EFFECT OF PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN AND SAND WITH FOUNDRY SAND IN SELF COMPACTING CONCRETE

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By

KARTIK SHARMA

(11510786)

Supervisor

Mr. PARIJAT HASIJA

Transforming Education Transforming India

School of Civil Engineering

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DECLARATION

I, **KARTIK SHARMA** (11510786), hereby declare that this submission is my own work and that to the best of my insight and conviction, it contains no material beforehand distributed or composed by other individual or office. No material which has been acknowledged for reward of some other degree or certificate of the college or other organization of higher learning with the exception of where due affirmations have been made in the content. It was arranged and displayed under the direction and supervision of **Mr. PARIJAT HASIJA** (Assistant Professor).

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This is to certify that **KARTIK SHARMA** under Registration No. **11510786** has prepared the dissertation-1 report titled "**EFFECT OF PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN AND SAND WITH FOUNDRY SAND IN SELF COMPACTING CONCRETE**" under my direction. This is a bonafide work of the above competitor and has been submitted to me in fractional satisfaction of the prerequisite for the honor of Masters of Technology in Civil Engineering.

Mr. Parijat Hasija

Supervisor

Assistant Professor

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ABSTRACT

Self Compacting Concrete (SCC), a recent innovation in concrete technology, has numerous advantages over conventional concrete. Self Compacting Concrete, as the name indicates, is a type of concrete that does not require external or internal compaction, because it becomes levelled and consolidated under its self weight. SCC can spread and fill all corners of the formwork, purely by means of its self weight, thus eliminating the need of vibration or any type of consolidating effect.

There has been a growing interest in the utilization of high reactivity metakaolin (MK) as a supplementary cementitious material in concrete industry. MK is an ultrafine pozzolana with particle size generally less than 2μm which is significantly smaller than that of cement particle.

Foundry sand is a high quality silica sand used as a moulding material by ferrous and non-ferrous metal casting industries. It can be reused several times in foundries but, after a certain period, cannot be used further and becomes waste material, referred to as used or spent foundry sand (UFS or SFS).

This report demonstrates the investigation performed to evaluate the hardening properties of SCC in which natural sand is replaced with five percentages (0%, 10%, 15%, 20% and 25%) of waste foundry sand by weight and cement is replaced with fixed percentage (10%) of metakaolin by weight. Strength properties were evaluated at age of 7, 14 and 28 days. Water / cement ratio (w/c) = 0.43 was taken. To increase workability 1% admixture (Auramix 200) was used. Results showed that there is increase in strength properties by incorporating waste foundry sand as partial replacement by natural sand upto 10%.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Concrete is the man-made material which has the vastest utilization worldwide. This fact leads to important problems regarding its design and preparation to finally obtain an economic cost of the product on short and long time periods. The material has to be also “environment friendly” during its fabrication process and also its aesthetical appearance when it is used in the structures. Its success is when its raw materials that have a large spreading into the world, the prices of raw materials that are low and the properties and the performances of the concrete that confers it a large scale of application. Concrete’s performances have continuously rise in order to accomplish the society needs. Many studies have been made concerning the use of additives and super-plasticizers in the concrete by using less water content for a good workability of a concrete. As a result of this, high performance concretes develop having a superior durability.

1.2 DEVELOPMENT OF SELF COMPACTING CONCRETE

In 1983, the problem of the durability of concrete structures was a major topic in Japan. To make durable concrete structures, sufficient compaction by skilled labour is required. However, the gradual reduction of skilled labour in Japan’s construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of SCC, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibration compaction. The necessity of this type of concrete was proposed by Professor Hajime Okamura in 1986.studies to develop SCC, including a fundamental study on the workability of concrete, were carried out by Ozawa and Maekawa at the University of Tokyo. SCC technology in Japan was based on using conventional super-plasticizers to create highly fluidic concrete, by using viscosity-modifying agents (VMA) which increase plastic viscosity thus preventing segregation up to a level of fluidity that would normally cause segregation. The prototype of SCC was first completed in 1988 using materials already in the market.

