"STUDYING THE PROPERTIES OF CONCRETE BY REPLACING PART OF CEMENT WITH MUNICIPAL SOLID WASTE INCINERATED ASH"

A PROJECT

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the project title **“** Studying The Properties Of Concrete By Replacing Part Of Cement With Municipal Solid Waste Incinerated Ash **”** in partial fulfilment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Vipul Pathak during a period from July 2015 to December 2015 under the supervision of **Mr. Abhilash Shukla , Project Coordinator** and **Dr. Rajiv Ganguly** ,**Project Guide,** Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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ABSTRACT

Ultra-high performance concrete is a recent and important advancement in composite. It 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 ultra high performance concrete is that it can be used for defence structures like in underground bunkers. The underground bunkers should be blast resistant which is a very important aspect. The materials should be ductile enough and able to absorb energy generated from a blast source and prevent the structures from collapsing. Ultra-high performance concrete can be very useful in this aspect as it has high strength, high ductility and high fracture energy. It has a very important use of blocking & stabilization of containment of nuclear waste. Trials were made by selecting binary combination 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. Samples were casted in form of cubes of size 7.04 x 7.04 x 7.04 cm^3. Compression test were done at the end of 3 days of hot water curing and strength of 89.98 MPa was achieved.

Incinerated ash of municipal solid waste accounts for a great portion of the matter in landfills, and minimization of resource consumption and recycling of waste are important factors for ensuring the future welfare of humankind. Hence the results of the treatment of the ash from a municipal solid waste incinerator (MSWI) by melting are described and studied. This MSWI fly ash slag was found to be comprised mainly of SiO_2 and CaO, which can be substituted for up to 20% of the cement content in mortar, without sacrificing the quality of the resultant concrete. In fact, the concrete thus produced has greater compressive strength, 10% higher than that without the substitution. The aggregates retained on the 90 microns sieve were considered for investigation .The setting time of the fresh mortar becomes lengthens as increasing amounts of cement are replaced, while the spread flow value increases with the increasing percentage of cement substitution. According to the results of the toxic characteristic leaching procedure analysis, MSWI fly ash slag should be classified as general non-hazardous industrial waste that meets the effluent standard. Therefore, the reuse of MSWI fly ash slag is feasible, and will not result in pollution due to the leaching of heavy metals.

ABBREVIATIONS

MSWIA	Municipal Solid Waste Incinerated Ash
OPC	Ordinary Portland cement of 53 Grade
PPC	Portland pozzolana cement
MSW	Municipal Solid waste
SF	Silica Fume
QZ	Quartz Sand
CSQ-1	Cement+20% Silica Fume + Non-Fibred
UHPC	Ultra-High Performance Concrete
UFS	Ultra-fine slag
UFA	Ultra-Fine Fly ash
EMMA	Elkem Materials Mix Analyser

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Chapter 1. Introduction

1.1. General Introduction

About ultra high performance concrete:

Ultra high performance 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. Ultra high performance concrete is based on the implementation of some basic principles to achieve increased uniformity, high workability, high packing density, improved microstructure and high ductility. Ultra high performance 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 Ultra high performance concrete and high performance concrete indicates that ultra high performance 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 Ultra high performance 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. Ultra high performance 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 Ultra high performance concrete, ultra-high strength and durability. Ultra high performance concretes have compressive strengths from 200 MPa to 810 MPa. Ultra high performance 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 Ultra high performance 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 negligible and Tritium diffusion is about 45 times lower than conventional containment materials. Recent applications of Ultra high performance 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. Ultra high performance 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.

About municipal solid waste incinerated ash:

Civilization and development comes with various adverse impacts on humanity. One such area of severe human impact is the waste management in urban areas. The management of solid waste in urban areas is a growing problem which is being continually aggravated by poor management practices, poor collection and disposal practices as well as non-availability of space in the urban environment to accommodate and store the waste generated. As a result, solid wastes are collected in mixed state and are dumped in environments close to sensitive places like roads sides, marshy lands, low lying areas, public places, vacant lands within residential areas, forests, wild life areas, water courses, etc.

Municipal solid waste consists of household waste, construction and demolition debris, sanitation residue, and waste from streets. This garbage is generated mainly from residential and commercial complexes. With rising urbanization and change in lifestyle and food habits, the amount of municipal solid waste has been increasing rapidly and its composition changing.

Waste is a continually growing problem at global and regional as well as at local levels. Solid wastes arise from human and animal activities that are normally discarded as useless or unwanted. In other words, solid wastes may be defined as the organic and inorganic waste materials produced by various activities of the society and which have lost their value to the first user. As the result of rapid increase in production and consumption, urban society rejects and generates solid material regularly which leads to considerable increase in the volume of waste generated from several sources such as, domestic wastes, commercial wastes, institutional wastes and industrial wastes of most diverse categories. Management of solid waste may be defined as that discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations. In its scope, solid waste management includes all administrative, financial, legal, planning, and engineering functions involved in the whole spectrum of solutions to problems of solid wastes thrust upon the community by its inhabitants. Solid wastes have the potential to pollute all the vital components of living environment (i.e., air, land and water) at local and at global levels. The problem is compounded by trends in consumption and production patterns and by continuing urbanization of the world. The problem is more acute in developing nations than in developed nations as the economic growth as well as urbanization is more rapid in developing nations.

Reduce, Reuse, and Recycle – there are often still residual materials left over requiring treatment or disposal. At this point, it is also important to minimize the human health and environmental effects by managing wastes in an environmentally sound manner.

Municipal solid waste incinerated ash (MSWIA) was used as partial replacement of cement in concrete; strength was not negatively affected up to 20 % replacement, the prepared concrete had sufficient durability. The rate of solid waste generation is an increasing phenomenon and it is accelerated by rapid population growth and urbanization, technological development and changing life styles. One major issue related to solid waste management is how to cope with the huge wastes generated from the municipalities in a sustainable way.

Traditionally, municipal solid wastes have been managed through landfills, recycling, composting and incineration in decreasing order of priority. Whereas modern waste management is focused towards zero waste or wastes prevention, other wastes management techniques such as recycling, re-use, incineration and composting still leaves some residual material to be disposed of. Incineration in particular, has been used as a solid waste management option to reduce the volume of the waste by about 90% and to convey the remaining to sanitary land fill sites. Incineration of solid waste also results in the formation of other waste products, such as bottom ash and to manage this material in a sustainable way is a challenge posed to modern solid waste management.

The high cost of treatment or disposal, the shortage of land fill space and increased environmental awareness in urban areas have prompted the need to find other uses of the incinerated ash than disposal. A wide range of options is available for the re-use of incinerator bottom ash, such as in desert sand stabilization, as an aggregate in concrete, as in bitumen related works, as sub base in road construction, as an admixture in road embankment material; as in micro-biological studies; as in clay based ceramics; as a glass raw material; as a cementitious material; as a replacement for cement in cement mortar; as for manufacturing of light weight aggregates. The potential for the re-use of bottom ash is enormous.

While if we talk about MSWIA, Incinerator ash from combustion of solid waste consists mainly of bottom ash and fly ash. Bottom ash consists of slag, glasses and partially unburned organic matter. It is generally coarse sandy in appearance with a diameter varying between 0.1mm and 100mm. Fly ash on the hand consists of partially burned organic matter and its dust-like grey particles approximating 1-500 μm in diameter. Physical and chemical properties of the incinerated bottom ash vary depending on the type and source of the solid waste.

A standard solid waste incinerator is hard to see in the study area. A locally built incinerator was therefore used to burn the waste. This was a simple fixed type kiln of red burnt bricks capable of withstanding temperatures up to 1000^{o}C. The kiln has a chimney and an oven with openings for loading and for igniting the solid waste. To achieve uniform combustion, air was introduced at intervals and a stirrer manually used to expose the incombustible portions of the waste. The waste was fed into the incinerator in batches of between 5 to 15Kg at intervals of 15 to 30minutes.

To achieve complete combustion, secondary incineration was carried on the waste samples by gas firing. The primary incinerated bottom ash was batch fed into the chamber which stands on top of a metal grate. The chamber was then fired and the batch inside the chamber was ignited for one hour to ensure complete combustion. With the use of the manually operated stirrer, the ash generated dropped through the metal grates into ash trays at the base of the chamber. The bottom ash collected was allowed to cool for 12 hours before being prepared for use in the research.

1.2. Composition of Ultra high performance concrete and MSWIA

Ultra high performance 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 Ultra high performance concrete ultra-high strength and durability. Ultra high performance concretes have compressive strengths ranging from 200 MPa to 800 MPa.

The mixture design of Ultra high performance 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 and the following composition of MSWIA is found:

Table 1 Composition of MSWIA

Serial Number	Constituent	Values (mg/kg)
1	Chloride	84.97
2	Sulphur	50.5
3	Silicon	809.03
4	Calcium	70.58
5	Iron	39.66
6	Magnesium	35.90
7	Sodium	52.33
8	Phosphorus	45.24
9	Sulphur	0.50
10	Copper	1.58
11	Zinc	11.98
12	Lead	0.08
13	Chromium	84.97
14	Manganese	4.77

Chapter 2. Literature Review

2.1. Mix Proportions for UHPC and percentage use of MSWIA

Richard and Cheyrezy (1995) indicated the principles for developing Ultra high performance 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 Ultra high performance concrete.

Staquet and Espion (2002) studied the mechanical properties of Ultra high performance concrete which was developed with the materials available in Belgium. Also, it was suggested CEM152.5 which was used in Ultra high performance 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 Ultra high performance concrete made by white and black silica fume from silicium industry.

Plawsky (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.

