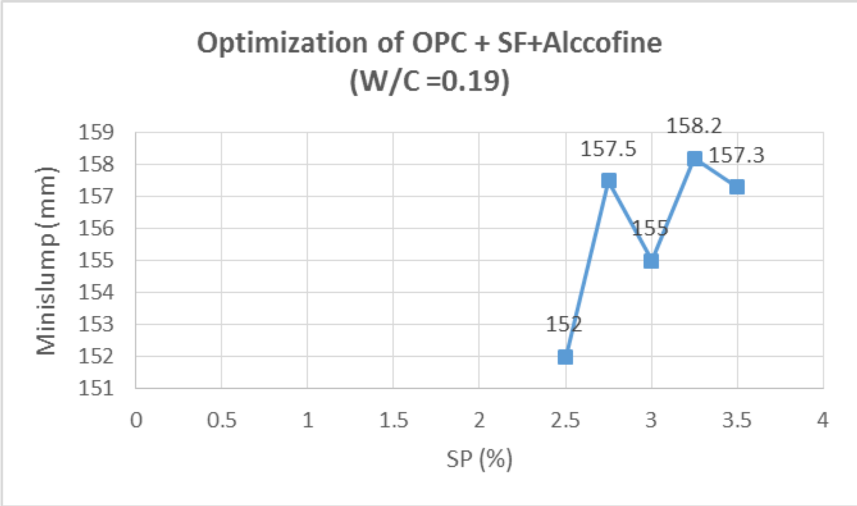


Figure 21: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (20%) +Alcofine (10%), W/c Ratio=0.19

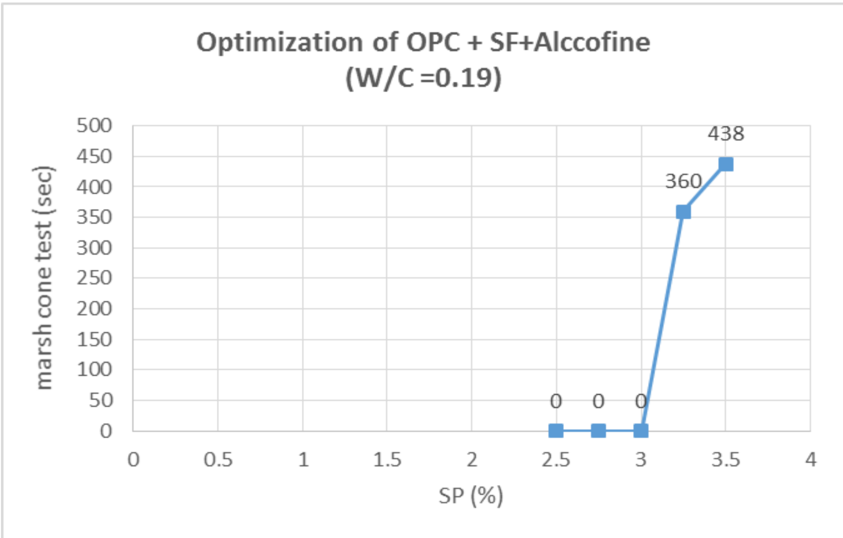


Table 16: SP optimisation for OPC (70%) +Silica fume (10%) +Alcofine (15%) + Ultrafine fly ash (5%), W/c =0.19

Total Cementitious material (g)	Cement (g)	Silica fume (10%) (g)	Alcofine (15%)	UFA (5%)	Water (g)	SP (%)	SP in ml	modified water content (g)	marsh cone test (sec)	Mini slump (mm)
1886.3	1320.43	188.63	282.949	94.32	358.40	4.75	89.601	301.06	306.6	143
1886.3	1320.43	188.63	282.949	94.32	358.40	5	94.316	298.04	295.1	156
1886.3	1320.43	188.63	282.949	94.32	358.40	5.5	103.75	292.00	291.3	156

Figure 22: Mini Slump values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c =0.19

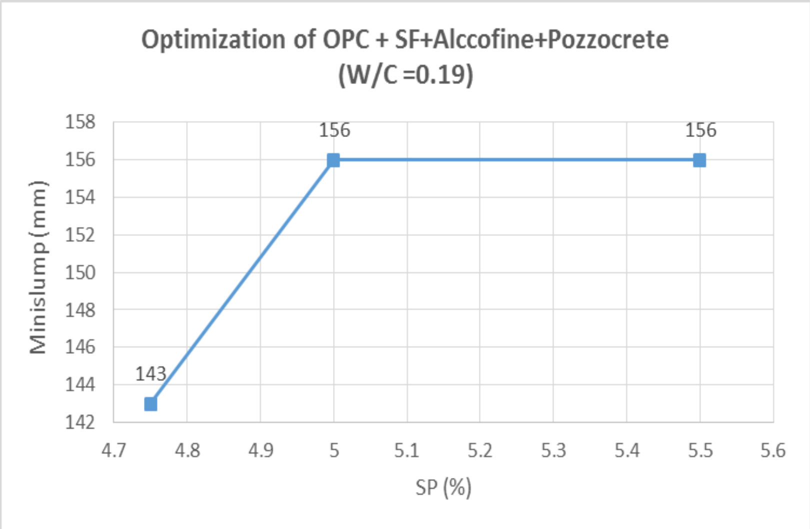


Figure 23: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c =0.19

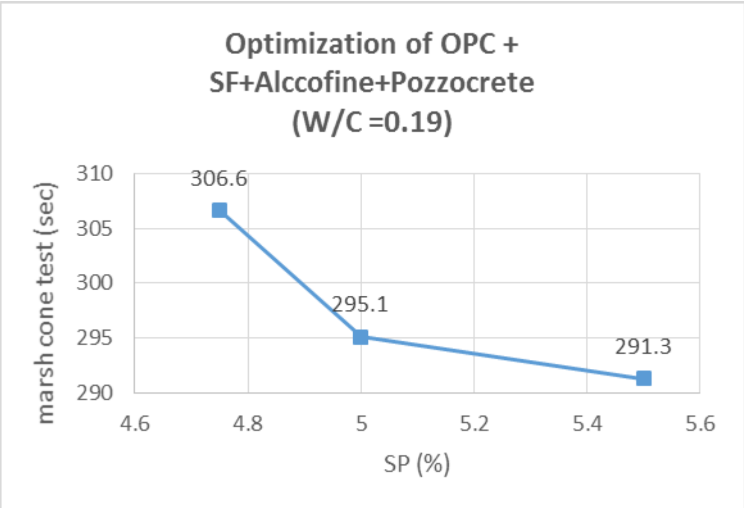


Table 17: SP optimisation for OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.19

Total Cementitious material (g)	Cement (g)	Silica fume (5%) (g)	Alcofine (20%)	UFA (5%)	water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1886.3	1320.431	94.32	377.265	94.32	358.40	0.5	9.43	352.37	DISCONT. FLOW	135
1886.3	1320.431	94.32	377.265	94.32	358.40	0.75	14.14	349.35	341.7	156
1886.3	1320.431	94.32	377.265	94.32	358.40	1	18.86	346.33	187.6	169.5

Figure 24: Mini Slump values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.19

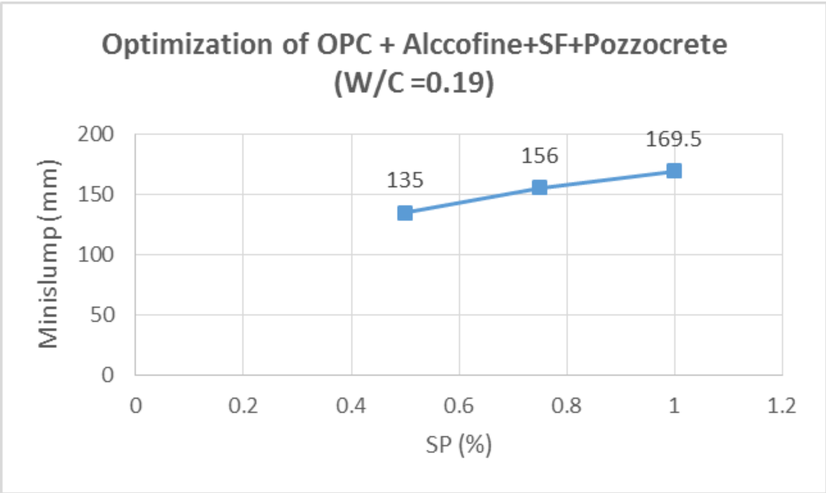
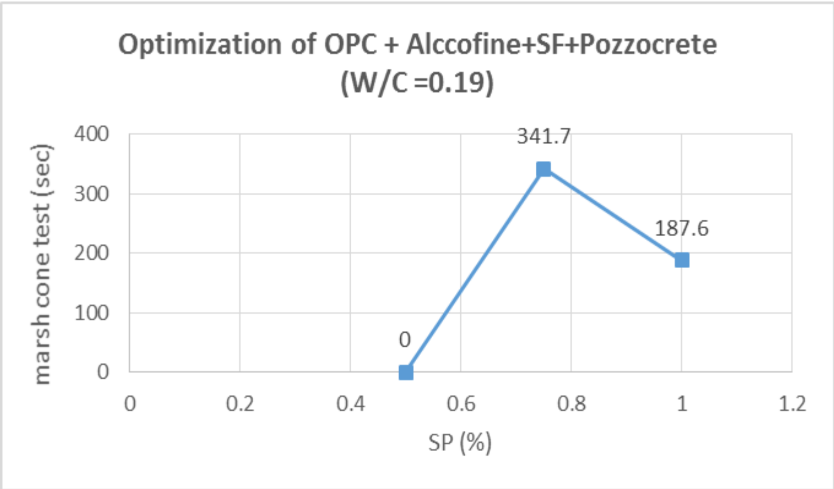


Figure 25: Marsh Cone values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.19



From the above graphs, the optimum SP values were found for each of the mix proportions and they are

OPC 53(80%) + Ultra-fine slag(20%) ,w/c ratio=0.19	1.25%
OPC 53(80%) + Silica fume (20%) ,w/c ratio=0.19	5.25%
OPC 53 (70%)+ Ultra-fine slag (20%)+silica fume(10%) , w/c ratio=0.19	2%
OPC 53 (70%)+ Ultra-fine slag (10%)+silica fume(20%) , w/c ratio=0.19	3.25%
OPC53(70%)+ Ultra-fine slag (10%)+silica fume(15%)+Ultra-fine fly ash (5%),w/c=0.19	5%
OPC53(70%)+ Ultra-fine slag (20%)+silica fume(5%)+ Ultra-fine fly ash (5%),w/c=0.19	1%

Table 18: SP optimisation for OPC (80%) +Alcofine (20%), w/c Ratio=0.20

Total Cementitious material (g)	Cement (g)	Alcofine (20%) (g)	Water (g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)	Minislu mp (mm)
1912.288	1529.83	382.46	382.46	1	.36	19.12	6.88	370.22	153.2	183
1912.288	1529.83	382.46	382.46	1.25	.45	23.9	8.60	367.16	148.6	185
1912.288	1529.83	382.46	382.46	1.5	.54	28.68	10.326	364.10	141.8	192
1912.288	1529.83	382.46	382.46	1.75	.63	33.47	12.047	361.04	130.6	200