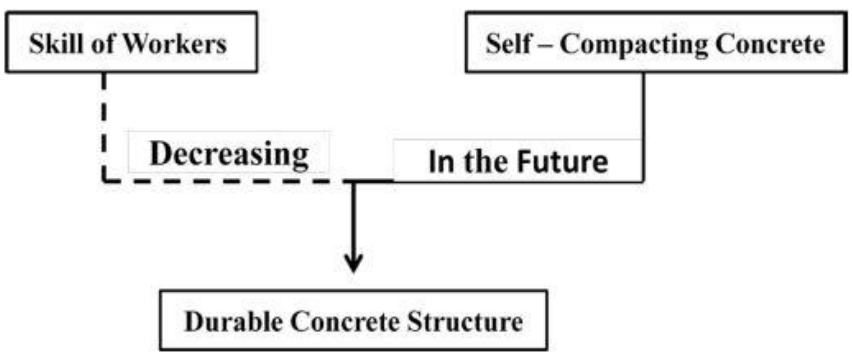

Fig 1.1: Necessity of SCC (Ouchi and Hibino, 2000)

1.3 PROPERTIES OF SELF COMPACTING CONCRETE

Fresh SCC must possess at required levels the following key properties related to workability:

Filling ability: This is the ability of SCC to flow, spread and fill into all spaces within the formwork under its own weight.

Passing ability: This is the ability of SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight without blocking them.

Resistance to segregation: The SCC must meet the required levels of properties and its composition remains uniform throughout the process of transport and placing that is keeps the sand and aggregate in suspension.

Fig 1.2 Self Compacting Concrete

1.4 ADVANTAGES OF SELF COMPACTED CONCRETE

- No vibration of fresh concrete is necessary during placement into forms.
- Placement of concrete is easier.
- Faster and more efficient placement of fresh concrete is achieved. Total concreting time is reduced.
- Energy consumption is reduced.
- Required number of workers on construction site is reduced.
- Good bond between concrete and reinforcement is obtained, even in congested reinforcement.

- High quality surface finish is obtained.
- Reduced construction costs due to reduced labour costs and reduced equipment purchase and maintenance costs.
- Increase construction speed.
- Faster unloading of ready mixed concrete trucks.
- Improved durability and strength of the hardened concrete in some cases.

1.5 NEED FOR THIS RESEARCH

There are many situations in today's construction market that makes SCC an interesting alternative to conventional slump concrete. In general cost savings and/or performance enhancement tend to be the driving forces behind the added value of SCC. Contractors, producers and owners are under great pressure to produce better quality construction at lower costs of labour, materials and equipment. They are also faced with tougher environmental and safety regulations and increased insurance costs. The economic benefits of a less intensive construction environment results in labour savings , time savings from higher productivity and greater flexibility of design. SCC offers some help in all of the following areas. The main barrier to the increased use of SCC seems to be the lack of experience of the process and the lack of published guidance, codes and specifications. This situation will improve, however, as experience and knowledge increases and each country begins to produce its own guidance and specifications for the production of SCC with local marginal aggregates and the harsh environmental conditions prevailing in the region. Therefore, there is a need to conduct studies on SCC.

1.6 PRODUCTION OF FOUNDRY SAND IN INDIA AND WORLD

Country	2009		2010		2011	
	M.T.	R	M.T.	R	M.T.	R
China	35.3	1	39.6	1	41.26	1
US	7.40	2	8.24	3	10.01	2
Japan	4.40	4	4.76	5	5.47	4
India	7.40	3	9.05	2	9.99	3
Germany	3.90	5	4.79	4	5.46	5
Brazil	2.30	7	3.24	7	3.34	7
Italy	1.67	9	1.97	9	2.21	9
France	1.74	10	1.96	10	2.04	10
Korea	2.10	8	2.23	8	2.34	8
Russia	4.20	6	4.20	6	4.3	6

M.T. = Million Tons R = Rank

1.7 PROPERTIES OF WASTE FOUNDRY SAND

1.7.1 PHYSICAL PROPERTIES

Generally, WFS is sub-angular to round in shape. Green sands are black or grey, whereas chemically bounded sands are of medium tan or off white color. Grain size distribution of waste foundry sand is uniform with 85-95% of material in between 0.6 mm to 0.15 mm and approximately 5 to 20% of foundry sand can be smaller than 0.075 mm.