Uzawa, (2005) improved the Ultra high performance concrete which existed earlier and thus a new material was proposed with simple curing process. This ultra-high performance concrete material (UHPCM) has high compressive strength and toughness in spite of simple curing techniques unlike Ultra high performance concrete. This UHPCM 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 UHPCM 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 Santhanam (2005) developed two Ultra high performance 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 Ultra high performance concrete mix. Also characterization of mechanical properties was carried out.

Dattatreya (2007) examined several particle packing models so as to develop a mix proportion for the Ultra high performance 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.
Percentage of OPC that will be replaced by MSWIA and studied will be for 18, 19, 20 and 21%. The results obtained will be compared with original OPC mix.

Deepak and Dr. Ramesh (2015) concluded that the untreated MSWI bottom ash was used as partial cement replacement in concrete after sieving in 90 μm. This ash, by its chemical composition, does not fulfill the standard requirements on concrete admixtures but the prepared concrete had acceptable properties. The 28-days compressive strength of material with 20 % cement replacement was comparable with the reference concrete; the 56-days strength was also acceptable. The frost resistance of bottom ash containing concrete was very good. The prepared concrete contained relatively low content of MSWI ash; this approach represents a compromise between the ecological request on a practical utilization of MSWI ashes and properties of the acquired product. Higher ash dosage without any accompanied loss of concrete properties would be possible only when the ash would be treated in some way but in such case there would arise additional costs suppressing the MSWI ashes utilization attractiveness for building industry.

Collivignarelli and Sabrina Sorlini (2002) showed that M.S.W.I ashes reused as construction materials can represent an interesting alternative to final landfill disposal. All the fly ashes analyzed in this work, produced by different incineration facilities, show a good chemical and physical quality for the production of concrete mixtures, whose final mechanical quality is acceptable for different applications. In fact, although concrete mechanical characteristics are worsened by waste addition, the minimum compressive resistance of 40 MPa, required for concrete structural utilization, is reached by most of the concrete mixtures after 28 days of curing. A good environmental compatibility of ‘‘recycled concrete’’ is also confirmed by the leaching behavior that is very similar for natural concrete and waste containing concrete.

2.2. Non Destructive Test for UHPC

Waher (2004) performed non-destructive tests on Ultra high performance concrete (UHPC) 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 Ultra high performance 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 of UHPC

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.

Bioizi et al. (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.

Bonneau and Lachemi, (1997) produced two Ultra high performance concretes (UHPC) at a precast plant in Sherbrooke University. One was a ready mix Ultra high performance concrete and the other was used in precast plant. In ready mix Ultra high performance concrete samples were prepared both with and without fibres. All these Ultra high Performance 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 Ultra high performance 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 Ultra high performance concrete impregnated with steel fibres.

2.4. Durability Properties of UHPC

Vodak. (1997) performed experiments to study the thermal characteristics of Ultra high performance concrete like thermal conductivity, thermal diffusivity and linear thermal expansion coefficient of UHPC. 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.

Morin (2002) examined the capillary network of Ultra high performance concrete by use of ultrasonic and autogenous shrinkage measurements. The evaluation of the activation of different modes during hydration processes was conducted. Segmentation of sedimentary pores occurs due to segmentation of capillary network and because of chemical activity induced in C-S-H chains. This study of the capillary network is important due to fact that it provides information about the porosity evolution, which is a crucial parameter in the transport properties of the concrete, which in turn is related to its durability.

Saremi and Mahallati(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.

Yazici (2007) explored an Ultra-high performance concrete by combining pulverized granulated blast furnace slag (PS), pulverized fly ash (FA) and silica fume (SF) with the portland cement (PC). PC was replaced with FA and PS at specified ratios. Quartz powder and basalt were used as an aggregate in the mixtures. Three different curing methods (Standard, autoclave and steam curing) were applied to the samples. Test results showed that high strength concrete could be obtained with high volume mineral admixtures. Compressive strength of these mixtures is over 170 MPa.

2.5. Design Considerations of UHPC

Rossi and Parant (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 and Muttoni (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.

Orgass and Yuette (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 Ultra high performance 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.

Almansour and Lounis (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 %.

2.6. Applications of UHPC

Donnaes and Phillippe (1998) developed Ultra high performance concrete (UHPC) 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 Ultra high performance 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 Ultra high performance concrete can directly take the compressive stress developed during prestressing. Also a 2,150 sq.ft, facade for a Paris school was constructed using Ultra high performance concrete. The façade demonstrated the materials aesthetic qualities creating plates with an untreated surface similar to polished concrete.

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 UHPC 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 UHPC/RC decreased significantly more with freeze – thaw cycles as compared with that of UHPC/UHPC.

Uzawa(2005) explored the practical applications of the Ultra high performance concrete with steel fibres with a high compressive strength of 200 MPa .Uzawa improved the already existing Ultra high performance concrete (UHPC) and a new material was proposed with simple curing process. This reactive powder composite material (UHPCM) has high compressive strength and toughness in spite of simple curing techniques unlike Ultra high performance concrete. This UHPCM 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 UHPCM 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 (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.

2.7 Geotechnical and Chemical properties of MSWI

The geotechnical properties of the MSWI bottom ash are shown below along with the chemical properties. The CBR results for un-soaked samples range between 50 to 73% while for the soaked samples the values are in the order of 25 to 44%. These values pass for materials to be used as sub grade, filling and sub bases in road construction while CBR values for the remoulded samples which range between 14 to 42% could only pass to be used as sub grade and fill material. Results of the permeability test also presented table 1.0 indicates that bottom ash is a free draining material with coefficient of permeability for all the samples ranging between 5.9 $x10^{-4}$m /sec to 6.75 $x10^{-4}$m /sec, which is close to the range for fine sand (K values ranges from 2.6 x 10^{-4} to 4.32 x 10^{-4} m /sec). According to U.S Bureau of Reclamation, soils are classified to be pervious if K values are greater than 10^{-4}cm/sec. MSWI bottom ash falls into these categories and can be said to be a pervious, free draining material. Drainage is crucial in highway and geotechnical application of construction material. A well-drained material prevents development of pore pressure during loading in fills. It also accelerates the consolidation of the surrounding low permeable soils, leading to enhance stability of structures founded on these materials.

The average shear strength parameters for the MSWI bottom ash fall within the range for sand. Thus the material can be used for a number of applications such as filling, improvement of grading properties for clayey soils, and as a free draining material. The unconfined compression test revealed that the MSWI bottom ash has 7-day strength, about 3 times that of clay. Thus MSWI ash could be employed as an admixture in pre-treatment and stabilization of soft clay. The CBR value of the MSWI bottom ash could be used as sub base layer materials for CBR values greater than 40%. Chemical characterization revealed that SiO_2, a network glass former oxide, was present in a relatively high content (43.28 %wt), indicating the suitability for this waste to be employed in the development of vitreous materials. The MSWI bottom ash could be reused as cement replacement materials since it contained SiO_2 which is one of the main building components in cement and concrete utilizations. CaO, Na_2O and K_2O, which act as fluxing agents, were present in various amounts (1.78.20wt %) together with several other oxides normally present in ceramic and glass raw materials. Furthermore, the MSWI bottom ash contains Ca, Fe, Si, and heavy metals such as Cu, Pb, Mn, Zn, but it is deficient in Al. It must be noted that Zinc is available in significant quantities in all the dumping sites followed by Manganese and Copper. A summary of the chemical composition of the ash is given below:

Table 2 Geotechnical Property of MSWIA

S.no	Geotechnical Property	Value
1.	Specific Gravity	2.20
2.	Optimum Moisture Content	10.25
3.	Maximum Dry Density	1.65
4.	Fine fraction	87.25
5.	Permeability (m/s)	6.23×10^{-4}
6.	CBR	53.50
7.	Cohesion, c (kN/m^2)	7

Table 3 Chemical properties

S.No.	Chemical properties	Values (mg/kg)
1.	Chloride (mg/kg)	84.97
2.	Sulphate (mg/kg)	50.5
3.	Silicon (mg/kg)	809.03
4.	Calcium (mg/kg)	70.58
5.	Iron (mg/kg)	39.66
6.	Magnesium (mg/kg)	35.90
7.	Sodium(mg/kg)	52.33
8.	Phosphorus (mg/kg)	45.24
9.	Sulphur (mg/kg)	0.50
10.	Copper(mg/kg)	1.58
11.	Zinc (mg/kg)	11.98
12.	Lead (mg/kg)	0.08
13.	Chromium (mg/kg)	0.25
14.	Manganese (mg/kg)	4.77

2.8 Tests performed on UHPC replaced with MSWIA:

1. Compression test:

   Compression Test of the Concrete Specimen is most widely used test to measure its compressive strength. Two types of concrete specimen: Cubes & Cylinders are used for this purpose: Cubes of size 150mm are more common in Asia, Russia & European countries while Cylinders of 150mm in diameter & 300mm high are common in U.S and

Australia. Cubes for compression test are casted in a steel or cast-iron moulds of prescribed dimensions. BS 1881: Part 108: 1983 prequires filling the mould in layers of approximately 50 mm. Compaction of each layer is achieved by not less than 35 strokes for 150mm cubes or 25 strokes for 100 mm cubes. A standard tamping bar of a 25mm square of steel section is used for this purpose. Compaction by vibration may also be used. After finishing the cube, it should be stored at a temperature of 150°C to 250°C, when the cubes are to be tested at or more than 7 days. When the test days is less than 7 days the temperature to be maintained is 180°C to 220°C. Also, relative humidity of 90 percent is to be maintained always.

The cube is demoulded just before testing at 24 hours. For greater ages at test, demoulding takes place between 16 to 28 hours after adding water in a concrete mix and the specimens are stored in a curing tank at 180 to 220°C until the required age.