Figure 26: Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

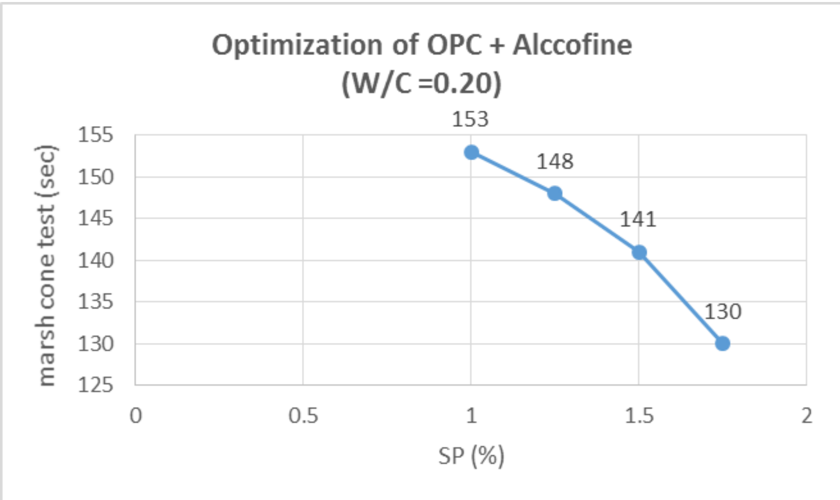


Figure 27: Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

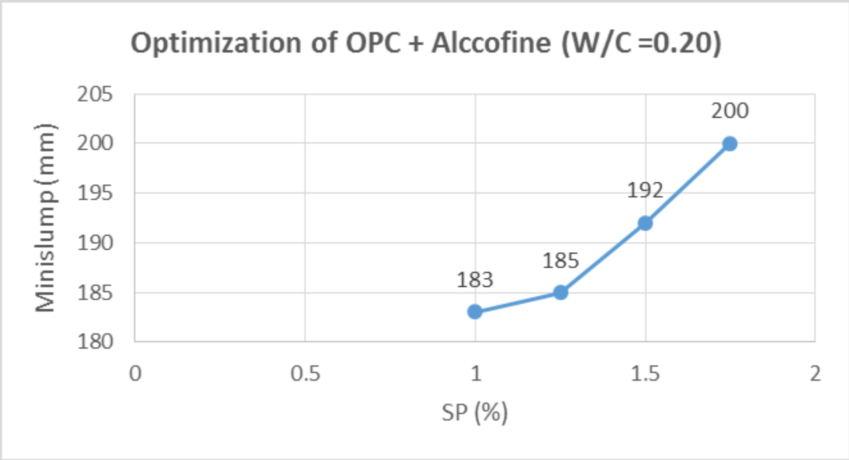


Table 19: SP optimisation for OPC (80%) +Silica Fume (20%), w/c Ratio=0.20

Total Cementitious material (g)	Cement (g)	Silica fume (20%) (g)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini slump (mm)
1842.1	1473.68	368.42	368.42	4.75	1.71	87.5	31.5	312.42	DISCON T. FLOW	141
1842.1	1473.68	368.42	368.42	5	1.8	92.105	33.158	309.47	DISCON T. FLOW	141
1842.1	1473.68	368.42	368.42	5.25	1.89	96.711	34.816	306.53	280.6	155.9
1842.1	1473.68	368.42	368.42	6	2.16	110.53	39.789	297.68	223.5	157.2

Figure28: Mini Slump values graph for SP Optimization of OPC (80%) + Silica Fume (20%)

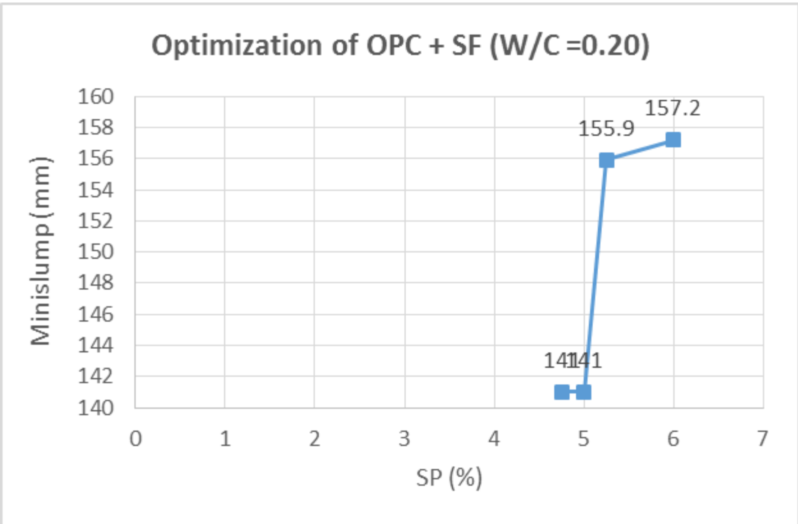


Table 20: SP optimisation for OPC (70%) +Alcofine (20%) +Silica fume (10%) w/c Ratio=0.20

Total Cementitious material (g)	Cement (g)	Alcofine (20%) (g)	Silica Fume (10%)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini slump (mm)
1867	1306.8	373.39	186.7	373.39	.75	.27	14	5.041	364.43	DISCONT FLOW	143.8
1867	1306.8	373.39	186.7	373.39	1	.36	18.7	6.721	361.44	297	152.5
1867	1306.8	373.39	186.7	373.39	1.25	.45	23.3	8.401	358.45	248.7	174
1867	1306.8	373.39	186.7	373.39	1.5	.63	28	10.08	355.47	224.5	179
1867	1306.8	373.39	186.7	373.39	1.75	.72	32.7	11.76	352.48	214.6	186
1867	1306.8	373.39	186.7	373.39	2	.81	37.3	13.44	349.49	210.5	191

Figure 29: Mini Slump values graph for SP Optimization of OPC (70%) +Alcofine (20%) +Silica fume (10%), w/c Ratio=0.20

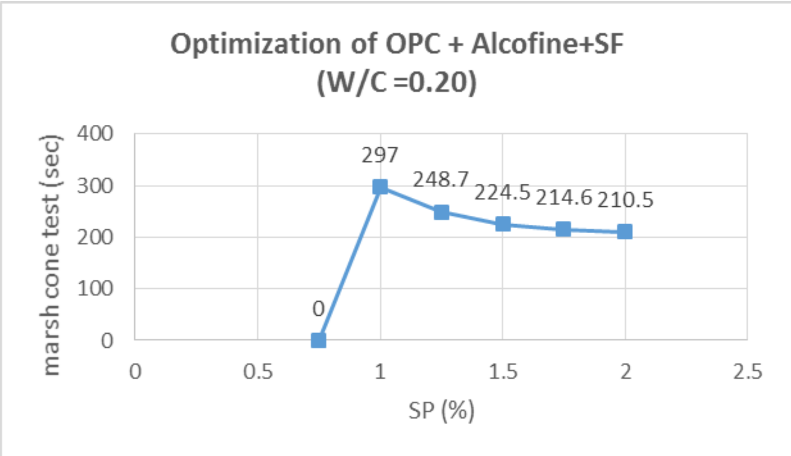


Table 21: SP optimisation for OPC (70%) +Silica fume (20%) +Alcofine (10%) w/c Ratio=0.20

Total cementitious material (g)	Cement (g)	Silica fume (20%) (g)	Alcofine (10%)	Water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1832.9	1283.005	366.57	183.286	366.57	4.5	82.47	310.85	DISCONT. FLOW	119
1832.9	1283.005	366.57	183.286	366.57	5	91.64	307.92	311.2	155.8
1832.9	1283.005	366.57	183.286	366.57	6	109.97	296.19	300.1	160.5

Figure 30: Mini Slump values graph for SP Optimization of OPC (70%) +Silica Fume (20%) +Alcofine (10%), w/c Ratio=0.20

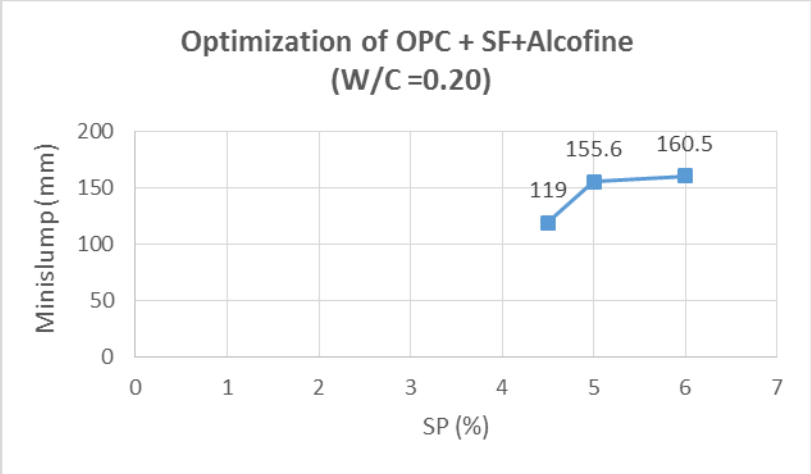


Figure 31: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (20%) +Alcofine (10%), w/c Ratio=0.20

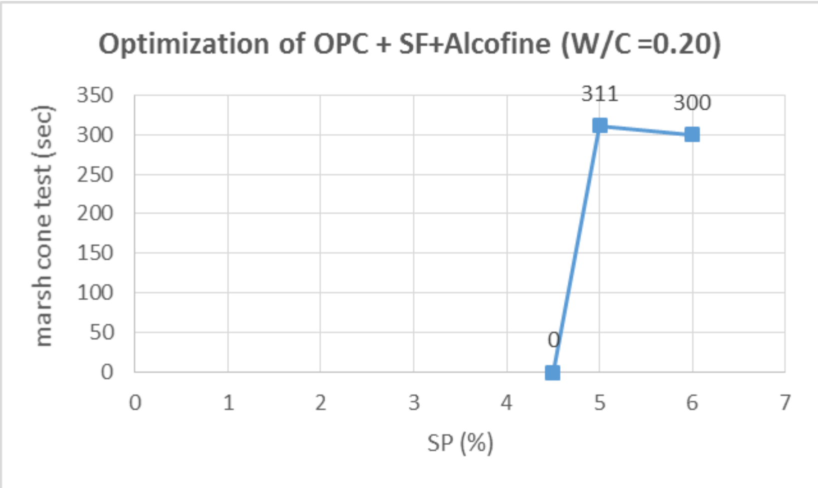


Table 22: SP optimisation for OPC (70%) +Silica fume (10%) +Alcofine (15%) + Ultrafine fly ash (5%), w/c Ratio =0.20

Total cementitious material (g)	Cement (g)	Silica fume (10%) (g)	Alcofine (15%)	UFA (5%)	Water (g)	SP (%)	SP in ml	Modified water content (g)	Marsh cone test (sec)	Mini Slump (mm)
1851.4	1295.98	185.14	277.71	92.57	370.28	4.5	83.313	316.96	260.7	151.3
1851.4	1295.98	185.14	277.71	92.57	370.28	4.75	87.942	314.00	247.3	154.5
1851.4	1295.98	185.14	277.71	92.57	370.28	5	92.57	311.04	247.1	154

Figure 32: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c Ratio =0.20

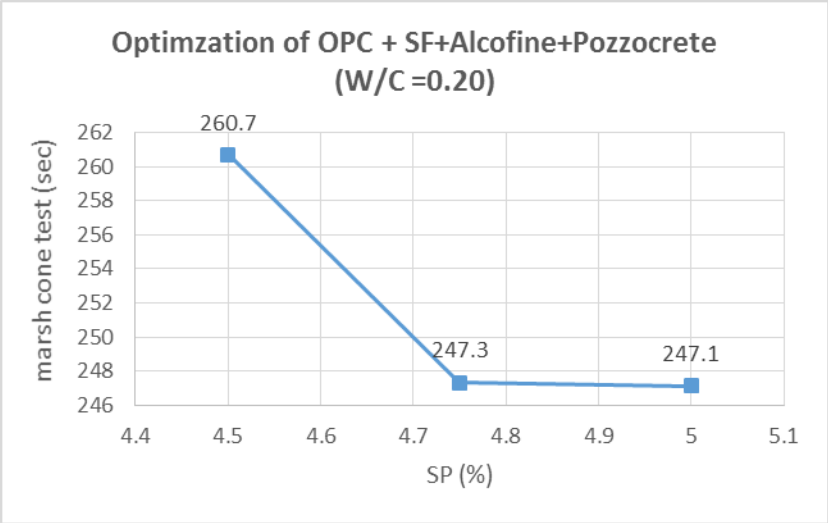


Figure 33: Mini Slump values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c Ratio=0.20

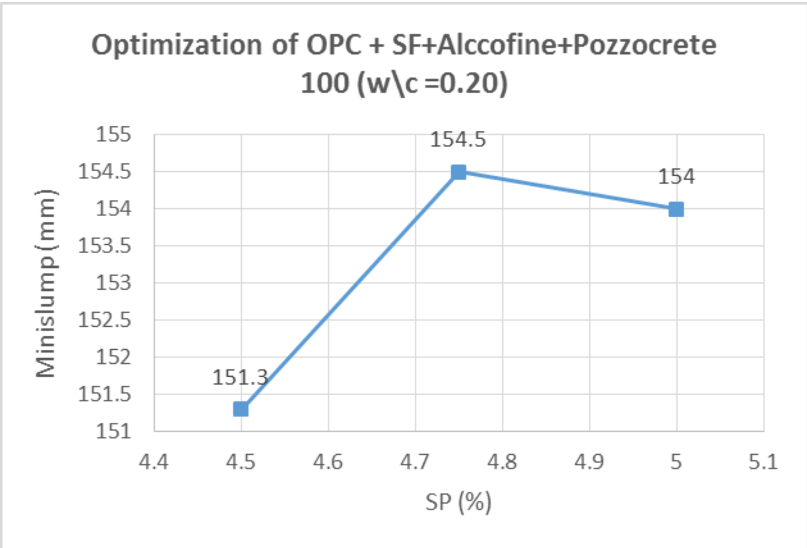


Table 23: SP optimisation for OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c Ratio=0.20