Table 1.1 Physical Properties of WFS

Property	Javed and Lovell	Naik et al.	Guney et al.	Siddique et al.
	(1994)	(2001)	(2010)	(2011)
Specific gravity	2.39-2.55	2.79	2.45	2.61
Fineness modulus	-	2.32	-	1.78
Unit Weight (kg/m^3)	-	1784	-	1638
Absorption (%)	0.45	5	-	1.3
Moisture content (%)	0.1-10.1	-	3.25	-
Clay lumps and friable particles	1-44	0.4	-	0.9
Materials finer than 75µm (%)	-	1.08	24	18

1.7.2 CHEMICAL PROPERTIES

Chemical composition of the waste foundry sand depends on the type of metal, type of binder and combustible used. The chemical composition of waste foundry sand may influence its performance. Waste foundry sand is rich in silica content. It is coated with a thin film of burnt carbon, residual binder and dust. Silica sand is hydrophilic and consequently attracts water to its surface. Chemical composition of waste foundry sand is given in Table 1.2

Table 1.2 Chemical Properties of WFS

Constituent	Value (%)			
	American Foundryman's Society (1991)	Guney et al. (2010)	Etxeberria et al. (2010)	Siddique et al. (2011)
SiO_2	87.91	98	95.1	78.81
Al_2O_3	4.7	0.8	1.47	6.32
Fe_2O_3	0.94	0.25	0.49	4.83
CaO	0.14	0.035	0.19	1.88
MgO	0.3	0.023	0.19	1.95
SO_3	0.09	0.01	0.03	0.05
Na_2O	0.19	0.04	0.26	0.1
K_2O	0.25	0.04	0.68	-
TiO_2	0.15	-	0.04	-
Mn_2O_3	0.02	-		-
SrO	0.03	-		-
LOI	5.15	-	1.32	2.15

1.7.3 MECHANICAL PROPERTIES

Waste foundry sand has good durability properties as measured by low Micro-Deval Abrasion have revealed relatively high soundness loss, which may be due to the samples of bound sand loss and not a breakdown of individual sand particles. The angle of shearing resistance (also known as friction angle) of waste foundry sand varies between 33 to 40 degrees, which is comparable to that of conventional sands. Typical mechanical properties of waste foundry sand are given in Table 1.3

Table 1.3 Mechanical Properties of WFS

Property	Results
Micro-deval abrasion loss (%) (MNR–1992)	< 2
Magnesium sulfate soundness loss (%)(MNR–1992)	5 – 15 6 – 47
Friction angle (deg)	33 – 40
California bearing ratio (%) (Javed and Lovell 1994)	4 – 20

1.8 PROPERTIES OF CEMENTITIOUS MATERIALS

Table 1.4 Physical Properties of Metakaolin

Property	Value
Specific Gravity	**2.60**
Bulk Density(gm/cm^3)	**0.3-0.4**
Physical Form	**Powder**
Colour	**White**

Table 1.5 Chemical Composition of cementitious Materials

Chemicals	Cement (%)	Metakaolin (%)
SiO_2	21.0	51.2
Al_2O_3	5.2	45.3
Fe_2O_3	2.3	0.60
MgO	3.9	-----
CaO	63.9	0.05
Na_2O	0.5	0.21
K_2O	0.5	0.16
SO_3	2.4	-----

1.9 REACTION MECHANISM OF METAKAOLIN

Metakaolin is a thermally activated pozzolanic material that is obtained by the calcination of kaolinite clay at moderate temperatures ranging from 650 to 800 C.

$$Al_2Si_2O_5(OH)_4 \rightarrow Al_2Si_2O_7 + 2\,H_2O$$

Kaolinite **metakaolin**

Hydration is a chemical reaction in which the major compounds in cement forms chemical bonds with water molecules and become hydrates or hydration products.

$$\text{Cement} + \text{Water} \rightarrow \text{C-S-H gel} + Ca(OH)_2 \quad \text{(hydration)}$$

Metakaolin is its high reactivity with calcium hydroxide, $Ca(OH)_2$, and its ability to accelerate cement hydration. Metakaolin is expected to be more significant due to its high concentration of silica and alumina. Specifically, the calcium to silicon (C/S) ratio of the produced calcium silica hydrates (C–S–H gel) is expected to be higher than of other SCM's.