The most common age at testing is 28 days, but tests can be made at 1, 3, 7 & 14 days also. At the time of testing the specimen is placed in a "Compression Testing Machine" with the position of cubes at right angles to the position of cast. The load is applied at a constant rate of stress within the range of 0.2 to 0.4 MPa/sec.

Under pure uniaxial compression loading, the failure cracks generated are approximately parallel to the direction of applied load (Fig-1) with some cracks formed at an angle to the applied load. Practically, the compression testing system rather develops a complex system of stresses due to end restraints by steel plates .It is quite clear that due to Poisson's effect, cube or cylinder specimens undergo lateral expansion. The steel plates don't undergo lateral expansion to the same extent that of concrete. There exists a differential tendencies of lateral expansion between steel plates and concrete cube faces; as a result of which tangential forces are induced between the end surfaces of the concrete specimen and the adjacent steel plates of the testing machine. The degree of platen restraint on the concrete section depends on the friction developed at the concrete-platen interfaces, and on the distance from the end surfaces of the concrete.

As a result, in addition to applied compressive stress, lateral shearing stresses are also effective in the concrete specimen. Effect of this shear decreases towards the centre of cube; so that sides of cube have near vertical cracks at cube's centre, or completely disintegrates so as to leave a relatively undamaged central core.

As the degree of end restraint depends on the friction at the interfaces, this frictional value can be eliminated by applying grease, graphite or paraffin wax to the bearing surfaces of the specimen. It helps the specimen to undergo a larger and uniform lateral expansion and eventually splits along its full length.

It should be noted that with end restraints in full effect, the compression test yields the higher value of cube strength. When the height of specimen increases with respect to its width, the influence of shear becomes smaller so that the central part of the specimen may fail by lateral splitting; thereby exhibiting the lower compressive strength.

2. Flexural test :

   Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 6 x 6 inch (150 x 10mm) concrete beams with a span length at least three times the depth. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).

   Flexural strength of concrete is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. The MR determined by third-point loading is lower than the MR determined by center-point loading, sometimes by as much as 15%.

Figure 1 Flexure test on beam

3. Split tensile Test:

Cylinders of 10 cm diameter and 20 cm length were prepared and tested under increasing loading at 14 MPa/min. Three cylinders were tested at each stage of curing for the mentioned mix design. The Split Tensile Strength is determined by 2P/πld Where P= Load at which sample fails, L= length of the specimen cylinder, D= diameter of the specimen cylinder**.**

Figure 2 Split tensile test on cylinder

2.9 Design Considerations of M40 concrete with and without MSWIA

Jaypee's Municipal Solid Waste Processing Plant, sec-25, Chandigarh was identified as the site for procurement of MSWIA and used in this study.As per the assumptions taken in mix design, we have collected 90 µm size aggregates by the help of sieve analysis.

Table 4 Sieve analysis of MSWIA

Sieve size	% Retained on each sieve	Cumulative % Retained	Cumulative % passing
	90 µm	**90 µm**	**90 µm**
250 µm	0	0	100
125 µm	22.24	22.24	77.76
90µm	61.88	84.12	15.88

Mix design for M40 (0.4: 1: 1.65: 2.92)

Table 5 Mix Design for M40 (Without replacement)

	Cement(kg)	Water(kg)	Fine aggregates(kg)	Coarse aggregates(kg)
For $1m^3$	400	160	660	1170
For $3.375x10^{-3}\, m^3$	1.35	0.54	2.2275	3.94875

Table 6 Mix Design for M40 (With 18 % replacement)

	Cement(kg)	Water(kg)	Fine aggregates(kg) sand + MSWIA	Coarse aggregates(kg)
For $1m^3$	328	160	660 + 72 =732	1170
For $3.375x10^{-3}\, m^3$	1.107	0.54	2.2275 + 0.243 =2.4705	3.94875

Table 7 Mix Design for M40 (With 19 % replacement)

	Cement(kg)	Water(kg)	Fine aggregates(kg) sand + MSWIA	Coarse aggregates(kg)
For 1m^3	324	160	660 + 76 =736	1170
For 3.375x10^{-3} m^3	1.10935	0.54	2.2275 + 0.2565 =2.484	3.94875

Table 8 Mix Design for M40 (With 20 % replacement)

	Cement(kg)	Water(kg)	Fine aggregates(kg) sand + MSWIA	Coarse aggregates(kg)
For 1m^3	320	160	660 + 80 =740	1170
For 3.375x10^{-3} m^3	1.08	0.54	2.2275 + 0.27 =2.4975	3.94875

Table 9 Mix Design for M40 (With 21 % replacement)

	Cement(kg)	Water(kg)	Fine aggregates(kg) sand + MSWIA	Coarse aggregates(kg)
For 1m^3	316	160	660 + 84 =744	1170
For 3.375x10^{-3} m^3	1.0665	0.54	2.2275 + 0.2835 =2.511	3.94875

2.10 Applications of MSWIA

Deepak, Ramesh (2015) observed that MSWIA can be used in small dosages i.e. up to 20% making the project economic but higher ash dosage without any accompanied loss of concrete properties would be possible only when the ash would be treated in some way but in such case there would arise additional costs suppressing the MSWI ashes utilization attractiveness for building industry.

Pera (2012) used MSWI bottom ash as partial coarse aggregates replacement in concrete; they The 28-days compressive strength of material with 10 % sand replacement was comparable with the reference concrete; the 90-days strength was lower which can be explained by different hydration process. The frost resistance of bottom ash containing concrete was very good. The prepared concrete contained relatively low content of MSWI ash; this approach represents a compromise between the ecological request on a practical utilization of MSWI ashes and properties of the acquired product.

2.11 Significance and scope of project:

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 Ultra high performance concrete with enhanced mechanical properties, enhanced durability, with high fracture energy and different approaches for the mix design of Ultra high performance 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 Ultra high performance 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.

Now if take the scenario of MSWIA, many cities and towns are rapidly depicting landfill space. As a result, some communities have opted to incinerate their municipal solid waste (MSW). The motive behind the choice is that incineration significantly reduces the volume of solid waste in need of disposal, destroys the harmful organic compounds that arc present in MSW, and provides an attractive source of alternative energy.

It is also significantly reducing the volume of garbage generated per year and destroying pathogens and toxic chemicals, incineration also helps by providing a very attractive source of alternative energy, preserving natural resources, and minimizing the impact of foreign dependency on energy

Also, replacing the volume of cement paste with MSWIA tends to economise the concrete and simultaneously no negative change in strength of concrete.

Project Scope:

This project will consist of optimization of OPC and OPC replaced with incinerated ash by polycarboxylate ether to achieve UHPC. The UHPC can be used for in now a days high rise buildings as well as in the nuclear power plant due to its ultra-high strength. Along with that the replacement with MSWIA make the project economic also as up to **20 %** of the cement is being replaced by bottom ash in municipal waste incinerator. Hence the cost will be decrease significantly and there is no chance of gaining less strength than the original concrete in which the % replacement of ash is 0% implying to a good scope in future.

Chapter 3. Objective

3.1. Objectives of the study

Ultra high performance concrete:

1. To Study the Materials and select the required combinations for UHPC.

2. To optimize PCE based plasticizer with the selected combinations for UHPC.

3. To Study the Strength Aspects

Municipal solid waste incinerated ash:

1. To procure municipal solid waste incinerated ash

2. To replace a part of OPC with incinerated ash (MSWIA)

3. To compare the results of concrete formed after and before the replacement of MSWIA

Chapter 4. Results and Discussions

4.1 Introduction

As we have already understood from the literature that Ultra high performance concrete is prepared by using ultra-fine materials. So Ultra high performance concrete was prepared by using binary 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.

4.2 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.

4.3 Specific gravity of Materials

Table 10 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

4.4 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 to 150 μm 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 11 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 12 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 13 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 14 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 15 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

4.5 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 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.

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 all these different proportions the cement was taken to be a constant amount of 900g 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.