Total cementitious material (g)	Cement (g)	Silica fume (5%) (g)	Alcofine (20%)	UFA (5%)	Water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1851.4	1295.98	92.57	370.28	92.57	370.28	.5	9.25	364.36	157.3	16.2
1851.4	1295.98	92.57	370.28	92.57	370.28	.75	13.88	361.39	149.28	176.6
1851.4	1295.98	92.57	370.28	92.57	370.28	1	18.514	358.43	145.87	185.6
1851.4	1295.98	92.57	370.28	92.57	370.28	1.25	23.14	355.47	139.32	192.4

Figure 34: Mini Slump values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.20

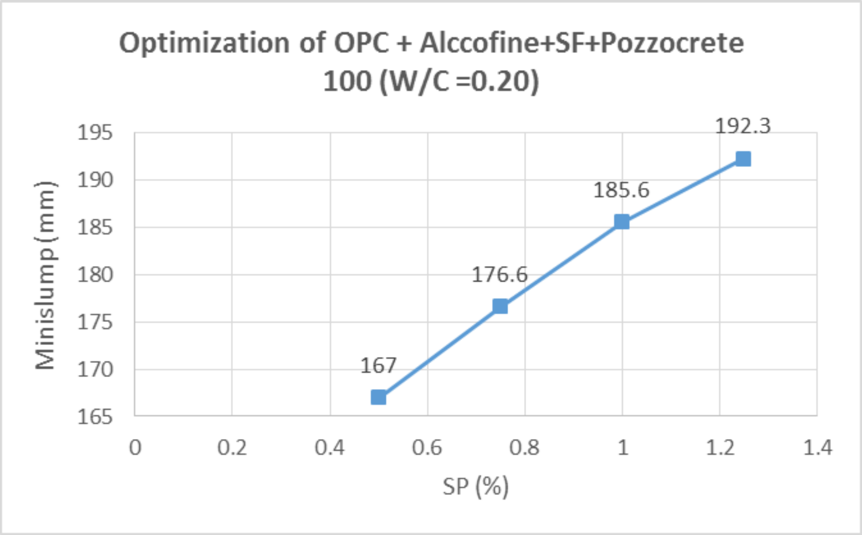
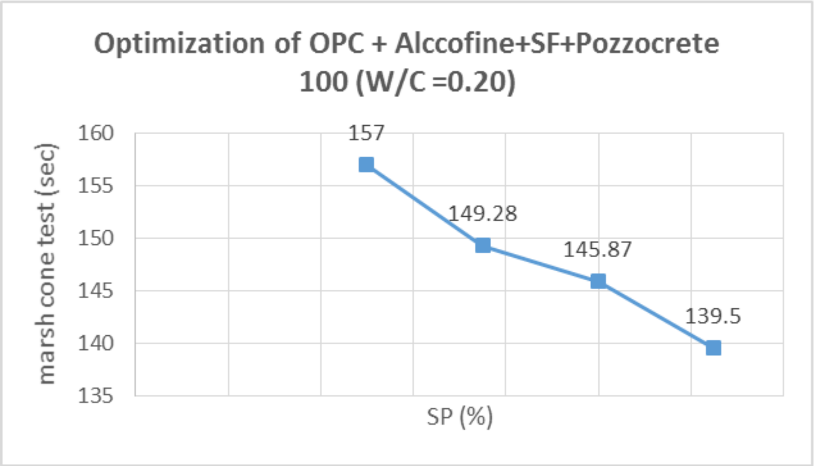


Figure 35: Marsh Cone values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.20



From the above graphs, the optimum SP values were found for each of the mix proportions and they are

OPC 53(80%) + Ultra-fine slag(20%) ,w/c ratio=0.20	1.25%
OPC 53(80%) + Silica fume (20%) ,w/c ratio=0.20	5.25%
OPC 53 (70%)+ Ultra-fine slag (20%)+silica fume(10%) , w/c ratio=0.20	1.25%
OPC 53 (70%)+ Ultra-fine slag (10%)+silica fume(20%) , w/c ratio=0.20	5%
OPC53(70%)+ Ultra-fine slag (10%)+silica fume(15%)+Ultra-fine fly ash (5%),w/c=0.20	4.75%
OPC53(70%)+ Ultra-fine slag (20%)+silica fume(5%)+ Ultra-fine fly ash (5%),w/c=0.20	.75%

Table 24: SP optimisation for OPC (80%) +Alcofine (20%), w/c Ratio=0.21

Total Cementitious material (g)	Cement (g)	Alcofine (20%) (g)	Water (g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)	Mini slump (mm)
1876.405	1501.125	375.28	394.05	.75	.27	14.07	5.0663	385.04	109	197
1876.405	1501.125	375.28	394.05	1	.36	18.76	6.7551	382.04	98.6	200.5
1876.405	1501.125	375.28	394.05	1.25	.45	23.46	8.4438	379.03	84.1	215.6
1876.405	1501.125	375.28	394.05	1.5	.54	28.15	10.133	376.03	80	223

Figure 36: Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

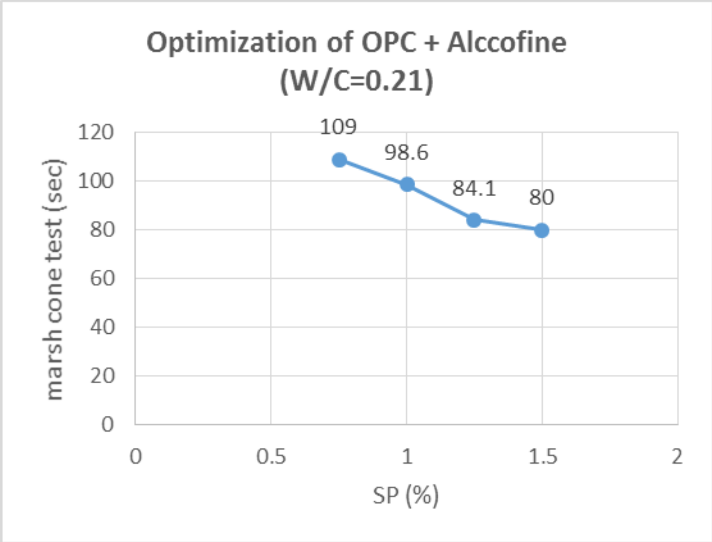


Figure 37: Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

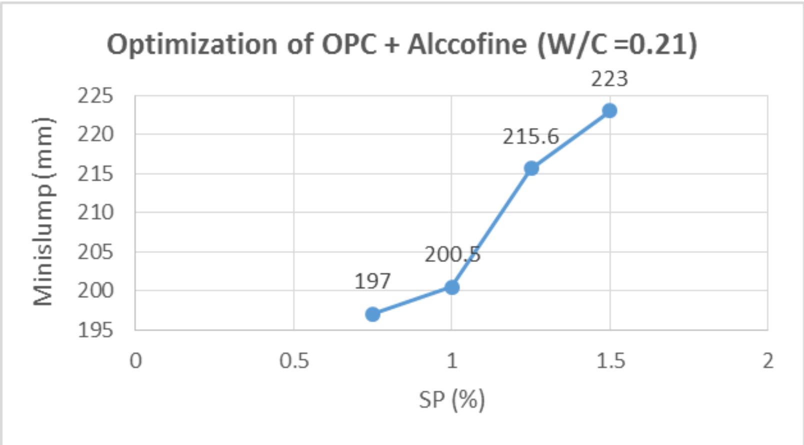


Table 25: SP optimisation for OPC (80%) +Silica Fume (20%), w/c Ratio=0.21

Total cementitious material (g)	Cement (g)	Silica fume (20%) (g)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini Slump (mm)
1808.8	1447	361.76	379.84	4.75	1.71	85.917	30.93	324.86	DISCONT. FLOW	143.2
1808.8	1447	361.76	379.84	5	1.8	90.439	32.558	321.96	DISCONT. FLOW	146
1808.8	1447	361.76	379.84	5.25	1.89	94.961	34.186	319.07	219.2	160.2
1808.8	1447	361.76	379.84	6	2.16	108.53	39.07	310.39	210.7	161.1

Figure 38: Mini Slump values graph for SP Optimization of OPC (80%) + Silica Fume (20%)

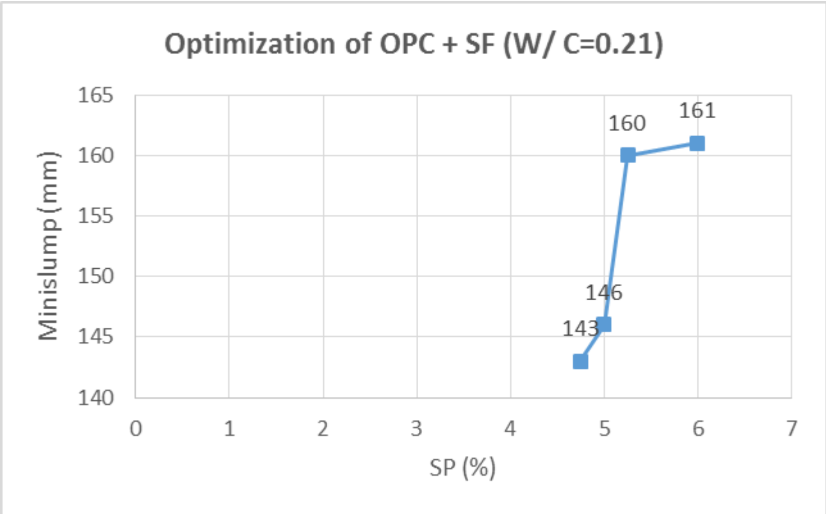


Table 26: SP optimisation for OPC (70%) +Alcofine (20%) +Silica fume (10%) w/c =0.21

Total Cementitious material (g)	Cement (g)	Alcofine (20%) (g)	Silica Fume (10%)	Water (g)	SP (%)	Solid content of SP in %	SP in ml	Solid content BWOC	Modified water content (g)	Marsh cone test (sec)	Mini slump (mm)
1832.7	1282.91	366.54	183.2	384.87	1	.36	18.3	6.598	373.15	192.56	195.5
1832.7	1282.91	366.54	183.2	384.87	1.25	.45	22.9	8.247	370.21	189.2	202
1832.7	1282.91	366.54	183.2	384.87	1.5	.54	27.5	9.897	367.28	185.3	205
1832.7	1282.91	366.54	183.2	384.87	2	.72	36.7	13.2	361.42	182.7	205

Figure 39: Mini Slump values graph for SP Optimization of OPC (70%) +Alcofine (20%) +Silica fume (10%), w/c =0.21

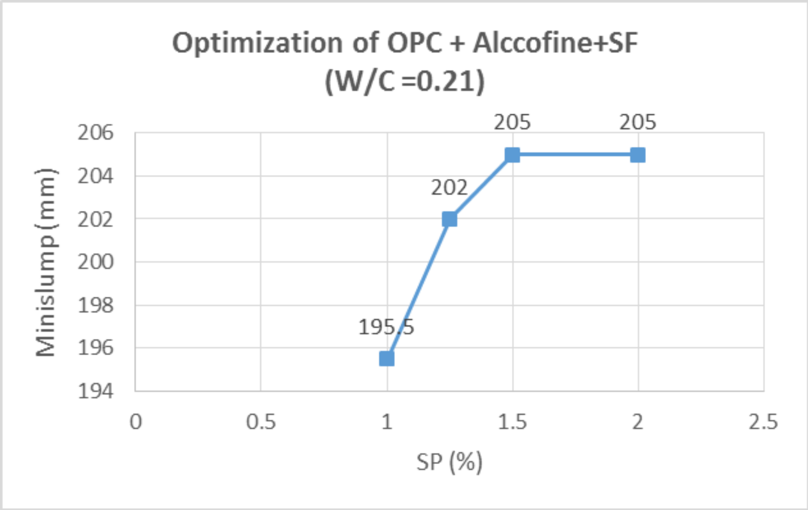


Table 27: SP optimisation for OPC (70%) +Silica fume (20%) +Alcofine (10%) w/c Ratio=0.21

Total Cementitious material (g)	Cement (g)	Silica fume (20%) (g)	Alcofine (10%)	water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Mini slump (mm)
1799.9	1259.91	359.98	179.98	377.97	4.5	80.99	326.14	DISCONT. FLOW	117
1799.9	1259.91	359.98	179.98	377.97	5	89.99	320.38	308.52	165.95
1799.9	1259.91	359.98	179.98	377.97	6	107.99	308.86	294.8	169.2
1799.9	1259.91	359.98	179.98	377.97	6.5	116.99	303.10	286.5	168.1