Metakaolin + $Ca(OH)_2$ → CSH GEL

Fig 1.3 Metakaolin

CHAPTER-2

LITERATURE REVIEW

2.1 METAKAOLIN

Luc Courard (2003): Investigated the effects of Metakaolin on properties of mortar. Comparisons are made to ordinary Portland cement to determine the influence of replacement. Cement is replaced on mass basis of 5% to 20% for metakaolin. The transport properties and chemical behaviors are analyzed by means of chloride diffusion tests and sulfate immersion. Observations made after more than 100 days are used to prescribe mixtures that reduce the rate of chloride diffusion and sulfate degradation. For metakaolin the optimum percentage is between 10% and 15% with regard to inhibition effect on chloride diffusion and sulfate attack.

E. Badogiannis et al (2005): Investigation aimed at the use of produced metakaolin as supplementary cementitious material. Samples of poor Greek kaolin and a high purity commercial kaolin were tested. Samples were heated at different temperatures and time intervals. The optimization of calcination conditions was studied by DTA-TG and XRD analysis of the raw and thermal treated kaolin samples, by pozzolanic activity analysis of metakaolin and finally by strength development analysis of cement-metakaolin mixtures. This approach showed that heating at 650°C for 3 hours is efficient to convert poor kaolins with low alunite content to highly reactive metakaolins. However in the case of kaolin with a high alunite content, thermal treatment at 850°C for 3 hours is required in order to remove undesirable SO3. Evidence was found that poor kaolins can be efficiently used for the production of highly reactive metakaolin.

Rafat Siddique et al (2009): Stated an overview on the use of MK as partial replacement of cement in mortar and concrete. He concluded the Reduction in the slump values and increase in the setting times of concrete. Fluidity of MK-blended cement became poorer. Metakaolin helps in enhancing the early age mechanical properties and long-term strength properties of cement paste mortar and cement concrete. Metakaolin replacement reduces the water penetration into concrete by capillary action. MK modifies the pore structure of the cement mortar and cement concrete and remarkably reduces the permeability, which results in resistance of transportation of water and diffusion of harmful ions which led to the deterioration of the matrix. Metakaolin replacement of cement is effective in improving the resistance of concrete to sulphate attack. Concrete containing 10% and 15% Metalaolin replacements showed excellent durability to sulphate attack.

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M. Shekarchi et al (2010): Researched on various transport properties of concrete modified with metakaolin(MK). Usage of metakaolin decreases the initial setting time however the final setting time remains unchanged. Compressive strength increased by 20% when 15% replacement of cement with metakaolin was done. Transport properties measured in terms of water penetration, gas permeability, water absorption, electrical resistivity, and ionic diffusion were improved up to 50%, 37%, 28%, 450%, and 47%, respectively.

Sadaqat Ullah Khan et al (2014): Investigated the properties of fresh concrete i.e. workability, heat of hydration, setting time, bleeding, and reactivity by using mineral admixtures that are fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK), and rice husk ash (RHA). Comparison of normal and high-strength concrete in which cement has been partially replaced by mineral admixture has been considered. It has been concluded that mineral admixtures may be categorized into two groups i.e. chemically active mineral admixtures (SF and MK) and micro filler mineral admixtures (FA, GGBS and RHA). A chemically active mineral admixture decreases workability and setting time of concrete but increases the heat of hydration and reactivity. On the other hand, a micro filler mineral admixture increases workability and setting time of concrete but decreases the heat of hydration and reactivity. Small particle size mineral admixtures are favourable to produce highly dense and impermeable concrete but they decreases workability and need more water which may be fulfilled by adding super plasticizer. All mineral admixtures reduce bleeding in concrete. The reactivity of mineral admixtures is of the order:

$MK > SF > FA > GGBS$.