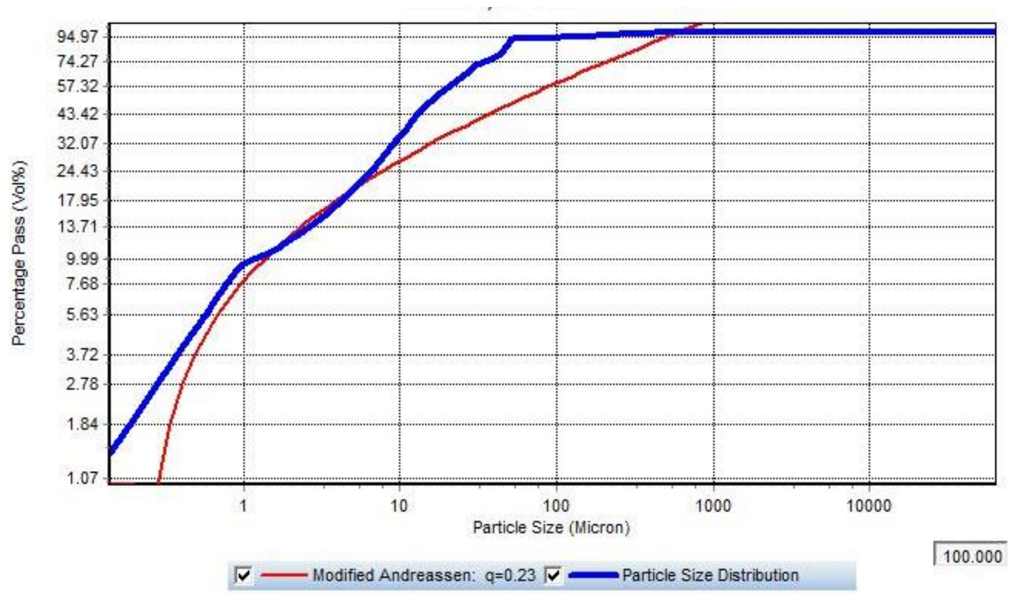

Figure 3 EMMA Analysis Cement 95% + Silica fume 5%, w/c ratio=0.17

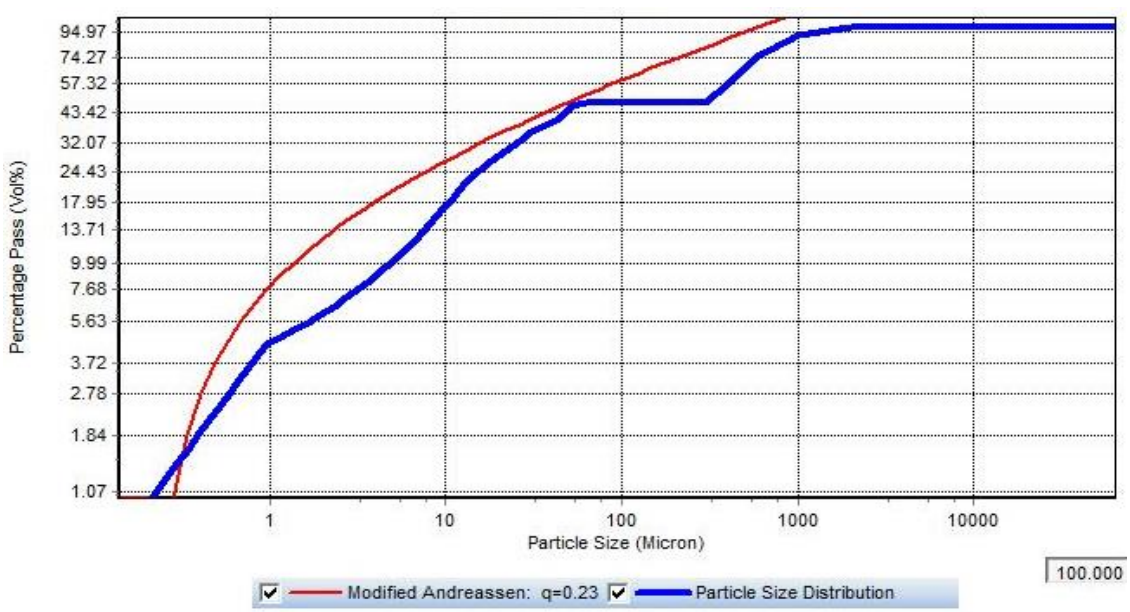

Figure 4 EMMA Analysis OPC 53 (80%) + Ultrafine slag (20%), w/c ratio=0.25

4.6 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 superplastizer. The marsh cone test gives an idea about the viscosity of the mixture under different proportions of the superplastizer. 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 16 SP optimisation for OPC (80%) +Alccofine (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

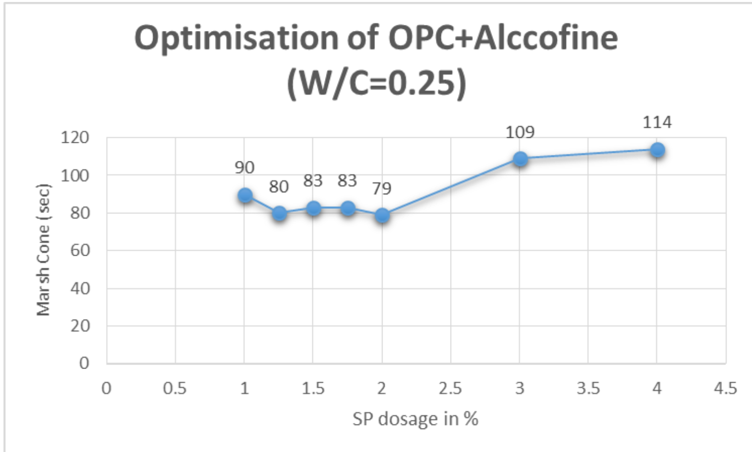

Figure 5 Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

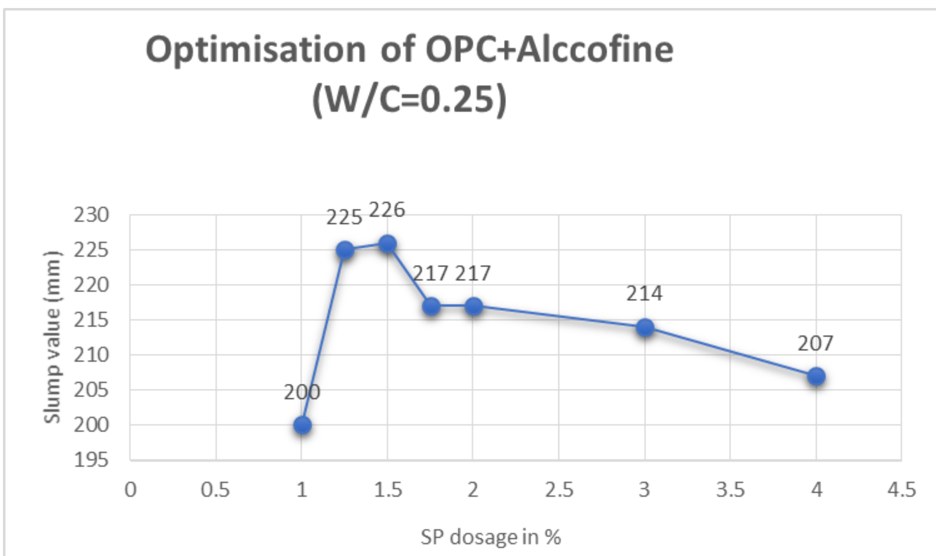

Figure 6 Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%)

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=0.25	1.5%

Table 17 SP optimisation for OPC (80%) +Alccofine (20%), W/c Ratio=0.19

Total Cementitious material (g)	cement (g)	Alccofine (20%) (g)	Water (g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)	Minislump (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

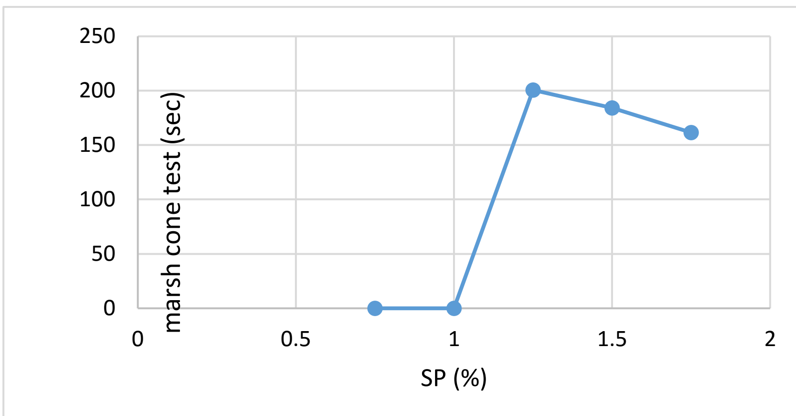

Figure 7 Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%) for w/c ratio of 0.19

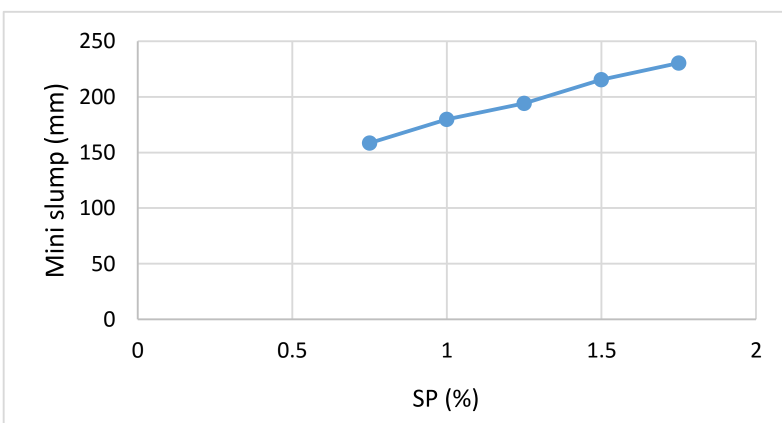

Figure 8 Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%) (W\C =0.19)

Table 18 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

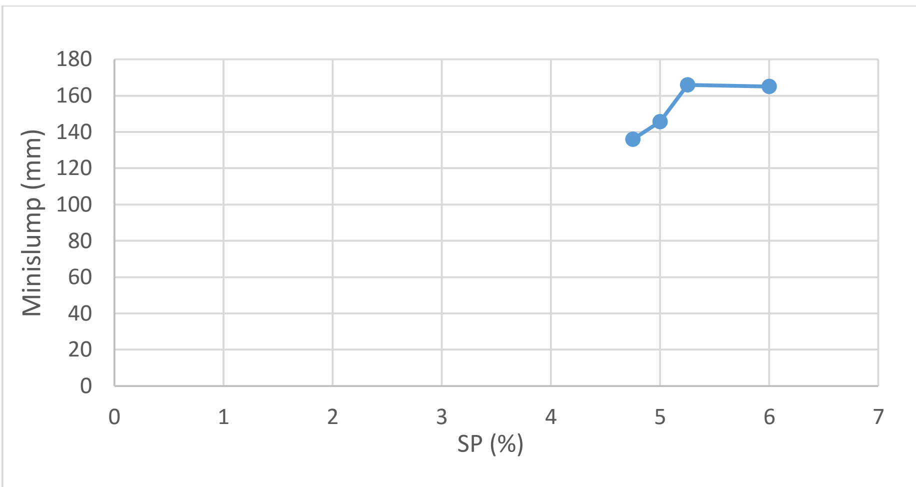

Figure 9 Mini Slump values graph for SP Optimization of OPC (80%) + Silica Fume (20%) (W\C =0.19)