Figure 40: Mini Slump values graph for SP Optimization of OPC (70%) +Silica Fume (20%) +Alcofine (10%), w/c Ratio=0.21

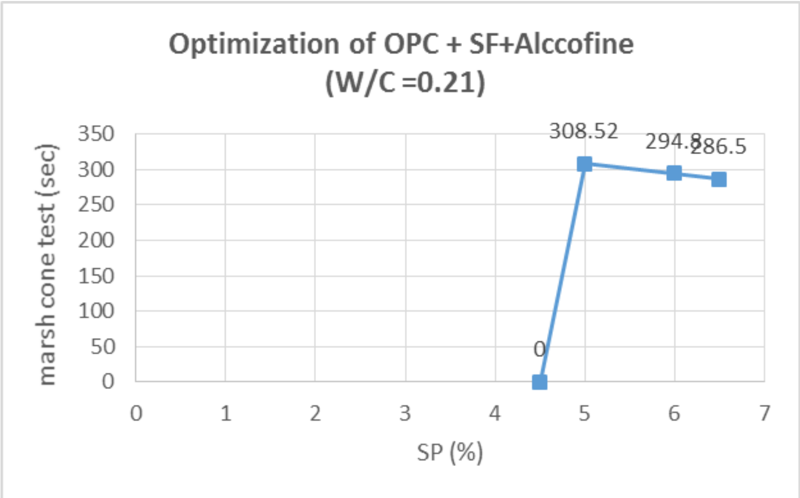


Figure 41: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (20%) +Alcofine (10%), w/c Ratio=0.21

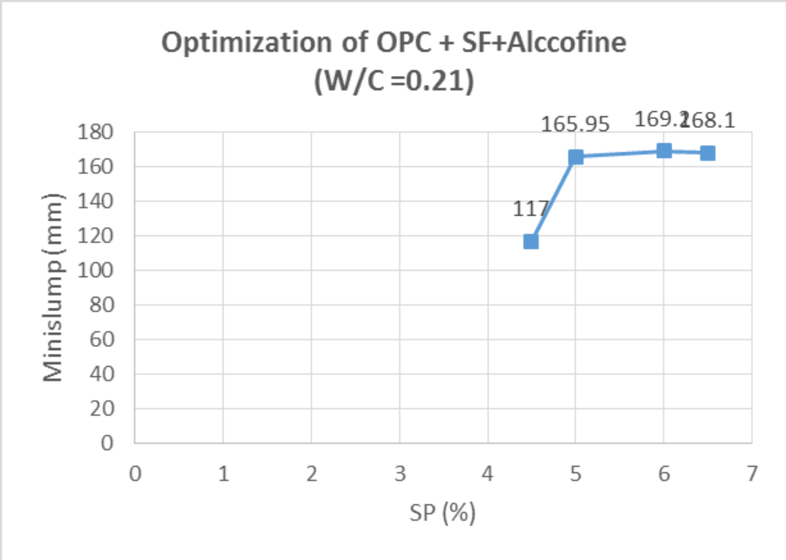


Table 28: SP optimisation for OPC (70%) +Silica fume (10%) +Alcofine (15%) + Ultrafine fly ash (5%), w/c Ratio=0.21

Total Cementitious material (g)	Cement (g)	Silica fume (10%) (g)	Alcofine (15%)	UFA (5%)	Water (g)	SP (%)	SP in ml	Modified water content (g)	Marsh cone test (sec)	Mini slump (mm)
1817.8	1272.42	181.78	272.662	90.89	381.73	.75	13.633	373	269.1	146.5
1817.8	1272.42	181.78	272.662	90.89	381.73	1	18.178	370.03	178.2	163.5
1817.8	1272.42	181.78	272.662	90.89	381.73	2	36.355	358.46	145.5	186
1817.8	1272.42	181.78	272.662	90.89	381.73	2.75	49.988	349.74	148.7	176.05
1817.8	1272.42	181.78	272.662	90.89	381.73	3.75	68.166	338.10	153	181.8
1817.8	1272.42	181.78	272.662	90.89	381.73	4.25	77.254	332.29	191.7	170
1817.8	1272.42	181.78	272.662	90.89	381.73	4.5	81.799	329.38	215.1	165

Figure 42: Mini Slump values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c Ratio=0.21

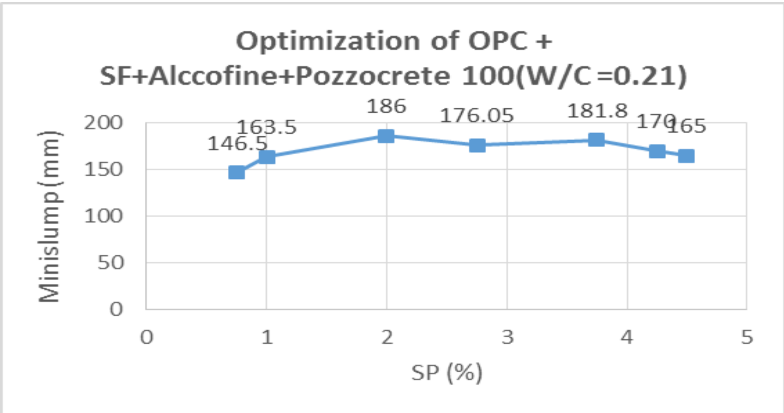


Figure 43: Marsh Cone values graph for SP Optimization of OPC (70%) + Silica fume (10%) +Alcofine (15%) + Ultrafine flyash (5%), w/c Ratio =0.21

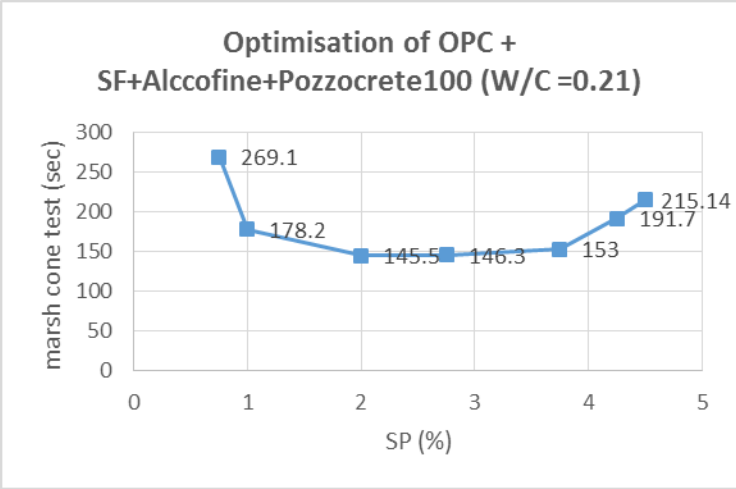


Table 29: SP optimisation for OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c Ratio=0.21

Total Cementitious material (g)	Cement (g)	Silica fume (5%) (g)	Alcofine (20%)	UFA (5%)	Water(g)	SP (%)	SP in ml	Modified water content(g)	Marsh cone test (sec)	Minislump (mm)
1817.8	1272.426	90.89	363.55	90.89	381.73	.5	9.088	375.91	DISCONT. FLOW	NO SLUMP
1817.8	1272.426	90.89	363.55	90.89	381.73	.75	13.633	373	146.7	183
1817.8	1272.426	90.89	363.55	90.89	381.73	1	18.177	370.09	141.9	188.5
1817.8	1272.426	90.89	363.55	90.89	381.73	1.25	22.72	367.19	139.4	189.2
1817.8	1272.426	90.89	363.55	90.89	381.73	1.5	27.26	364.28	136.8	192.3

Figure 44: Mini Slump values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c Ratio=0.21

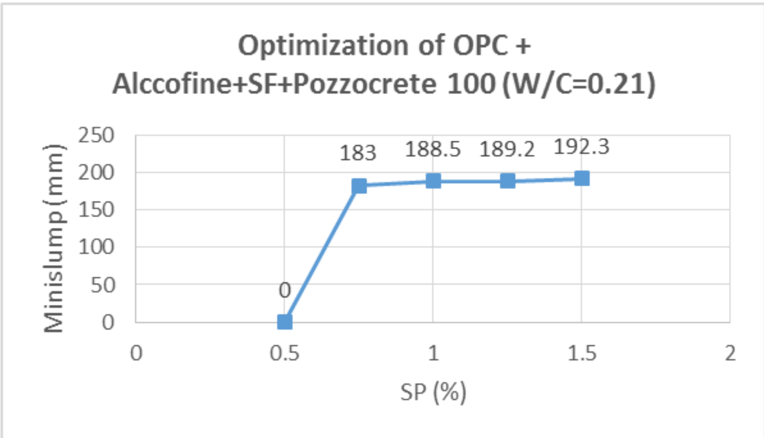
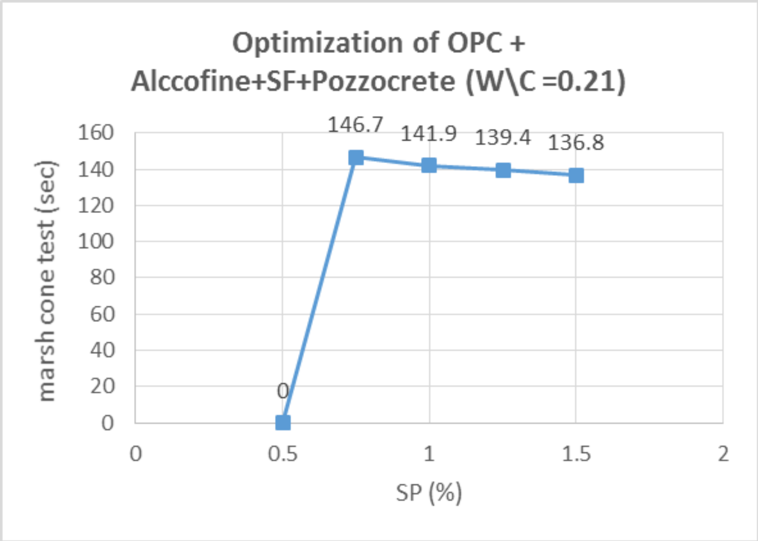


Figure 45: Marsh Cone values graph for SP Optimization of OPC 53 (70%) + Silica fume (5%) + Ultra-fine slag (20%) + Ultra-fine fly ash (5%), w/c ratio=0.21



From the above graphs, the optimum SP values were found for each of the mix proportions and they are

OPC 53(80%) + Ultra-fine slag(20%) ,w/c ratio=0.21	1%
OPC 53(80%) + Silica fume (20%) ,w/c ratio=0.21	5.25%
OPC 53 (70%)+ Ultra-fine slag (20%)+silica fume(10%) , w/c ratio=0.21	1%
OPC 53 (70%)+ Ultra-fine slag (10%)+silica fume(20%) , w/c ratio=0.21	5%
OPC53(70%)+ Ultra-fine slag (10%)+silica fume(15%)+Ultra-fine fly ash (5%),w/c=0.21	2%
OPC53(70%)+ Ultra-fine slag (20%)+silica fume(5%)+ Ultra-fine fly ash (5%),w/c=0.21	.1%

4.7 Casting Calculations

The casting calculations are based on the total volume of the concrete which is 1200ml.According to the proportions of the materials in the concrete, the amounts of various materials has been decided. The SP values has been decided according to the graphs obtained by the marsh cone test and the mini slump tests.

Also in order to overcome the gap grading of aggregates particles (mainly from 10µ-30µ and 300-600µ) we replaced certain percentages of the quartz sand with manufactured sand and secondly quartz sand was replaced with quartz powder in proportion of 40% of Total Cementitious material as well. Then various preliminary test were carried out and casting was done, the results shows that there was an increase in water absorption by 2% (mainly by manufactured sand) which led to increase in water demand. But as water content can't be increased further as it will lead to decrease in strength in certain cases.Various Test were carried out which showed that there was an increase superplasticizer content in range of 0.3-0.6%.