Guang Jiang et al (2015): Investigated the pozzolanic reactivity of Metakaolin and the effects of Metakaolin on mechanical properties, pore structure and hydration heat of mortars by replacement of cement with Metakaolin at 0%, 6%, 10%, and 14% by weight at a constant 0.17 w/c ratio. The experimental results show that the pozzolanic reactivity of Metakaolin is higher than that of silica fume, especially at 28 d. For mortars without steel fibers, the flexural strength decreases with the inclusion of Metakaolin, whereas 10% MK blended mortars show the highest compressive strength compared to the others. For reinforced mortars with 2% steel fibers by volume, both flexural and compressive strength are remarkably enhanced. Heat of hydration tests results show that 6% Metakaolin accelerates the cement hydration, with an advanced accelerating period starting time, and maximize the heat flow which indicates maximum temperature rise. Although 14% Metakaolin blended mortar minimizes the total heat evolved, the optimal Metakaolin content is 10% with the consideration of mechanical properties.

O.R. Kavitha et al (2015): Investigated the effect of metakaolin on the fresh, micro- and macro level properties of self compacting concrete. Cement content considered = 500 kg/m^3, while the MK was used to replace cement by 5, 10 and 15%. Fresh concrete property test performed = slump flow, V-funnel flow times, L-box. Macro level properties performed = compressive strength and split tensile strength. The micro structural changes were studied using a Scanning Electron Microscope (SEM), X-ray Diffraction Analysis (XRD) and Energy Dispersive X-ray Analysis (EDX). The fresh concrete results show that SCC mixes prepared at different Water: Cement (W: C) ratios satisfied the rheological properties. MK inclusion enhanced the macro level properties. The micro level studies indicated that micro crack width was reduced due to inclusion of MK in the control mix. The optimum replacement of MK was 10%.

2.2 WASTE FOUNDRY SAND

Rafat Siddique et al. (2008) investigated on used foundry sand as a replacement of fine aggregate in self compacted concrete. He used foundry sand as a replacement of fine aggregate. The test samples were tested for Split tensile, compressive and Flexural strength from casting of Cylinders, Cubes and Beams respectively. Their study showed that in comparison to conventional concrete, adding admixtures increased the split tensile, compressive strength and durability up to 19 percent, 14.5 percent and 12 percent respectively.

Rafat Siddique et al. (2013) carried out experimental investigation to check durability properties and hardening properties of self compacting concrete in which some amount of natural sand is replaced with used foundry sand. Replacement of 0%, 10%, 15% and 20% by weight was made. Their study showed that in comparison to conventional concrete, adding admixtures increased the durability properties and hardening properties. There was increase in resistance to sulphate attacks and rapid chloride permeability.

Kiran K. Shetty et al. (2014) investigated on used foundry sand as a replacement of natural sand abd red mud as a replacement of cementitious material. Red mud replacement was 1%, 2%, 3% and 4% by weight. For each red mud replacement level, 10% of natural sand was replaced by used foundry sand (UFS). Compressive strength increased by 15.4% for 2% red mud and 10% used foundry sand. Flexural strength increased by 9.9% for 1% red mud and 10% used foundry sand

Preeti Pandey et al. (2015) presents experimental investigation to describes the utilization of foundry sand, a waste material as the replacement of natural sand. In this investigation, natural sand has been replaced by used foundry sand accordingly in the range of (10% to 60% at the interval of 10%). Mixes were casted and tested for workability and compressive strength. Compressive strength of concrete at 10% replacement level was more than that of referral concrete. Workability of concrete made using foundry sand observed to be increased slightly with replacement level.

Prof. S.R. Vaniya et al. (2016) prepared samples of foundry sand replacing fine aggregate by different percentage for making concrete of M- 25 and M-30. Replacement percentage will be 0%, 10%, 20%, 30%, 40% and 50% by weight with natural fine aggregates for casting cubes, beams and cylinders. Best result showed when spent foundry sand is replaced upto 15% by natural sand. Resistance to chloride permeability of concrete is also improved.

P Yazhini et al. (2016) did his experimental work on the foundry sand and tile powder which was usually used as a construction material. The main objective of his experimental work was to reduce the wastage and dumping problems of the industrial waste. The results in his study showed improvement in hardening properties by replacing 30% foundry sand with sand and 30% tile powder with cement.