Total Cementitious material (g)	cement (g)	Silica fume (5%) (g)	Alccofine (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

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%

Table 19 SP optimisation for OPC (80%) +Alccofine (20%), W/c Ratio=0.20

Total Cementitious material (g)	cement (g)	Alccofine (20%) (g)	Water (g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)	Minislump (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

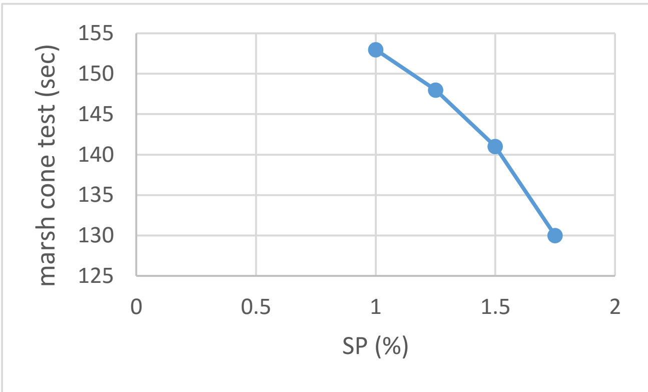

Figure 10 Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%) (W\C =0.20)

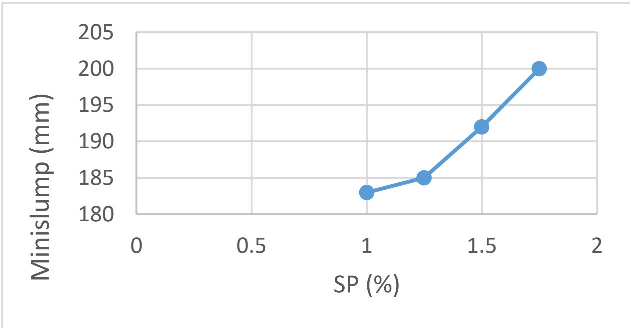

Figure 11 Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%) (W\C =0.20)

Table 20 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	DISCONT. FLOW	141
1842.1	1473.68	368.42	368.42	5	1.8	92.105	33.158	309.47	DISCONT. 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

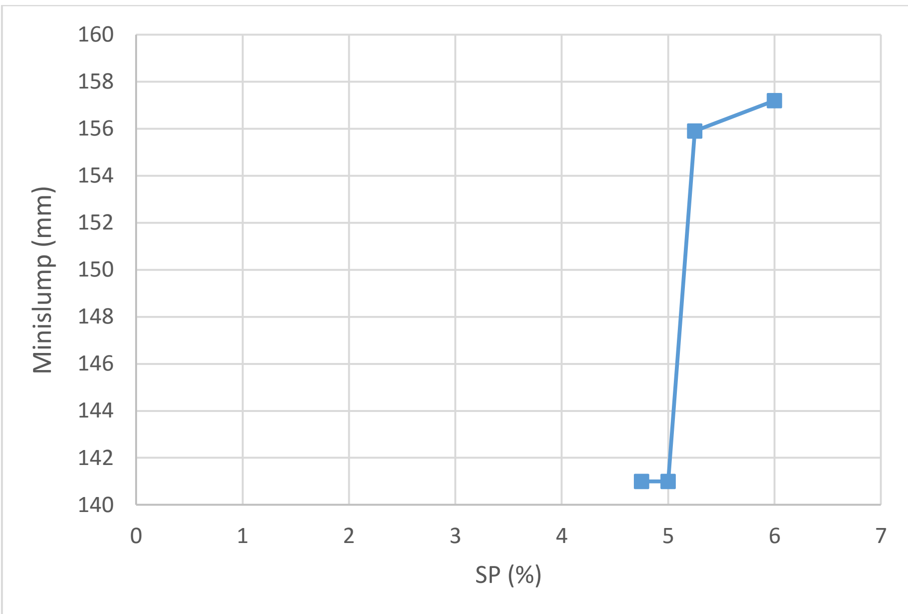

Figure 12 Mini Slump values graph for SP Optimization of OPC (80%) + Silica Fume (20%) (w\c =0.20)

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%

Table 21 SP optimisation for OPC (80%) +Alccofine (20%), W/c Ratio=0.21

Total Cementitious material (g)	cement (g)	Alccofine (20%) (g)	Water (g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)	Minislump (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

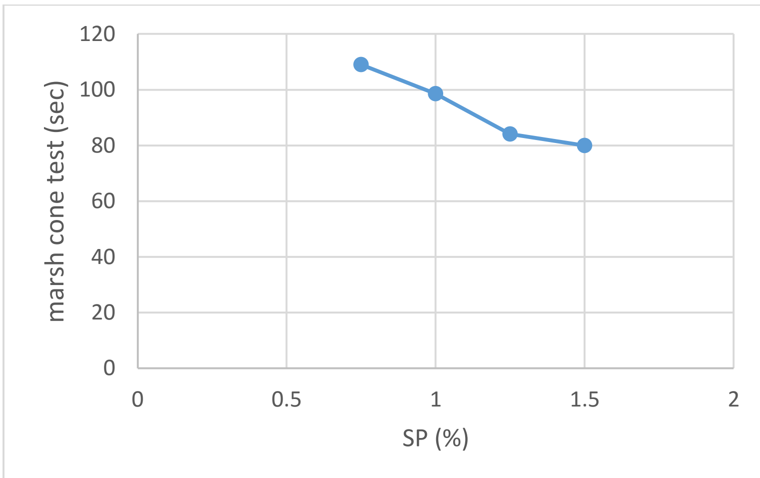

Figure 13 Marsh Cone values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%) (W\C=0.21)

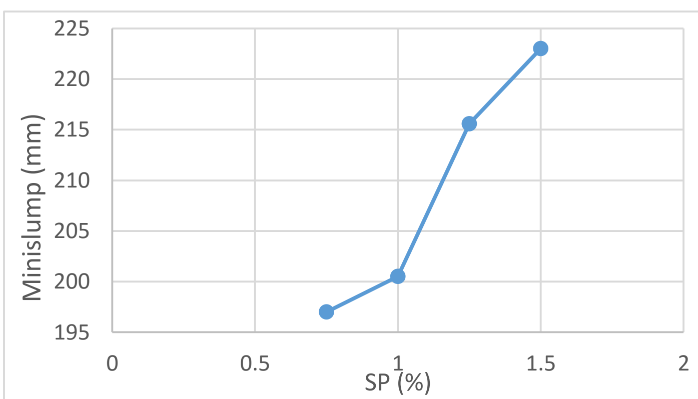

Figure 14 Mini Slump values graph for SP Optimization of OPC (80%) + Ultra-fine slag (20%) (w\C =0.21)

Table 22 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

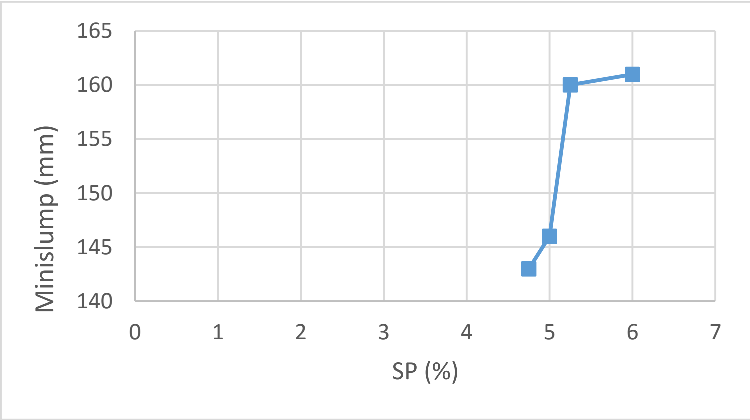

Figure 15 Mini Slump values graph for SP Optimization of OPC (80%) + Silica Fume (20%) (W\ C=0.21)

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%

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.

Table 23 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 24 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 25 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 26 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 27 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 28 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 29 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

4.8 Hot water Curing

The Ultra high performance 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 16 Blocks Before Hot Water Curing

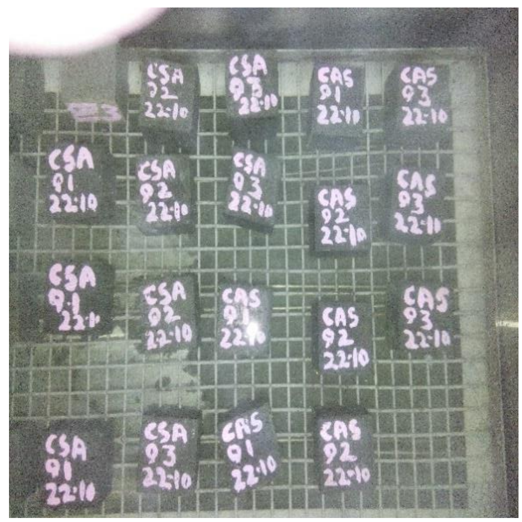

Figure 17 Blocks in Curing Tanks

Figure 18 Blocks after Hot Water Curing

4.9 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.