Table 30: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.19

TCM	Cement	UFS	water	quartz sand	SP	Solid content BWOC	modified water content	sand water absorption	Total water content
1350	1080	270	256.50	1314.52	16.875	6.075	245.7	2.629	248.329

Table 31: Casting Calculations for the OPC 53(80%) + Silica fume (20%) w/c Ratio=0.19

TCM	Cement	Silica Fume	Water	Quartz sand	SP	Solid content BWOC	Modified water content	sand water absorption	Total water content
1350	1080	270	256.5	1244.86	70.875	25.515	211.14	2.4897	213.62

Table 32: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%), w/c Ratio=0.19

TCM	Cement	Silica fume	Alcofine	water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	154.28	308.571	293.14	967.76	30.85	11.1085	273.39	1.9355	275.32

Table 33: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%), w/c Ratio=0.19

TCM	Cement	Silica fume	Alcofine	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	308.57	154.28	293.14	967.76	50.142	18.05	261.051	1.9355	262.98

Table 34: Casting Calculations OPC 53 (70%) + Alcofine (15%) + silica fume (10%) + UFA (5%), w/c Ratio=0.19

TCM	Cement	Silica fume	Alcofine	UFA	Water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	154.28	231.42	77.142	293.14	989.14	77.14	243.77	1.979	245.750

Table 35: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio=0.19

TCM	Cement	Silica fume	Alcofine	UFA	Water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1542.857	1080	77.142	308.57	77.14	293.14	1009.50	15.42	283.26	2.019	285.28

Table 36: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.20

TCM	Cement	UFS	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water content
1350	1080	270	270	1279.56	16.87	6.075	259.2	2.559	261.75

Table 37: Casting Calculations for the OPC 53(80%) + Silica fume (20%), w/c Ratio=0.20

TCM	Cement	Silica Fume	water	quartz sand	SP	Solid content BWOC	modified water content	sand water absorption	Total water content
1350	1080	270	270	1209.9	70.875	25.515	224.64	2.4198	227.05

Table 38: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%), w/c Ratio=0.20

TCM	Cement	Silica fume	Alcofine	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	154.28	308.571	308.57	927.80	19.28	6.942	296.228	1.8556	298.08

Table 39: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%), w/c Ratio=0.20

TCM	Cement	Silica fume	Alcofine	water	quartz sand	SP	Solid content BWOC	modified water content	sand water absorption	Total water to be added
1542.85	1080	308.57	154.28	308.57	927.80	77.14	27.77	259.2	1.855	261.05

Table 40: Casting Calculations OPC 53 (70%) + Alcofine (10%) + Silica fume (15%) + UFA (5%), w/c Ratio=0.20

TCM	Cement	Silica fume	Alcofine	UFA	water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	154.28	231.42	77.142	308.57	949.64	73.286	261.66	1.89	263.56

Table 41: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio=0.20

TCM	Cement	Silica fume	Alcofine	UFA	Water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1542.857	1080	77.142	308.57	77.14	308.57	969.54	11.57	301.165	1.939	303.10

Table 42: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.21

TCM	Cement	UFS	water	quartz sand	SP	Solid content BWOC	modified water content	sand water absorption	Total water content
1350	1080	270	283.5	1244.59	13.5	4.86	274.86	2.489	277.34

Table 43: Casting Calculations for the OPC 53(80%) + Silica fume (20%), w/c Ratio=0.21

TCM	Cement	Silica Fume	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water content
1350	1080	270	283.5	1174.93	70.875	25.515	238.14	2.34	240.48

Table 44: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%), w/c Ratio=0.21

TCM	Cement	Silica fume	Alcofine	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	154.28	308.571	324	887.84	15.42	5.55	314.12	1.775	315.90

Table 45: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%), w/c Ratio=0.21

TCM	Cement	Silica fume	Alcofine	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	308.57	154.28	324	887.84	77.14	27.77	274.62	1.7756	276.4

Table 46: Casting Calculations OPC 53 (70%) + Alcofine (15%) + silica fume (10%) + UFA (5%), w/c Ratio=0.21

TCM	Cement	Silica fume	Alcofine	UFA	Water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	154.28	231.42	77.142	324	909.68	30.857	304.25	1.819	306.07

Table 47: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio=0.21

TCM	Cement	Silica fume	Alcofine	UFA	water	quartz sand	SP	modified water content	sand water absorption	Total water to be added
1542.857	1080	77.142	308.57	77.14	324	929.58	15.42	314.125	1.8591	315.98

Table 48: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.25

TCM	Cement	UFS	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water content
1147.9	917.99	229.489	286.862	1055.6	17.211	6.196	275.846	2.111305	277.96

Table 49: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%), w/c Ratio=0.25

TCM	Cement	Silica fume	Alcofine	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.857	1080	154.285	308.571	385.714	767.813	46.28	16.662	356.091	1.535	357.63

Table 50: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%), w/c Ratio=0.25

TCM	Cement	Silica fume	Alcofine	Water	Quartz sand	SP	Solid content BWOC	Modified water content	Sand water absorption	Total water to be added
1542.85	1080	308.57	154.28	385.71	728.00	61.71	22.217	346.217	1.456	347.67

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Table 51: Casting Calculations OPC 53 (70%) + Alcofine (10%) + silica fume (15%) + UFA (5%), w/c Ratio=0.25

TCM	Cement	Silica fume	Alcofine	UFA	Water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1573.07	1101.15	157.307	235.961	78.653	393.269	703.648	15.730	383.202	1.407	384.61

Table 52: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio=0.25

TCM	Cement	Silica fume	Alcofine	UFA	Water	Quartz sand	SP	Modified water content	Sand water absorption	Total water to be added
1583.417	1108.392	79.170	316.68	79.17	395.85	708.27	23.75	380.65	1.416	382.069

Table 53: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.19 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Water	Quartz sand	Manf Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf Sand										
50%	50%	1350	1080	270	256.50	657.26	657.26	16.88	245.70	10.52	256.22
60%	40%	1350	1080	270	256.50	788.72	525.81	16.88	245.70	8.94	254.64
40%	60%	1350	1080	270	256.50	525.81	788.72	16.88	245.70	12.09	257.79
30%	70%	1350	1080	270	256.50	394.36	920.17	16.88	245.70	13.67	259.37
70%	30%	1350	1080	270	256.50	920.17	394.36	16.88	245.70	7.36	253.06

Table 54: Casting Calculations for the OPC 53(80%) + Silica fume (20%) w/c Ratio=0.19 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Silica Fume	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand										
50%	50%	1350	1080	270	256.50	657.26	657.26	70.88	211.14	10.52	221.66
60%	40%	1350	1080	270	256.50	746.92	497.95	70.88	211.14	8.47	219.61
40%	60%	1350	1080	270	256.50	497.95	746.92	70.88	211.14	11.45	222.59
30%	70%	1350	1080	270	256.50	373.46	871.41	70.88	211.14	12.95	224.09
70%	30%	1350	1080	270	256.50	871.41	373.46	70.88	211.14	6.97	218.11

Table 55: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%), w/c Ratio=0.19 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1543	1080	154	309	293.14	503.79	503.79	30.86	273.39	8.06	281.45
60%	40%	1543	1080	154	309	293.14	604.54	403.03	30.86	273.39	6.85	280.25
40%	60%	1543	1080	154	309	293.14	403.03	604.54	30.86	273.39	9.27	282.66
30%	70%	1543	1080	154	309	293.14	302.27	705.30	30.86	273.39	10.48	283.87
70%	30%	1543	1080	154	309	293.14	705.30	302.27	30.86	273.39	5.64	279.04

Table 56: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%) w/c Ratio=0.19 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1543	1080	154	309	293.14	483.88	483.88	50.14	261.05	7.74	268.79
60%	40%	1543	1080	154	309	293.14	580.66	387.11	50.14	261.05	6.58	267.63
40%	60%	1543	1080	154	309	293.14	387.11	580.66	50.14	261.05	8.90	269.95
30%	70%	1543	1080	154	309	293.14	290.33	677.44	50.14	261.05	10.06	271.12
70%	30%	1543	1080	154	309	293.14	677.44	290.33	50.14	261.05	5.42	266.47

Table 57: Casting Calculations OPC 53 (70%) + Alcofine (15%) + silica fume (10%) + UFA (5%), w/c Ratio =0.19 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	231	154	77	293.14	494.80	494.80	77.14	243.77	7.92	251.69
60%	40%	1543	1080	231	154	77	293.14	593.76	395.84	77.14	243.77	6.73	250.50
40%	60%	1543	1080	231	154	77	293.14	395.84	593.76	77.14	243.77	9.10	252.88
30%	70%	1543	1080	231	154	77	293.14	296.88	692.72	77.14	243.77	10.29	254.06
70%	30%	1543	1080	231	154	77	293.14	692.72	296.88	77.14	243.77	5.54	249.31

Table 58: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio =0.19 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absor ption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	309	77	77	293.1	504.7	504.7	15.4	283.27	8.08	291.34
60%	40%	1543	1080	309	77	77	293.1	605.	403.8	15.4	283.27	6.86	290.13
40%	60%	1543	1080	309	77	77	293.1	403.80	605.7	15.4	283.27	9.29	292.56
30%	70%	1543	1080	309	77	77	293.1	302.85	706.6	15.4	283.27	10.50	293.77
70%	30%	1543	1080	309	77	77	293.1	706.65	302.8	15.4	283.27	5.65	288.92

Table 59 : Casting Calculations for the OPC 53(80%) + UFS (20%) w/c Ratio=0.20 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand										
50%	50%	1350	1080	270	270	639.78	639.78	16.9	259.2	10.236	269.436
60%	40%	1350	1080	270	270	767.74	511.82	16.88	259.20	8.70	267.90
40%	60%	1350	1080	270	270	511.82	767.74	16.88	259.20	11.77	270.97
30%	70%	1350	1080	270	270	383.87	895.69	16.88	259.20	13.31	272.51
70%	30%	1350	1080	270	270	895.69	383.87	16.88	259.20	7.17	266.37

Table 60: Casting Calculations for the OPC 53(80%) + Silica fume (20%), w/c Ratio=0.20 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Silica Fume	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand										
50%	50%	1350	1080	270	270	639.78	639.78	70.88	224.64	10.24	234.88
60%	40%	1350	1080	270	270	725.94	483.96	70.88	224.64	8.23	232.87
40%	60%	1350	1080	270	270	483.96	725.94	70.88	224.64	11.13	235.77
30%	70%	1350	1080	270	270	362.97	846.93	70.88	224.64	12.58	237.22
70%	30%	1350	1080	270	270	846.93	362.97	70.88	224.64	6.78	231.42

Table 61: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%) w/c Ratio=0.20 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alcofine	Silica Fume	Water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1543	1080	154.29	308.57	309	483.81	483.81	19.29	296.23	7.74	303.97
60%	40%	1543	1080	154	309	309	580.57	387.05	19.29	296.23	6.58	302.81
40%	60%	1543	1080	154	309	309	387.05	580.57	19.29	296.23	8.90	305.13
30%	70%	1543	1080	154	309	309	290.28	677.33	19.29	296.23	10.06	306.29
70%	30%	1543	1080	154	309	309	677.33	290.28	19.29	296.23	5.42	301.65

Table 62: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%) w/c Ratio=0.20 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1543	1080	154.29	308.57	309	463.90	463.90	77.14	259.20	7.42	266.62
60%	40%	1543	1080	154	309	309	556.68	371.12	77.14	259.20	6.31	265.51
40%	60%	1543	1080	154	309	309	371.12	556.68	77.14	259.20	8.54	267.74
30%	70%	1543	1080	154	309	309	278.34	649.46	77.14	259.20	9.65	268.85
70%	30%	1543	1080	154	309	309	649.46	278.34	77.14	259.20	5.20	264.40

Table 63: Casting Calculations OPC 53 (70%) + Alcofine (10%) + silica fume (15%) + UFA (5%), w/c Ratio =0.20 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	231	154.29	77	309	474.82	474.82	73.29	261.67	7.60	269.27
60%	40%	1543	1080	231	154	77	309	569.78	379.86	73.29	261.67	6.46	268.13
40%	60%	1543	1080	231	154	77	309	379.86	569.78	73.29	261.67	8.74	270.41
30%	70%	1543	1080	231	154	77	309	284.89	664.75	73.29	261.67	9.88	271.54
70%	30%	1543	1080	231	154	77	309	664.75	284.89	73.29	261.67	5.32	266.99

Table 64: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio =0.20 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	308.57	77	77	309	484.77	484.77	11.57	301.17	7.76	308.92
60%	40%	1543	1080	309	77	77	309	581.73	387.82	11.57	301.17	6.59	307.76
40%	60%	1543	1080	309	77	77	309	387.82	581.73	11.57	301.17	8.92	310.09
30%	70%	1543	1080	309	77	77	309	290.86	678.68	11.57	301.17	10.08	311.25
70%	30%	1543	1080	309	77	77	309	678.68	290.86	11.57	301.17	5.43	306.60

Table 65: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.21 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alcofine	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand										
50%	50%	1350	1080	270.0	283.5	622.30	622.30	13.50	274.86	9.96	284.82
60%	40%	1350	1080	270.0	283.5	746.76	497.84	13.50	274.86	8.46	283.32
40%	60%	1350	1080	270.0	283.5	497.84	746.76	13.50	274.86	11.45	286.31
30%	70%	1350	1080	270.0	283.5	373.38	871.22	13.50	274.86	12.94	287.80
70%	30%	1350	1080	270.0	283.5	871.22	373.38	13.50	274.86	6.97	281.83