S. Ramakrishna Raju et al. (2016) prepared samples of foundry sand replacing fine aggregate, with the different proportions of 0, 25, 50, 75 and 100 percent by weight. These proportions were tested for Compressive strength after different curing time period of 3, 7 and28 days. The result in his study showed that with the increase in percent of foundry sand the strength is achieved but workability is decreased. Best result showed when 25 % foundry sand is replaced with sand.

CHAPTER 3

SCOPE AND RATIONALE OF THE STUDY

3.1 Scope of the study

Self Compacting Concrete (S.C.C.) is being used for experimental work. The cement is to be replaced (by weight) by Metakaolin (MK) with the proportions of 10% and sand is to be replaced (by weight) by Foundry sand with the proportions of 10%, 15%, 20% and 25% to get optimized results. The various mechanical properties like compressive strength, split tensile strength and flexural strength for various mixes are being examined for the different proportions of the Metakaolin (MK) and Foundry sand. Normal specimen i.e. without replacement of cement is also casted. The results are compared for the normal/standard (without replacement) specimen and the experimented specimen (with replacement) are compared and the best result is used further for practical applications.

3.2 Objective of the study

The objective is to study the effect on Compressive Strength, Split Tensile Strength and Flexural Strength of Self Compacting Concrete with fixed percentage replacement of cement with Metakaolin (MK) and different percentage replacement of sand by Foundry sand.

CHAPTER 4

MATERIALS AND RESEARCH METHODOLOGY

4.1 GENERAL

The main objective is to check the properties of materials used for testing. The main materials which are used are Ordinary Portland cement, aggregates, sand, Admixture, Foundry sand and Metakaolin. The materials are used to check the mechanical properties of concrete mix.

4.2 Materials

4.2.1 Portland Cement

Portland cement is used as binder material in concrete mix. It's main aim is to make cohesive property at boom to make good strength .To use cement it's all physical properties and chemical properties are examined to make design mix. Specific gravity, fineness of cement, Consistency of cement is checked. It hydration process is examined after curing for its strength. Generally three grades of cement are available OPC 33, 43, 53 grades. In the present study OPC 43 grade cement for design mix. The various properties of cement are examined i.e. compressive strength after 3 days, 7 days and 28 days, specific gravity, consistency and initial and final setting of cement as shown in Table 4.1.

Table 4.1 Properties of OPC 43 grade Cement

S. no.	**Characteristics**	**Value obtained Experimentally**	**Values Specified by IS8112:1989**
1.	Fineness (retained on 90-µm sieve)	4.5g	<10% of 300g
2.	Normal Consistency	29.5%	-
3.	Initial Setting	47 minutes	Should not be less

	Time		than 30 minutes
4.	Final Setting Time	278 minutes	Should not be greater than 600 minutes
5.	Soundness	3mm	<10 mm
6.	Specific Gravity	3.15	-

4.2.2 Aggregate

Aggregates establish the bulk of a concrete mixture and give order firmness to concrete. To growth the density of resulting mix, the aggregates are frequently used in two or more dimensions. The best significant purpose of the fine aggregate is to support in creating workability and uniformity in mixture. The fine aggregates contribute the cement paste to grip the coarse aggregate particles in the medium. This action promotes plasticity in the mixture and prevents the possible segregation of cement and coarse aggregate, chiefly when it is essential to transport the concrete some distance from the mixing plant to placement. The aggregates deliver around 75% of the bulk of the concrete and hence its effect is tremendously significant. They should therefore meet certain provisions if the concrete is to be workable, strong, durable and reasonable. The aggregates must be proper shape, clean, hard, strong and well graded. The maximum sized aggregate used is of 10 mm in size. The aggregates remained washing away to eliminate dirt, dust and then dry to surface dry form.

Table 4.2 Physical properties of Fine aggregates.

Characteristics	**Description**
Color of aggregates	Grey
Shape of aggregates	Angular

Maximum Size of aggregates	10 mm
Specific Gravity of coarse aggregates 10 mm	2.71

Table 4.3 Sieve Analysis of Coarse aggregate (10mm)

S. no.	IS-Sieve(mm)	Wt. retained (gram)	%age retained	% passing	Cumulative retained
1	100	0	0	100	0
2	80	0	0	100	0
3	40	0	0	100	0
4	20	0	0	100	0
5	10	2012	67.07	32.93	0
6	4.75	958	31.93	1	67.07
7	Pan	30	1	0	99
	Total=3000 gm.			Sum=166.07	
				FM =(166.07 +500)/100=6.66	

Note: Weight of coarse aggregate taken: 3000 gm.