4.10 Results

Table 30 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	73.27608	70.39321639
	803.6	4963.16	347.7	70.05617	
	794.7	4872.7	330.6	67.84739	
CSQ2	815.2	5069.408	341	67.26624	71.33267081
	790.5	4886.904	356	72.84776	
	801.1	4956.417	366.2	73.88402	
CSQ3	794.7	4917.437	442.5	89.98591	79.86795182
	805.7	4940.37	382	77.32214	
	796	4947.728	357.7	72.29581	
CAQ1	802.7	4663.176	346.1	74.21981	75.06557481
	770.4	4449.76	330.2	74.20625	
	784.3	4516.048	346.7	76.77067	
CAQ2	808.3	4705.657	400.3	85.06782	80.65933949
	819.3	4738.96	373.3	78.77256	
	785.9	4562.462	356.5	78.13764	
CAQ3	817.8	4753.266	392	82.46961	76.25021836
	778.9	4527.86	343	75.75322	
	785.6	4591.096	323.8	70.52782	

Maximum strength=80.65 MPa

CSQ –Cement+silica + quartz sand (1-without steel fibres, 2-with 6mm steel fibres, 3-with 13mm steel fibres)

CAQ –Cement + Alccofine + quartz sand (1-without steel fibres, 2-with 6mm steel fibres, 3-with 13mm steel fibres)

Table 31 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	69.1833
	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.

Maximum strength = 77.65 MPa.

Table 32 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 33 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.

4.11 Discussions and conclusion

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

- The graph which was obtained from was not perfectly matching with the modified Andreessen model as some particle sizes were 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 19 The block showing the separation of the particle into two layers due to over compaction

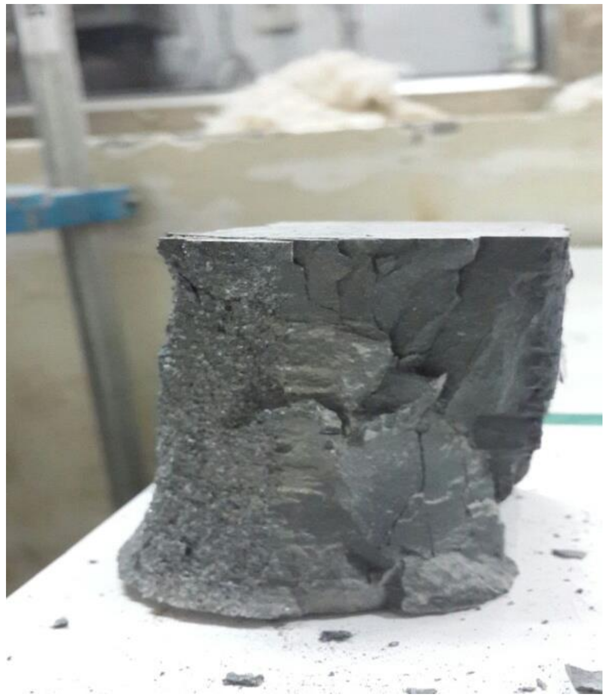

Figure 20 The failed block showing segregation of the material

Figure 21 The block which is compacted very less resulted in lot of pores which again lead to loss of strength

Results and calculations for concrete containing MSWIA:

1. 18% of cement with MSWIA

Table 34 Result of compression test for concrete without replacement

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load Mean(KN)	Strength(N/mm^2 or MPa)
1 days	120.12	158.4	155.3	145.1	6.5
7 days	601.4	604	610.5	605.45	27
14 days	750.6	790.12	810.8	787.5	35
28 days	830.5	855.9	880.7	855.34	38

Table 35 Result of compression test for concrete with 18% replacement

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load Mean(KN)	Strength(N/mm^2 or MPa)
1 days	120.9	122.3	130.5	124.9	5.5
7 days	535.5	555.9	580.3	560.3	25
14 days	750	740.5	810	753.7	33
28 days	830.5	820.9	880.3	821.9	36.5

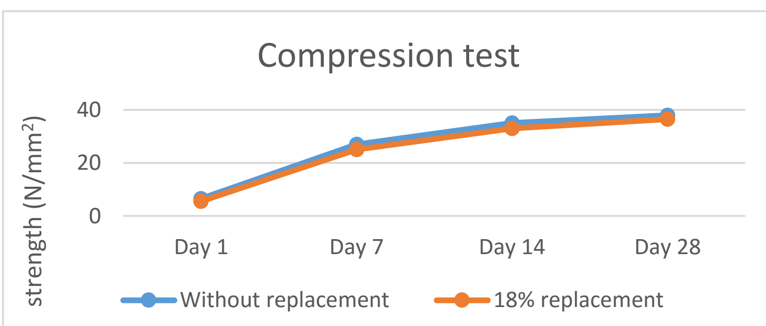

Figure 22 comparison of compression test result for 18 % replacement

Table 36 Result of flexure test for concrete without replacement:

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	339	330.4	320.6	332	4.99
28 days	452.3	461	468.1	459.86	6.89

Table 37 Result of flexure test for concrete with 18% replacement:

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	310.56	322	330.56	320.1	4.8
28 days	475.4	473.33	471.1	473.33	6.45

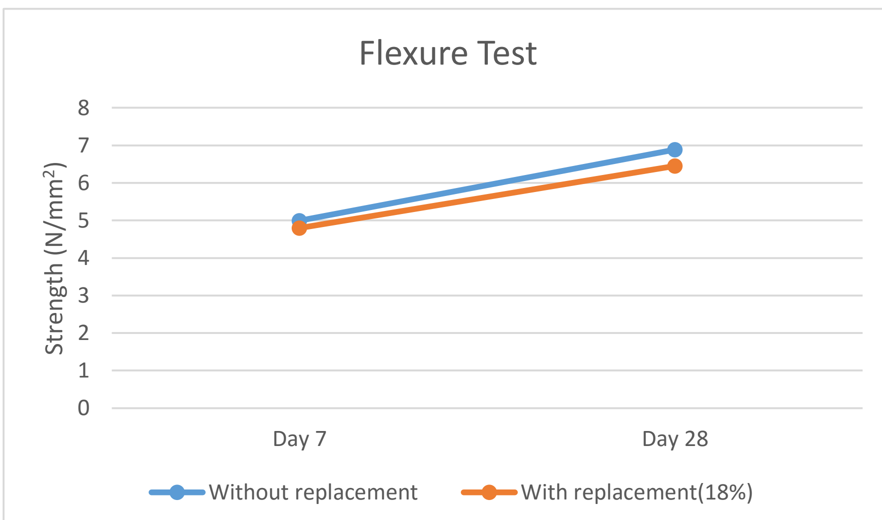

Figure 23 comparison of flexure test result for 18 % replacement

Table 38 Result of split tensile test for concrete without replacement:

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	111.1	123.32	129.4	122.2	3.89
28 days	125.6	129.1	135.6	130	4.14

Table 39 Result of split tensile test for concrete with 18% replacement

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	99.87	87.34	91.28	93.9	2.99
28 days	111.1	123.32	129.4	122.2	3.89

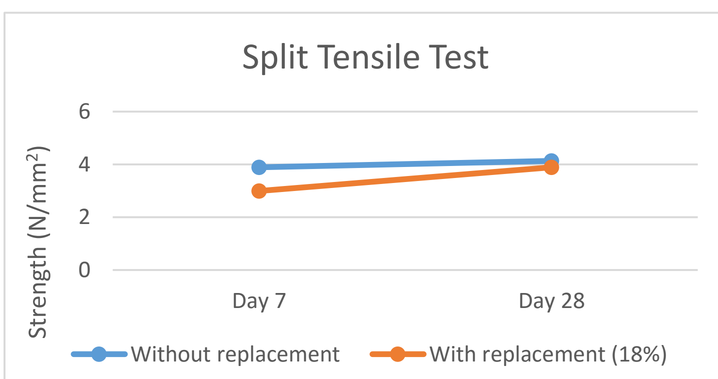

Figure 24 comparison of split tensile test result for 18 % replacement

2. 19% of cement with MSWIA

a) Compression test

Table 40 Result of compression test for concrete without replacement

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load Mean(KN)	Strength(N/mm^2 or MPa)
1 days	120.12	158.4	155.3	145.1	6.5
7 days	601.4	604	610.5	605.45	27
14 days	750.6	790.12	810.8	787.5	35
28 days	830.5	855.9	880.7	855.34	38

Table 41 Result of compression test for concrete with 19% replacement:

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load : Mean(KN)	Strength(N/mm^2 or MPa)
1 days	120.91	122.8	130.5	138.6	6.16
7 days	535.55	538.05	580.3	577.8	23.68
14 days	750	792.56	811.56	769	34.18
28 days	830.5	820.9	805.43	846	37.6

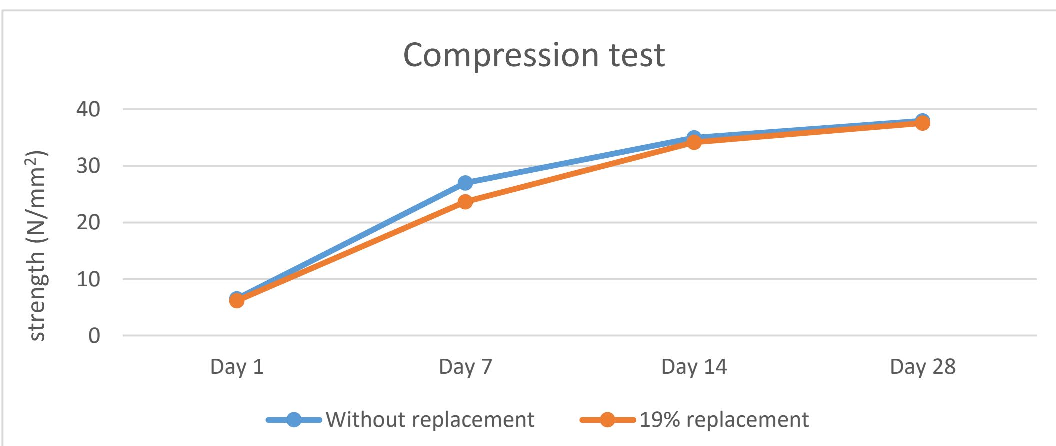

Figure 25 comparison of compression test result for 19 % replacement

b) Flexural test:

Table 42 Result of flexure test for concrete without replacement

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	339	330.4	320.6	332	4.99
28 days	452.3	461	468.1	459.86	6.89

Table 43 Result of flexure test for concrete with 19% replacement

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	310.56	323.3	326.89	320.25	4.27
28 days	475.44	443.33	435.17	451.315	6.15

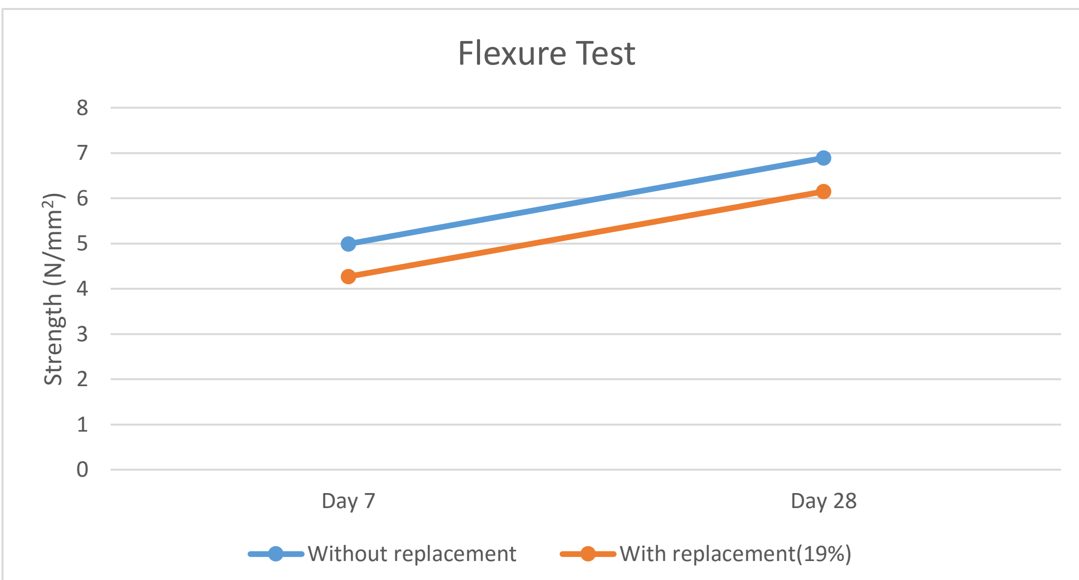

Figure 26 comparison of flexure test result for 19 % replacement

c) Split tensile Test:

Table 44 Result of split tensile test for concrete without replacement

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	111.1	123.32	129.4	122.2	3.89
28 days	125.6	129.1	135.6	130	4.14

Table 45 Result of split tensile test for concrete with 19% replacement:

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	99.87	80.34	73.225	84.47	2.69
28 days	103.4	88.2	109.49	100.27	3.19

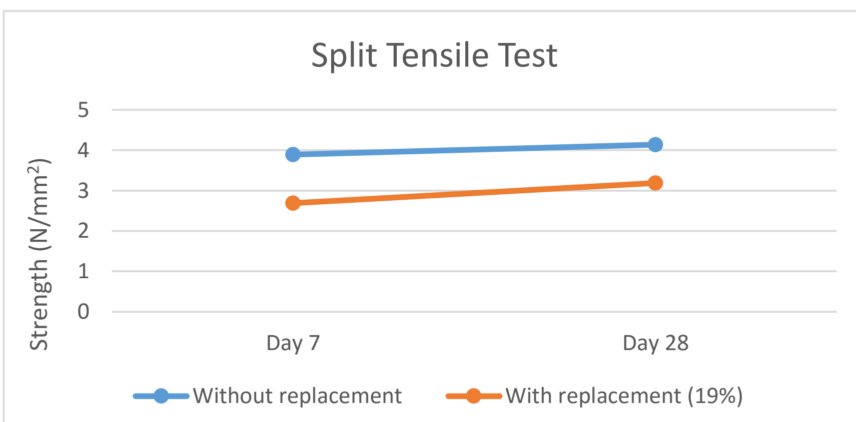

Figure 27 comparison of split tensile test result for 19 % replacement

3. 20% of cement with MSWIA

a) Compression test

Table 46 Result of compression test for concrete without replacement

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load Mean(KN)	Strength(N/mm^2 or MPa)
1 days	122.36	151.4	155.3	145.1	6.5
7 days	601.4	604	610.95	605.45	27
14 days	760.6	790.12	811.78	787.5	35
28 days	830.5	864.12	871.4	855.34	38

Table 47 Result of compression test for concrete with 20% replacement

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load : Mean(KN)	Strength(N/mm^2 or MPa)
1 days	122.36	161.54	151.4	141.8	6.36
7 days	535.55	538.05	580.3	577.8	21.68
14 days	750	792.56	811.56	797.8	35.46
28 days	830.5	820.9	805.43	877.7	39.01

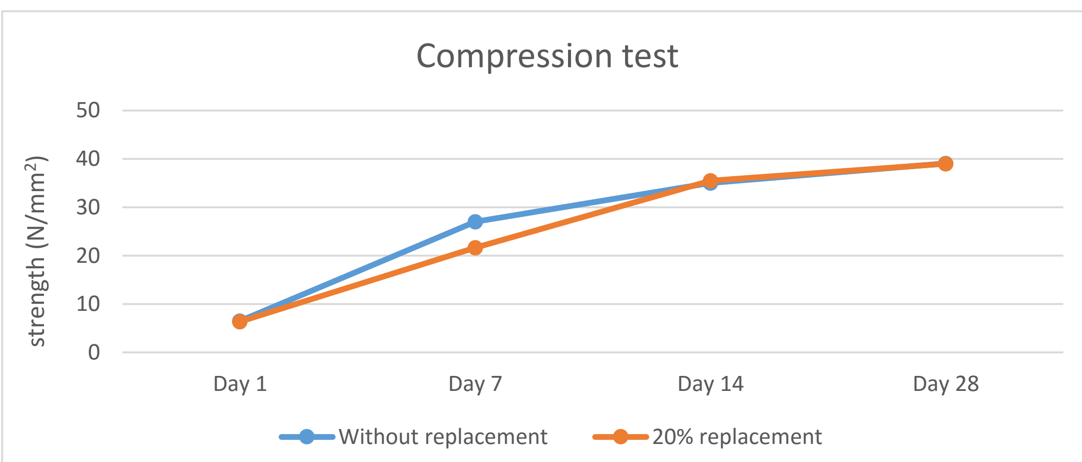

Figure 28 comparison of compression test result for 20 % replacement

b) Flexural test:

Table 48 Result of flexure test for concrete without replacement:

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	339	330.4	320.6	332	4.99
28 days	452.3	461	468.1	459.86	6.89

Table 49 : Result of flexure test for concrete with 20% replacement

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	310.56	323.3	326.89	294.25	4.01
28 days	436.39	443.33	430.17	436.63	5.95

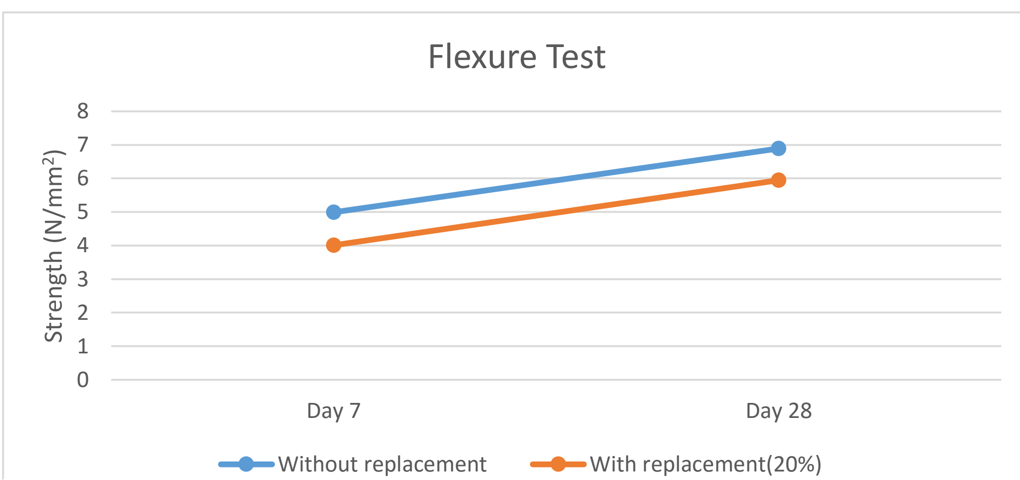

Figure 29 comparison of flexure test result for 20 % replacement

3. Split tensile Test:

Table 50 Result of split tensile test for concrete without replacement

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	111.1	123.32	129.4	122.2	3.89
28 days	125.6	129.1	135.6	130	4.14

Table 51 Result of split tensile test for concrete with 20% replacement

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	99.87	110.34	113.22	107.81	3.43
28 days	123.4	124.469	109.49	119.119	3.84