Table 66: Casting Calculations for the OPC 53(80%) + Silica fume (20%), w/c Ratio=0.21 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Silica Fume	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand										
50%	50%	1350	1080	270.0	283.5	622.30	622.30	70.88	238.14	9.96	248.10
60%	40%	1350	1080	270.0	283.5	704.96	469.97	70.88	238.14	7.99	246.13
40%	60%	1350	1080	270.0	283.5	469.97	704.96	70.88	238.14	10.81	248.95
30%	70%	1350	1080	270.0	283.5	352.48	822.45	70.88	238.14	12.22	250.36
70%	30%	1350	1080	270.0	283.5	822.45	352.48	70.88	238.14	6.58	244.72

Table 67: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%) w/c Ratio=0.21 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1543	1080	154.3	308.6	324.0	463.83	463.83	15.43	314.13	7.42	321.55
60%	40%	1543	1080	154.3	308.6	324.0	556.59	371.06	15.43	314.13	6.31	320.43
40%	60%	1543	1080	154.3	308.6	324.0	371.06	556.59	15.43	314.13	8.53	322.66
30%	70%	1543	1080	154.3	308.6	324.0	278.30	649.36	15.43	314.13	9.65	323.77
70%	30%	1543	1080	154.3	308.6	324.0	649.36	278.30	15.43	314.13	5.19	319.32

Table 68: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%) w/c Ratio=0.21 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1543	1080	154.3	308.6	324.0	443.92	443.92	77.14	274.63	7.10	281.73
60%	40%	1543	1080	154.3	308.6	324.0	532.71	355.14	77.14	274.63	6.04	280.67
40%	60%	1543	1080	154.3	308.6	324.0	355.14	532.71	77.14	274.63	8.17	282.80
30%	70%	1543	1080	154.3	308.6	324.0	266.35	621.49	77.14	274.63	9.23	283.86
70%	30%	1543	1080	154.3	308.6	324.0	621.49	266.35	77.14	274.63	4.97	279.60

Table 69: Casting Calculations OPC 53 (70%) + Alcofine (15%) + silica fume (10%) + UFA (5%), w/c Ratio =0.21 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	231.4	154.3	77.1	324.0	454.84	454.84	30.86	304.25	7.28	311.53
60%	40%	1543	1080	231.4	154.3	77.1	324.0	545.81	363.87	30.86	304.25	6.19	310.44
40%	60%	1543	1080	231.4	154.3	77.1	324.0	363.87	545.81	30.86	304.25	8.37	312.62
30%	70%	1543	1080	231.4	154.3	77.1	324.0	272.90	636.78	30.86	304.25	9.46	313.71
70%	30%	1543	1080	231.4	154.3	77.1	324.0	636.78	272.90	30.86	304.25	5.09	309.35

Table 70: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio =0.21 (Quartz Sand + Manufactured Sand)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz sand	Manf. Sand	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	308.6	77.1	77.1	324.0	464.79	464.79	15.43	314.13	7.44	321.56
60%	40%	1543	1080	308.6	77.1	77.1	324.0	557.75	371.83	15.43	314.13	6.32	320.45
40%	60%	1543	1080	308.6	77.1	77.1	324.0	371.83	557.75	15.43	314.13	8.55	322.68
30%	70%	1543	1080	308.6	77.1	77.1	324.0	278.88	650.71	15.43	314.13	9.67	323.79
70%	30%	1543	1080	308.6	77.1	77.1	324.0	650.71	278.88	15.43	314.13	5.21	319.33

Table 71: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.19 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alcofine	water	Quartz sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1350	1080	270.0	256.5	657.26	657.26	458.76	16.88	245.70	10.52	256.22
60%	40%	1350	1080	270.0	256.5	788.72	525.81	458.76	16.88	245.70	8.94	254.64
40%	60%	1350	1080	270.0	256.5	525.81	788.72	458.76	16.88	245.70	12.09	257.79
30%	70%	1350	1080	270.0	256.5	394.36	920.17	458.76	16.88	245.70	13.67	259.37
70%	30%	1350	1080	270.0	256.5	920.17	394.36	458.76	16.88	245.70	7.36	253.06

Table 72: Casting Calculations for the OPC 53(80%) + Silica fume (20%) w/c Ratio=0.19 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Silica Fume	water	Quartz sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1350	1080	270.0	256.5	657.26	657.26	476.57	70.88	211.14	10.52	221.66
60%	40%	1350	1080	270.0	256.5	467.45	311.63	476.57	70.88	211.14	5.30	216.44
40%	60%	1350	1080	270.0	256.5	311.63	467.45	476.57	70.88	211.14	7.17	218.31
30%	70%	1350	1080	270.0	256.5	233.72	545.36	476.57	70.88	211.14	8.10	219.24
70%	30%	1350	1080	270.0	256.5	545.36	233.72	476.57	70.88	211.14	4.36	215.50

Table 73: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%), w/c Ratio=0.19 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	water	Quartz sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	154.3	308.6	293.1	241.23	241.23	537.27	30.86	273.39	3.86	277.25
60%	40%	1543	1080	154.3	308.6	293.1	289.48	192.99	537.27	30.86	273.39	3.28	276.68
40%	60%	1543	1080	154.3	308.6	293.1	192.99	289.48	537.27	30.86	273.39	4.44	277.83
30%	70%	1543	1080	154.3	308.6	293.1	144.74	337.73	537.27	30.86	273.39	5.02	278.41
70%	30%	1543	1080	154.3	308.6	293.1	337.73	144.74	537.27	30.86	273.39	2.70	276.10

Table 74: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%) w/c Ratio=0.19 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	water	Quartz sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	154.3	308.6	293.1	216.35	216.35	547.45	50.14	261.05	3.46	264.51
60%	40%	1543	1080	154.3	308.6	293.1	259.63	173.08	547.45	50.14	261.05	2.94	263.99
40%	60%	1543	1080	154.3	308.6	293.1	173.08	259.63	547.45	50.14	261.05	3.98	265.03
30%	70%	1543	1080	154.3	308.6	293.1	129.81	302.90	547.45	50.14	261.05	4.50	265.55
70%	30%	1543	1080	154.3	308.6	293.1	302.90	129.81	547.45	50.14	261.05	2.42	263.47

Table 75: Casting Calculations OPC 53 (70%) + Alcofine (15%) + silica fume (10%) + UFA (5%), w/c Ratio =0.19(Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand													
50%	50%	1543	1080	231.4	154.3	77.1	293.1	230.00	230.00	541.87	77.14	243.77	3.68	247.45
60%	40%	1543	1080	231.4	154.3	77.1	293.1	276.00	184.00	541.87	77.14	243.77	3.13	246.90
40%	60%	1543	1080	231.4	154.3	77.1	293.1	184.00	276.00	541.87	77.14	243.77	4.23	248.00
30%	70%	1543	1080	231.4	154.3	77.1	293.1	138.00	322.00	541.87	77.14	243.77	4.78	248.56
70%	30%	1543	1080	231.4	154.3	77.1	293.1	322.00	138.00	541.87	77.14	243.77	2.58	246.35

Table 76: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio =0.19 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand													
50%	50%	1543	1080	308.6	77.1	77.1	293.1	242.44	242.44	536.78	15.43	283.27	3.88	287.15
60%	40%	1543	1080	308.6	77.1	77.1	293.1	290.93	193.95	536.78	15.43	283.27	3.30	286.57
40%	60%	1543	1080	308.6	77.1	77.1	293.1	193.95	290.93	536.78	15.43	283.27	4.46	287.73
30%	70%	1543	1080	308.6	77.1	77.1	293.1	145.46	339.42	536.78	15.43	283.27	5.04	288.31
70%	30%	1543	1080	308.6	77.1	77.1	293.1	339.42	145.46	536.78	15.43	283.27	2.72	285.98

Table 77 : Casting Calculations for the OPC 53(80%) + UFS (20%) w/c Ratio=0.20 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage(%)		TCM	Cement	Alcofine	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1350	1080	270.0	270.0	639.78	639.78	467.70	16.88	245.70	10.52	256.22
60%	40%	1350	1080	270.0	270.0	767.74	511.82	467.70	16.88	259.20	8.70	267.90
40%	60%	1350	1080	270.0	270.0	511.82	767.74	467.70	16.88	259.20	11.77	270.97
30%	70%	1350	1080	270.0	270.0	383.87	895.69	467.70	16.88	259.20	13.31	272.51
70%	30%	1350	1080	270.0	270.0	895.69	383.87	467.70	16.88	259.20	7.17	266.37

Table 78: Casting Calculations for the OPC 53(80%) + Silica fume (20%) w/c Ratio=0.20(Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage(%)		TCM	Cement	Silica Fume	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1350	1080	270.0	270.0	639.78	639.78	485.52	70.88	224.64	10.24	234.88
60%	40%	1350	1080	270.0	270.0	441.23	294.15	485.52	70.88	224.64	5.00	229.64
40%	60%	1350	1080	270.0	270.0	294.15	441.23	485.52	70.88	224.64	6.77	231.41
30%	70%	1350	1080	270.0	270.0	220.61	514.76	485.52	70.88	224.64	7.65	232.29
70%	30%	1350	1080	270.0	270.0	514.76	220.61	485.52	70.88	224.64	4.12	228.76

Table 79: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%) w/c Ratio=0.20 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage(%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	154.3	308.6	308.6	216.26	216.26	547.49	19.29	296.23	3.46	299.69
60%	40%	1543	1080	154.3	308.6	308.6	259.51	173.01	547.49	19.29	296.23	2.94	299.17
40%	60%	1543	1080	154.3	308.6	308.6	173.01	259.51	547.49	19.29	296.23	3.98	300.21
30%	70%	1543	1080	154.3	308.6	308.6	129.76	302.76	547.49	19.29	296.23	4.50	300.73
70%	30%	1543	1080	154.3	308.6	308.6	302.76	129.76	547.49	19.29	296.23	2.42	298.65

Table 80: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%) w/c Ratio=0.20(Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage(%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	154.3	308.6	308.6	191.38	191.38	557.67	77.14	259.20	3.06	262.26
60%	40%	1543	1080	154.3	308.6	308.6	229.66	153.10	557.67	77.14	259.20	2.60	261.80
40%	60%	1543	1080	154.3	308.6	308.6	153.10	229.66	557.67	77.14	259.20	3.52	262.72
30%	70%	1543	1080	154.3	308.6	308.6	114.83	267.93	557.67	77.14	259.20	3.98	263.18
70%	30%	1543	1080	154.3	308.6	308.6	267.93	114.83	557.67	77.14	259.20	2.14	261.34

Table 81: Casting Calculations OPC 53 (70%) + Alcofine (10%) + silica fume (15%) + UFA (5%), w/c Ratio =0.20 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand													
50%	50%	1543	1080	231.4	154.3	77.1	308.6	205.03	205.03	552.09	73.29	261.67	3.28	264.95
60%	40%	1543	1080	231.4	154.3	77.1	308.6	246.03	164.02	552.09	73.29	261.67	2.79	264.46
40%	60%	1543	1080	231.4	154.3	77.1	308.6	164.02	246.03	552.09	73.29	261.67	3.77	265.44
30%	70%	1543	1080	231.4	154.3	77.1	308.6	123.02	287.04	552.09	73.29	261.67	4.26	265.93
70%	30%	1543	1080	231.4	154.3	77.1	308.6	287.04	123.02	552.09	73.29	261.67	2.30	263.96

Table 82: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio =0.20 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand													
50%	50%	1543	1080	308.6	77.1	77.1	308.6	217.47	217.47	547.00	11.57	301.17	3.48	304.65
60%	40%	1543	1080	308.6	77.1	77.1	308.6	260.96	173.97	547.00	11.57	301.17	2.96	304.12
40%	60%	1543	1080	308.6	77.1	77.1	308.6	173.97	260.96	547.00	11.57	301.17	4.00	305.17
30%	70%	1543	1080	308.6	77.1	77.1	308.6	130.48	304.45	547.00	11.57	301.17	4.52	305.69
70%	30%	1543	1080	308.6	77.1	77.1	308.6	304.45	130.48	547.00	11.57	301.17	2.44	303.60