4.2.3 Fine Aggregates

The aggregates greatest of which permit through 4.75 mm IS sieve are called as fine aggregates. IS: 383-1970 has separated the fine aggregate into four grading zones. The classifying zones become progressively finer from grading zone I to IV.

In this trial program, fine aggregates (stone dust) were collected from Jalandhar and compatible to grading zone II. It was coarse sand bright brown in colour. The sand was sieved through 4.75 mm sieve to remove particles greater than 4.75 mm size. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and outcomes are shown in Table 7.

Specific gravity of fine aggregates is 2.49.

4.2.4 Water

The potable water is usually measured reasonable for mingling and curing of concrete. Accordingly potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

4.2.5 Admixtures

Auramix 200 combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability retention. Auramix 200 is a strong super plasticiser allowing production of consistent concrete properties around the required dosage.

4.3 Test Methods

Self- Compacting Concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters. Table 4 gives the recommended values for different tests given by different researchers for mix to be characterized as SCC mix.

Table 4.4 Recommended Limits for Different Properties

S.NO.	Property	Range
1.	Slump Flow Diameter	500-700 mm
2.	T_{50cm}	2-5 sec
3.	L-Box H2/H1	≥ 0.8

4.3.1 Slump Flow Test

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time T_{50cm} is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm.

4.3.2 L-Box Test

The passing ability is determined using the L- box test. The vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1). This is an indication of passing ability. The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be ≥ 0.8.

4.3.3 Compressive Strength of Concrete

Cube specimens of size 150 mm x 150 mm x 150 mm were taken out form the curing tank at the ages of 7, 14 and 28 days and tested immediately on removal from the water (while they were still in the wet condition). Surface water was wiped off, the specimens were tested. The position of cube when tested was at right angle to that as cast. The load (P) is applied gradually i.e. 5.1KN/sec. without shock till the failure of the specimen occurs and thus the compressive strength was found. The magnitude of compressive stress (C) acting uniformly on cube of applied loading is given by formula:

C=P/A

Where P = Applied load

A = Area of cube

Fig 4.1 Compressive Strength test of Cube

4.3.4 Split Tensile Strength of Concrete

The split tensile strength of concrete is determined by casting cylinders of size 100 mm x200 mm. The cylinders were tested by placing them uniformly. Specimens were taken out from curing tank at age of 7, 14 and 28 days of moist curing and tested after surface water dipped down from specimens. This test was performed on compression Testing Machine. The load (P) is applied gradually i.e. 2.1KN/sec. The magnitude of tensile stress (T) acting uniformly to the line of action of applied loading is given by formula

T= 0.637P/DL

Where,

T = Split Tensile Strength in MPa

P = Applied load,

D = Diameter of Concrete cylinder sample in mm.

L =Length of Concrete cylinder sample in mm.

Fig 4.2 Split Tensile Strength test of cylinder

4.3.5 Flexural Strength of Concrete

The flexural strength of concrete is determined by casting beam of size 100 mm x100 mm x 500mm. The beams were tested by placing them uniformly. Specimens were taken out from curing tank at age of 7, 14 and 28 days of moist curing and tested after surface water dipped down from specimens. This test was performed on compression Testing Machine on beam attachment. The load (P) is applied gradually i.e. 0.1KN/sec. Beams are tested for two point loading. At 1/3rd from support from both ends.

Formula used for flexural strength 'fb'

fb = PL/bd2

(When a > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen)

or

fb = 3Pa/bd2 (when a < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.)

Where,

a = the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen

b = width of specimen

d = failure point depth

L = supported length

P = max. Load

Fig 4.3 Flexural Strength test of beam

4.3.6 Design Mix

Researchers have mentioned that the most popular mix design method for SCC has been introduced by Okamura.to proceed towards achieving SCC,

TR1 - First cement was taken as 480kg/m3, Sand was taken as 977kg/m3 and 10mm aggregates was taken as 570kg/m3 at water cement ratio 0.4 and admixtures 1% and but the slump flow and L-box were not obtained.