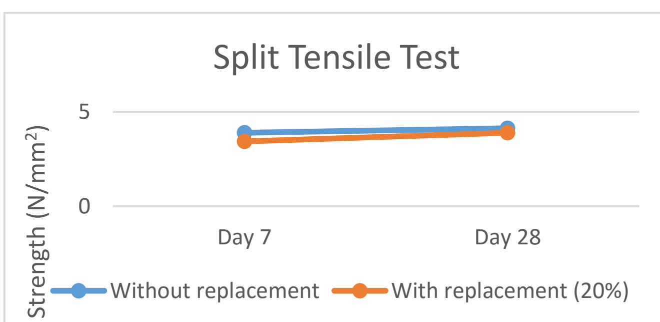

Figure 30 comparison of split tensile test result for 20 % replacement

4. 21% of cement with MSWIA

a) Compressive test

Table 52 Result of split tensile test for concrete without replacement:

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load Mean(KN)	Strength(N/mm^2 or MPa)
1 days	122.36	151.4	155.3	145.1	6.5
7 days	601.4	604	610.95	605.45	27
14 days	760.6	790.12	811.78	787.5	35
28 days	830.5	864.12	871.4	855.34	38

Table 53 Result of split tensile test for concrete with 21% replacement:

Age	Cube1(KN)	Cube2(KN)	Cube3(KN)	Max load : Mean(KN)	Strength(N/mm^2 or MPa)
1 days	112.48	161.54	151.4	141.8	6.36
7 days	565.55	617.55	580.3	577.8	21.68
14 days	722.9	772.56	678.64	724.7	32.209
28 days	830.5	820.9	805.43	7971	35.43

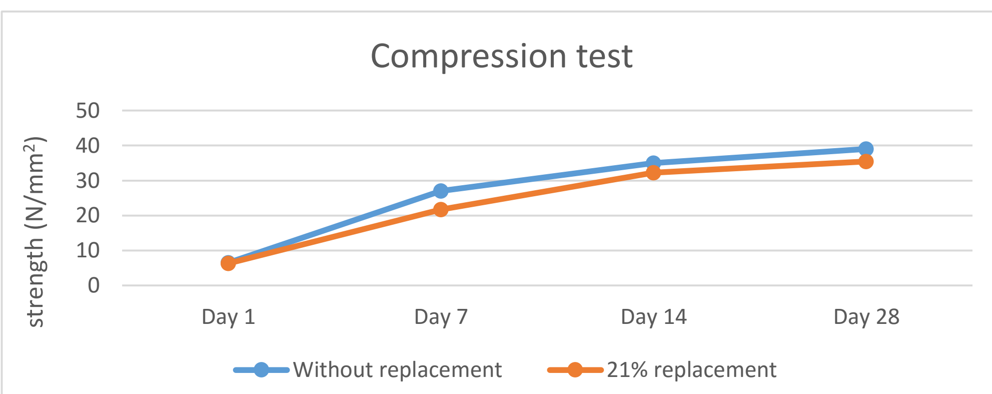

Figure 31 comparison of compression test result for 21 % replacement

b) Flexural test:

Table 54 Result of flexure test for concrete without replacement:

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	339	330.4	320.6	332	4.99
28 days	452.3	461	468.1	459.86	6.89

Table 46: Result of flexure test for concrete with 21% replacement:

Table 55 Result of flexure test for concrete with 21% replacement:

Age	Beam1(KN)	Beam2(KN)	Beam3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	310.56	323.3	326.89	294.25	4.01
28 days	325.16	371.6	366.5	354.42	4.83

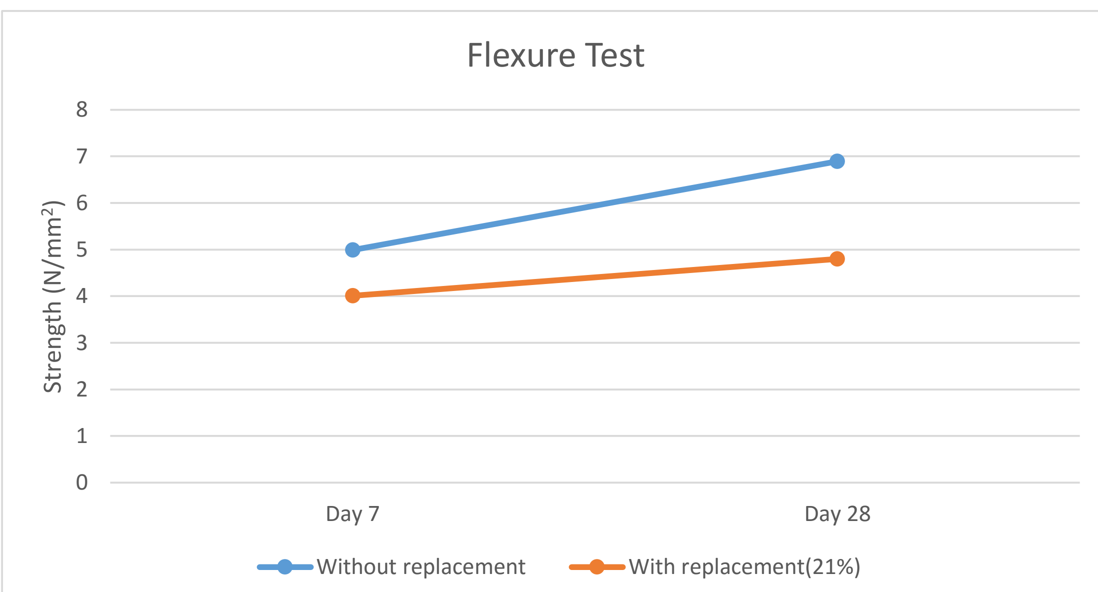

Figure 32 comparison of flexure test result for 21 % replacement

3. Split tensile Test:

Table 56 Result of split tensile test for concrete without replacement:

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	111.1	123.32	129.4	122.2	3.89
28 days	125.6	129.1	135.6	130	4.14

Table 57 Result of split tensile test for concrete with 21% replacement:

Age	Cylinder1(KN)	Cylinder2(KN)	Cylinder3(KN)	P=Max load Mean(KN)	Strength(N/mm^2 or MPa)
7 days	99.87	110.34	113.22	107.81	3.43
28 days	113.98	124.469	109.49	115.98	3.69

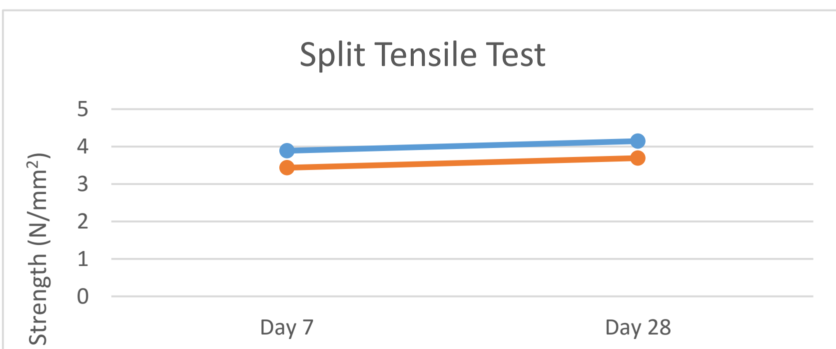

Figure 33 comparison of split tensile test result for 21 % replacement

References

1. Benjamin A.Grabeal (2006), "Material Property Characterization of Ultra-High Performance Concrete" Publication No.FHWA-HRT-06-103.

2. Dili.A.S, Manu Santhanam, (2005) Department of civil engineering, IIT Chennai, "Investigations on Ultra high performance concrete, A Developing Ultra High-Strength Technology", concrete technology.

3. Ming-Gin Lee, Yung-Chih Wang, Chui-Te Chiu, Taiwan (2005), " A Preliminary Study of Ultra high performance concrete as a New Repair Material", Construction and Building Material's.

4. Pierre Rossi and Edouard Parant(2001),"Mechanical Behaviour of An Ultra High Performance Fibre Reinforced Cement Composite Submited to Impact Loading Conditions", Report by Laboratoire Central des Ponts et Chaussees,France.

5. Matte.V., Moranville.M., (1999)France, "Durability of Reactive Powder Composites: Influence of Silica Fume on the Leaching Properties of Very Low Water/Binder Pastes", Cement and Concrete Composites 21,1-9.

6. Collepardi.S., Coppola.L., Troli.R., Collepardi.M.,(1998) "Mechanical Properties of Modified Ultra high performance concrete., A Report Vol.95, May – June 1998., 284 - 292.

7. Dattatreya, J.K., Harish, K. V., and Neelamegam,M.,(2007), " Use of Particle Packing Theory for the Development of Ultra high performance concrete", The Indian Concrete Journal, September 2007, 31-45.

8. Helene Zanni, Marcel Cheyrezy,Vincent Maret Samuel Philippot, and Fedro nie,(1996), " Investigation of Hydration and pozzolanic Reaction in Ultra high performance concrete(UHPC) using NMR" Cement and Concrete Research, Vol 26, No.1, 93-100,(1996).

9. ISWA, Management of APC residues from W-t-E plants; An overview of management options and treatment methods. International Solid Waste Association, Copenhagen, 2008

10. ČSN EN 12390-3, Testing hardened concrete Part 3:Compressive strength of test specimens, 2002

11. C. H. K. Lam, A. W. M. Ip, J. P. Barford and G. McKay, “Use of Incineration MSW ash: A review”, sustainability, vol. 2, 2010, pp. 1943-1968

12. J. Pera, L. Coutaz, J. Ambroise and M. Chababbet, “Use of Incinerator Bottom Ash in Concrete”, Cement and concrete Research, vol. 27, 1997, pp. 1–5.

13. S. Rémond, P. Pimienta and D. P. Bentz, “Effects of incorporation of Municipal Solid Waste Incineration fly ash in cement pastes and mortars I. Experimental study, Cement and Concrete Research, vol. 32, 2002, pp. 303-311.

14. ČSN EN 12390-3, Testing hardened concrete Part 3: Compressive strength of test specimens, 2002.