Table 83: Casting Calculations for the OPC 53(80%) + UFS (20%), w/c Ratio=0.21 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage(%)		TCM	Cement	Alcofine	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1350	1080	270.0	283.5	622.30	622.30	476.64	13.50	274.86	9.96	284.82
60%	40%	1350	1080	270.0	283.5	746.76	497.84	476.64	13.50	274.86	8.46	283.32
40%	60%	1350	1080	270.0	283.5	497.84	746.76	476.64	13.50	274.86	11.45	286.31
30%	70%	1350	1080	270.0	283.5	373.38	871.22	476.64	13.50	274.86	12.94	287.80
70%	30%	1350	1080	270.0	283.5	871.22	373.38	476.64	13.50	274.86	6.97	281.83

Table 84: Casting Calculations for the OPC 53(80%) + Silica fume (20%), w/c Ratio=0.21 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage(%)		TCM	Cement	Silica Fume	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand											
50%	50%	1350	1080	270.0	283.5	622.30	622.30	494.46	70.88	238.14	9.96	248.10
60%	40%	1350	1080	270.0	283.5	415.00	276.67	494.46	70.88	238.14	4.70	242.84
40%	60%	1350	1080	270.0	283.5	276.67	415.00	494.46	70.88	238.14	6.36	244.50
30%	70%	1350	1080	270.0	283.5	207.50	484.17	494.46	70.88	238.14	7.19	245.33
70%	30%	1350	1080	270.0	283.5	484.17	207.50	494.46	70.88	238.14	3.87	242.01

Table 85: Casting Calculations for the OPC 53(70%) + UFS (20%) + Silica fume (10%) w/c Ratio =0.21 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	154.3	308.6	324.0	191.28	191.28	557.71	15.43	314.13	3.06	317.19
60%	40%	1543	1080	154.3	308.6	324.0	229.54	153.03	557.71	15.43	314.13	2.60	316.73
40%	60%	1543	1080	154.3	308.6	324.0	153.03	229.54	557.71	15.43	314.13	3.52	317.65
30%	70%	1543	1080	154.3	308.6	324.0	114.77	267.80	557.71	15.43	314.13	3.98	318.10
70%	30%	1543	1080	154.3	308.6	324.0	267.80	114.77	557.71	15.43	314.13	2.14	316.27

Table 86: Casting Calculations for the OPC 53 (70%) + UFS (10%) + Silica fume (20%) w/c Ratio =0.21 (Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alcofine	Silica Fume	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand												
50%	50%	1543	1080	154.3	308.6	324.0	166.40	166.40	567.90	77.14	274.63	2.66	277.29
60%	40%	1543	1080	154.3	308.6	324.0	199.69	133.12	567.90	77.14	274.63	2.26	276.89
40%	60%	1543	1080	154.3	308.6	324.0	133.12	199.69	567.90	77.14	274.63	3.06	277.69
30%	70%	1543	1080	154.3	308.6	324.0	99.84	232.97	567.90	77.14	274.63	3.46	278.09
70%	30%	1543	1080	154.3	308.6	324.0	232.97	99.84	567.90	77.14	274.63	1.86	276.49

Table 87: Casting Calculations OPC 53 (70%) + Alcofine (15%) + silica fume (10%) + UFA (5%), w/c Ratio =0.21(Quartz Sand + Manufactured Sand+ Quartz Powder)

Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand													
50%	50%	1543	1080	231.4	154.3	77.1	324.0	180.05	180.05	562.31	30.86	304.25	2.88	307.13
60%	40%	1543	1080	231.4	154.3	77.1	324.0	216.06	144.04	562.31	30.86	304.25	2.45	306.70
40%	60%	1543	1080	231.4	154.3	77.1	324.0	144.04	216.06	562.31	30.86	304.25	3.31	307.56
30%	70%	1543	1080	231.4	154.3	77.1	324.0	108.03	252.07	562.31	30.86	304.25	3.75	308.00
70%	30%	1543	1080	231.4	154.3	77.1	324.0	252.07	108.03	562.31	30.86	304.25	2.02	306.27

Table 88: Casting Calculations OPC53 (70%) + Alcofine (20%) + silica fume (5%) + UFA (5%), w/c Ratio=0.21(Quartz Sand + Manufactured Sand+ Quartz Powder)

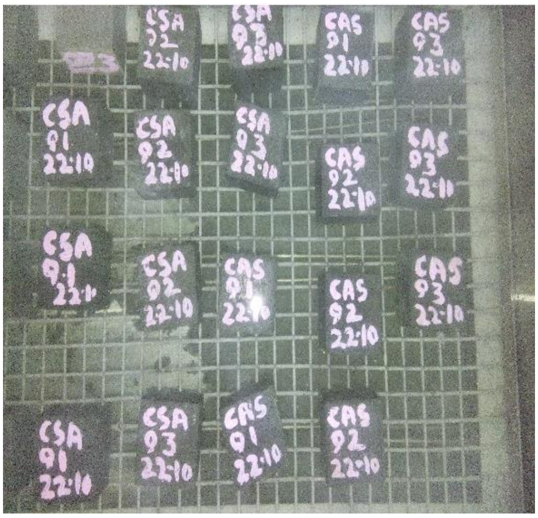
Percentage (%)		TCM	Cement	Alco fine	Silica Fume	Pozzo crete	water	Quartz Sand	Manf. Sand	Quartz Powder	SP	Modified water content	Sand water absorption	Final water content
Quartz sand	Manf. Sand													
50%	50%	1543	1080	308.6	77.1	77.1	324.0	192.49	192.49	547.00	15.43	314.13	3.08	317.21
60%	40%	1543	1080	308.6	77.1	77.1	324.0	230.99	153.99	547.00	15.43	314.13	2.62	316.74
40%	60%	1543	1080	308.6	77.1	77.1	324.0	153.99	230.99	547.00	15.43	314.13	3.54	317.67
30%	70%	1543	1080	308.6	77.1	77.1	324.0	115.49	269.49	547.00	15.43	314.13	4.00	318.13
70%	30%	1543	1080	308.6	77.1	77.1	324.0	269.49	115.49	547.00	15.43	314.13	2.16	316.28

4.7 Hot water Curing

The Reactive Powder concrete is targeted to get a high strength, hence the accelerated curing has been done to achieve the same. In normal curing the hydrated products form slowly whereas in accelerated curing, the hydrated forms very fast and hence the curing has to be done for only 3 days at 90˚C.

Figure 46: Blocks Before Hot Water Curing

Figure 47: Blocks in Curing Tanks



CHAPTER 4. RESULTS

4.1 Testing of the Blocks

The blocks are tested using the compression testing machine with a maximum load capacity of 2000kN.According to IS 516, the loading rate should be 140 kg/sq.cm/minute. For our cubes which is of area 49 sq.cm, it comes out to be 1.2kN/sec. The dimensions of the cubes are noted down and the dimensions had fluctuated a bit due the unevenness of the mould and also due to the extra material. The dimensions of the two faces which is to be kept facing the compression plates of the CTM are measured and their average is taken as the area of cross section of the cube.

Table 89: Compressive strength results for binary combinations (w/c=0.25)

Sample Name	Weight(g)	Area(average)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	791.2	4970.244	364.2	73.27	70.39
	803.6	4963.16	347.7	70.05	
	794.7	4872.7	330.6	67.84	
CSQ2	815.2	5069.408	341	67.26	71.33
	790.5	4886.904	356	72.84	
	801.1	4956.417	366.2	73.88	
CSQ3	794.7	4917.437	442.5	89.98	79.86
	805.7	4940.37	382	77.32	
	796	4947.728	357.7	72.29	
CAQ1	802.7	4663.176	346.1	74.21	75.06
	770.4	4449.76	330.2	74.20	
	784.3	4516.048	346.7	76.77	
CAQ2	808.3	4705.657	400.3	85.06	80.65
	819.3	4738.96	373.3	78.77	
	785.9	4562.462	356.5	78.13	
CAQ3	817.8	4753.266	392	82.46	76.25
	778.9	4527.86	343	75.75	
	785.6	4591.096	323.8	70.52	

Maximum Stress Reached=80.65 MPa

Table 90: Compressive strength results for Ternary Combinations (w/c=0.25)

Sample Name	Weight(g)	Area(average)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	802.5	5150.531	346.2	67.21	65.83
	797.4	5117.335	350.5	68.49	
	807.3	5228.043	323	61.78	
CASQ2	806.2	5206.16	327.1	62.82	65.70
	791.8	5089.434	350.8	68.92	
	813	5210.105	340.6	65.37	
CASQ3	811.4	5139.928	331.8	64.55	60.28
	812.4	5196.066	356.9	68.68	
	820.2	5244.695	249.7	47.61	
CSAQ1	784	5228.921	303.2	57.98	59.73
	802.3	5179.757	287	55.40	
	774.4	5246.912	345.3	65.81	
CSAQ2	791.2	5209.267	321.7	61.75	62.39
	797.6	5250.591	306.5	58.37	
	793.8	5146.558	345	67.03	
CSAQ3	799.9	5153.803	314.7	61.06	65.48
	787.7	5044.251	318.9	63.22	
	809.4	5197.573	375.2	72.18	

Maximum Strength Reached=65.83 MPa.

Table 91: Compressive strength results for Quaternary Combinations (w/c=0.25)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	804.6	5057.027	308.2	60.94	61.42
	802.2	5101.8	314.8	61.70	
	799.5	5081.522	313.1	61.61	
CASUQ2	821	5120.097	365.1	71.30	68.58
	814	5099.983	332.2	65.13	
	812.5	5068.052	351.3	69.31	
CASUQ3	823.8	5112.889	377.5	73.83	70.12
	804.8	5099.308	363.1	71.20	
	826.4	5179.68	338.4	65.33	
ASUQ1	779.6	4830.821	319.9	66.22	67.58
	771.6	4818.95	307.1	63.72	
	761.8	4781.83	348.1	72.79	
ASUQ2	798.9	5211.15	337.1	64.68	63.55
	800.5	4961.312	335.5	67.62	
	805.4	4979.469	290.6	58.35	
ASUQ3	806.5	5022.03	273	54.36	62.53
	802.4	4972.507	341.5	68.67	
	786.7	4885.716	315.5	64.57	

Maximum strength =70.12 MPa.

Table 92: Compressive strength results for binary combinations (w/c=0.19)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	813	5076.5	366.9	72.27	69.18
	824	5041	334.6	66.37	
	821	5053.95	348.3	68.91	
CAQ1	852.9	4892.7	412.6	84.20	87.08
	860.1	4899	468.6	95.65	
	854.8	4926.6	401.1	81.41	

Maximum strength = 87.08 MPa.

Table 93: Compressive strength results for binary combinations (w/c=0.19) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	835.2	5012.28	399.1	79.62	75.9
	814.2	5039.4	376.7	74.75	
	825.8	5019.3	368.1	73.33	
CAQ1	827	4872.8	472.3	96.92	98.10
	851.5	4932.8	489.7	99.27	
	845.2	5126.7	503.1	98.13	

Maximum strength = 98.107 MPa.

Table 94: Compressive strength results for binary combinations (w/c=0.19) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	817.3	5083.2	388.7	76.45	76.41
	835.6	5048.7	382.2	75.70	
	819.2	5021.5	387.2	77.10	
CAQ1	854.1	4871.9	498.2	102.26	102.59
	865.7	4854.3	512.8	105.64	
	861.2	4967.7	496.1	99.87	

Maximum strength = 102.59 MPa.

Table 95: Compressive strength results for Ternary combinations (w/c=0.19)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	836.7	5155.2	375.3	72.8	76.08
	803.0	4996.8	374.7	74.98	
	825.9	5083.6	409.1	80.47	
CSAQ1	800.8	5019.7	282.5	56.278	54.46
	833.9	4984	77.8	15.6(DISCARDED)	
	808.1	4970	261.7	52.65	

Maximum strength = 76.08 MPa.

Table 96: Compressive strength results for Ternary combinations (w/c=0.19) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	866.7	5121.2	381.3	74.45	77.246
	824.2	5004.5	382.3	76.39	
	826.7	5115.7	413.9	80.9	
CSAQ1	812.6	5001.7	357.8	71.53	70.57
	847.2	4991	345.2	69.16	
	835.4	4987.2	354.2	71.021	

Maximum strength = 77.246 MPa.

Table 97: Compressive strength results for Ternary combinations (w/c=0.19) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	876.7	5022.3	383.2	76.3	78.4
	843.1	5071.5	403.1	79.5	
	855.3	5056.1	401.8	79.5	
CSAQ1	802.6	5019.7	359.8	71.7	73.8
	835.8	4984	347.2	69.7	
	823.5	4970	398.1	80.1	

Maximum strength = 78.4 MPa.

Table 98: Compressive strength results for Quaternary combinations (w/c=0.19)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	816.40	5183	384.9	74.26	68.96
	807.70	5067.19	315.0	62.16	
	751.10	5076.5	357.8	70.48	
ASUQ1	880.2	4983.87	340.4	68.30	77.65
	856.4	5104	143.9	28.19(DISCARDED)	
	864.5	4948.22	430.5	87	

Maximum strength = 77.65 MPa.

Table 99: Compressive strength results for Quaternary combinations (w/c=0.19) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	855.2	5174.5	407.8	78.80	73.41
	814.4	5012.6	354.9	70.80	
	789.6	5047.4	356.5	70.63	
ASUQ1	891.2	4992.8	402.8	80.67	78.33
	880.3	4999.6	389.8	77.96	
	898.4	4978.2	380.1	76.35	

Maximum strength = 78.33 MPa.

Table 100: Compressive strength results for Quaternary combinations (w/c=0.19) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	859	5042	381.04	75.57	75.72
	811.2	5112.5	376.2	73.58	
	801.1	5080.8	396.3	77.99	
ASUQ1	885.2	4932.8	412.8	83.68	83.95
	876.7	4988.7	405.7	81.32	
	897.2	5124.4	445.1	86.85	

Maximum strength = 83.95 MPa.

Table 101: Compressive strength results for binary combinations (w/c=0.20)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	804.3	5106	268.2	52.52	66.53
	820.0	5054.4	357.2	70.67	
	797.4	5112	390.6	76.4	
CAQ1	848.6	4904.28	429.6	87.59	85.60
	866	5033	439.1	87.24	
	585.1	4940.4	405.1	81.99	

Maximum strength = 85.60 MPa.

Table 102: Compressive strength results for binary combinations (w/c=0.20) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	823.4	5112.2	356.5	69.74	77.52
	852.7	5011.5	401.3	80.08	
	806.5	5143.8	425.7	82.76	
CAQ1	859.7	4997.2	457.3	91.51	89.16
	874.2	4987.1	459.6	92.16	
	586.4	4913.1	411.8	83.82	

Maximum strength = 89.16 MPa.

Table 103: Compressive strength results for binary combinations (w/c=0.20) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	856	5142	387.4	75.34	78.69
	814.2	5068.4	411.2	81.13	
	803.5	5119.7	407.5	79.59	
CAQ1	832.3	4965.5	456.6	91.95	92.06
	851.2	5131.7	459.7	89.58	
	789.5	5001.4	473.3	94.63	

Maximum strength = 92.06 MPa.

Table 104: Compressive strength results for Ternary combinations (w/c=0.20)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	842.2	4970	375.3	75.51	77.91
	826.0	4900	374.7	76.47	
	836.7	5004	409.1	81.75	
CSAQ1	809.60	5184	325.2	62.73	65.086
	792.30	4970	327.5	65.89	
	792.00	4970	331.2	66.64	

Maximum strength = 77.91 MPa.

Table 105: Compressive strength results for Ternary combinations (w/c=0.20) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	872.2	4923	348.1	70.71	75.78
	825	4287.2	199.4	46.51(DISCARDED)	
	821.4	5113.7	413.5	80.86	
CSAQ1	819.5	5117.1	478.5	93.51	81.66
	832.4	4998.2	394.7	78.97	
	802.3	4963.1	359.9	72.52	

Maximum strength = 81.66 MPa

Table 106: Compressive strength results for Ternary combinations (w/c=0.20) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	825.1	4998.7	411.3	82.28	81.89
	829.7	5001.6	396.3	79.23	
	845.3	5028.3	423.2	84.16	
CSAQ1	802.1	5124.7	387.4	75.59	74.60
	796.8	4956.3	369.9	74.63	
	787.4	4982.2	366.6	73.58	

Maximum strength = 81.89 MPa

Table 107: Compressive strength results for Quaternary combinations (w/c=0.20)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	781.20	4703.52	292.5	62.18	59.144
	827.50	5019	320.0	63.75	
	810.60	4997.68	257.4	51.50	
ASUQ1	834.8	5026.56	367.8	73.17	61.32
	839.6	4977.28	351.2	70.56	
	871.20	5140.8	206.9	40.25	

Maximum strength = 61.32 MPa.

Table 108: Compressive strength results for Quaternary combinations (w/c=0.20) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	789.3	4821.2	323.8	67.16	67.28
	825.4	4987.5	340.1	68.19	
	823.7	4913.5	326.7	66.49	
ASUQ1	847.2	4982.2	387.4	77.76	71.90
	851.4	4933.5	369.3	74.86	
	879.3	4872.1	307.4	63.09	

Maximum strength =71.90 MPa.

Table 109: Compressive strength results for Quaternary combinations (w/c=0.20) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	792.5	4755.8	327.4	68.84	67.68
	847.1	4988.4	342.2	68.60	
	854.6	5011.5	328.7	65.59	
ASUQ1	852.2	5144.2	399.2	77.60	73.92
	858.9	4945.7	367.1	74.23	
	876.8	4987.1	348.7	69.92	

Maximum strength = 73.92 MPa.

Table 110: Compressive strength results for binary combinations (w/c=0.21)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	817.9	5090.7	322.1	63.27	68.57
	815.6	5005	321.3	64.19	
	804.1	5019.7	392.8	78.25	
CAQ1	864.6	5140.5	370.7	72.11	75.81
	840.5	4903.58	391.7	79.88	
	845.4	4837	365.7	75.45	

Maximum strength = 75.81 MPa.

Table 111: Compressive strength results for binary combinations (w/c=0.21) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	832.3	5087.4	325.8	64.04	70.29
	821.3	5014.7	336.5	67.10	
	806.1	5036.1	401.5	79.72	
CAQ1	849.2	5123.2	378.9	73.96	76.96
	821.7	4997.2	392.5	78.54	
	837.3	4911.6	384.9	78.37	

Maximum strength = 76.96 MPa.

Table 112: Compressive strength results for binary combinations (w/c=0.21) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CSQ1	822.4	5090.7	332.9	65.39	72.43
	829.8	5005	374.8	74.89	
	811.8	5019.7	386.6	77.02	
CAQ1	850.1	5140.5	375.4	73.03	77.00
	836.7	4903.58	392.1	79.96	
	851.1	4837	377.3	78.00	

Maximum strength = 77.00 MPa.

Table 113: Compressive strength results for Ternary combinations (w/c=0.21)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	837.30	5005.5	397.5	79.41	69.09
	812.40	5112	342.0	66.90	
	818.40	4998.4	304.8	60.97	
CSAQ1	799.30	5018.82	278.7	55.53	68.84
	806.90	5024.56	76.7	15.2(DISCARDED)	
	787.80	5112	420	82.159	

Maximum strength = 69.09 MPa.

Table 114: Compressive strength results for Ternary combinations (w/c=0.21) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	836.5	5014.7	387.2	77.21	71.05
	821.4	5123.8	355.7	69.42	
	817.4	4992.2	332.1	66.52	
CSAQ1	806.5	5112.3	314	61.42	70.62
	809	5047.7	356.4	70.61	
	798.7	5180.1	413.5	79.82	

Maximum strength = 71.05 MPa.

Table 115: Compressive strength results for Ternary combinations (w/c=0.21) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASQ1	84101	5173.2	406.8	78.64	74.11
	832.4	5041.6	366.2	72.64	
	819.4	5022.5	356.9	71.06	
CSAQ1	806.6	4983.2	387.4	77.74	78.91
	807.1	4899.7	378.2	77.19	
	776.8	4932.4	403.5	81.81	

Maximum strength = 78.91 MPa.

Table 116: Compressive strength results for Quaternary combinations (w/c=0.21)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	824.60	5040	380.8	75.55	67.996
	794.70	4913.92	286.9	58.38	
	818.80	5041	353.2	70.06	
ASUQ1	843.40	5097.95	383.3	75.18	73.876
	822.80	4955.16	357.7	72.18	
	844.20	5126.55	380.8	74.27	

Maximum strength = 73.876 MPa.

Table 117: Compressive strength results for Quaternary combinations (w/c=0.21) (Quartz Sand + Manufactured Sand)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	832.5	5114.7	379.4	74.18	70.28
	809.7	4968.7	321.4	64.68	
	823.7	5096.1	366.8	71.98	
ASUQ1	854.7	5088	389.7	76.59	73.46
	837.4	4921.4	340.8	69.25	
	852.1	5117.7	381.5	74.55	

Maximum strength = 73.46 MPa.

Table 118: Compressive strength results for Quaternary combinations (w/c=0.21) (Quartz Sand + Manufactured Sand + Quartz Powder)

Sample Name	Weight(g)	Area(average) (mm^2)	Load(kN)	Stress	Average Stresses (MPa)
CASUQ1	847.7	5023.7	380.8	75.80	71.76
	816.4	4899.7	305.4	62.33	
	834.2	4911.3	378.9	77.15	
ASUQ1	847.9	5039.2	387.4	76.88	74.35
	857.8	4977.2	351.2	70.56	
	851.3	5122.6	387.4	75.63	

Maximum strength = 74.35 MPa.

CHAPTER 5. CONCLUSION AND RESEARCH SIGNIFICANCE

5.1 Discussion

The strength achieved was less than the targeted strength because the following reasons.

- Even after the addition of Quartz Powder and Manufactured Sand the graph which was obtained was not perfectly matching with the modified Andreessen model as some particle sizes were still missing in the mixture we used.

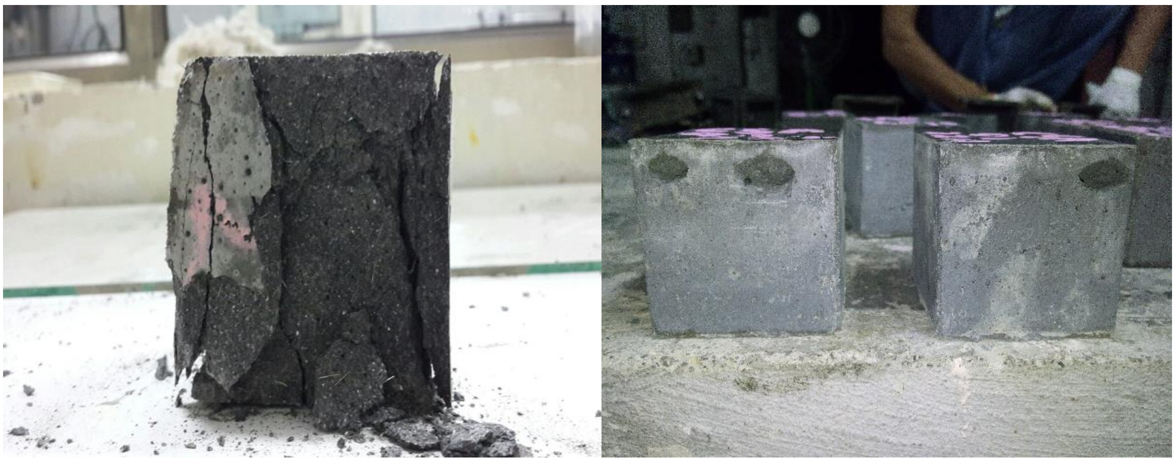
- The strength of the block was obtained less mainly due to the segregation of the materials due to over compaction. The quartz sand being the heavy material settled down whereas the cement, silica fume, UFS were at the top layer.

- Some blocks were also prepared without compacting much, but in this case the pores are formed in the blocks which again lead to the low strength of the block.

Figure 48: The block showing the separation of the particle into two layers due to over compaction

Figure 49: The failed block showing segregation of the material

Figure 50: The block which is compacted very less resulted in lot of pores which again lead to loss of strength



5.2 Research Significance

Numerous studies are being done but researchers have found very difficult to compare their performance because the materials have not been categorized under same blast conditions and different level of blast parameters. Much of the research has only been qualitative in character and the fundamental behaviour of reactive powder concrete with enhanced mechanical properties, enhanced durability, with high fracture energy and different approaches for the mix design of reactive powder concrete has been conducted. But for achieving such a high compressive strength high amount of cement is used which prove to be uneconomical but in my research my attempt will be to reduce the cement content. Also, the behaviour of reactive powder concrete under blast loading is not well understood with any design guidelines available. This limits the range of application to very simple structural systems, and makes it difficult to have confidence in large scale applications of the technology. The main and important reason for the lack of understanding is in the complexity of the problem, where many variables are involved so that experiments alone cannot lead to effective design methods. Instead, a proper consideration of the variables requires both an in-depth understanding of the structural behaviour and accurate modelling of the dynamics of the structure under the effects of shock waves induced by an explosion. Due to the sensitive nature of the subject, there is also a lack of essential information such as charge weights and standoffs in many papers. Together with the variables discussed in the studies, this makes comparisons between the results difficult and hinders the development of better understanding of the structural behaviour.

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