TR2 - Therefore, cement was increased to 500kg/m3 and water cement ratio to 0.43 and others kept constant but the slump flow and L-box were not obtained.

TR3 - Therefore, cement was again increased to 530kg/m3 and water cement ratio to 0.43 and others kept constant. Now the slump flow and L-box were obtained. Mix proportions for various trial mixes are given in Table 4.5

Table 4.5 Mix proportions for various trial mixes

Sr. No.	Mix	Cement (Kg/m^3)	F.A (Kg/m^3)	C.A (Kg/m^3)	S.P. (%)	W/c ratio	Slump Flow (mm)	L-box Blocking ratio(H2/H1)
1.	TR 1	480	977	570	1%	0.4	420	-
2.	TR 2	500	977	570	1%	0.43	490	-
3.	TR 3	530	977	570	1%	0.43	660	0.1
F.A: Fine Aggregate, C.A: Coarse Aggregate, S.P: Super plasticizer								

After obtained the trial mix, different mix proportions were made by replacement of cement with metakaolin by 10% (constant) and sand is replaced with foundry sand at 10%, 15%, 20% and

25% with a water-cement 0.43 and admixture 1% kept constant. Mix proportions for various mixes are given in Table 4.6

Table 4.6 Mix proportions for various mixes

Mix	MK (%)	FS (%)	Cement (Kg)	F.A. (Kg)	C.A. (10 mm) (Kg)	MK (Kg)	FS (Kg)	S.P. (ml)	Water (litre)
M0	0	0	19.50	35.92	20.48	0	0	195	8.385
M1	10	10	17.55	32.33	20.48	1.95	3.59	195	8.385
M2	10	15	17.55	30.54	20.48	1.95	5.38	195	8.385
M3	10	20	17.55	28.74	20.48	1.95	7.18	195	8.385
M4	10	25	17.55	26.95	20.48	1.95	8.97	195	8.385

MK: Metakaolin, FS: Foundry Sand, F.A.: Fine Aggregate, C.A. (10): Coarse aggregate of 10 mm, S.P.: Super plasticizer.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 General

This chapter deals with the presentation of results obtained from different tests conducted on the material utilized for developing self-compacting concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of Metakaolin and foundry sand on flexural strength, compressive strength and split tensile strength of self compacting concrete so as to assess its feasibility for use in building structures. The experimental program consists of casting of specimens, curing and testing of controlled mix concrete specimen and concrete specimen incorporated with metakaolin and foundry sand at different ages.

5.2 Compressive Strength

In most structural applications, concrete is employed primarily to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical crack occurs due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains. The 150 mm x 150mm x 150 mm cubes are used for testing the compressive strength after 7 days, 14 days and 28 days. Specimens has been made for control mix and compared with fixed percentage replacement of cement with Metakaolin i.e. for 10% and different percentage replacement of sand with foundry sand i.e. for 10%, 15%, 20% and 25%. Three samples have been casted for each percentage i.e. three for 7days, three for 14 days and three for 28 days testing. Specimens tested after 7 days, 14 days and 28 days age of curing and average results are shown in Table 5.1

Table 5.1 Compressive Strength of cubes

Compressive Strength (MPa)										
Curing age (days)	0% MK 0% FS		10% MK 10% FS		10% MK 15% FS		10% MK 20% FS		10% MK 25% FS	
7	23.1	24.86	36.18	36.40	33.67	35.98	33.34	34.43	30.21	32.60
	26.49		35.76		35.99		35.84		35.1	
	24.99		37.28		38.28		34.12		32.51	
14	26.56	29.72	39.75	39.78	37.12	38.92	32.39	35.23	36.77	34.71
	30.8		41.69		39.45		38.42		34.45	
	31.79		37.9		40.19		34.88		32.9	
28	35.39	37.37	45.91	45.60	42.99	43.18	39.37	41.8	40.12	38.73
	38.23		44.29		44.67		42.34		37.76	
	38.5		46.78		41.89		43.7		38.32	

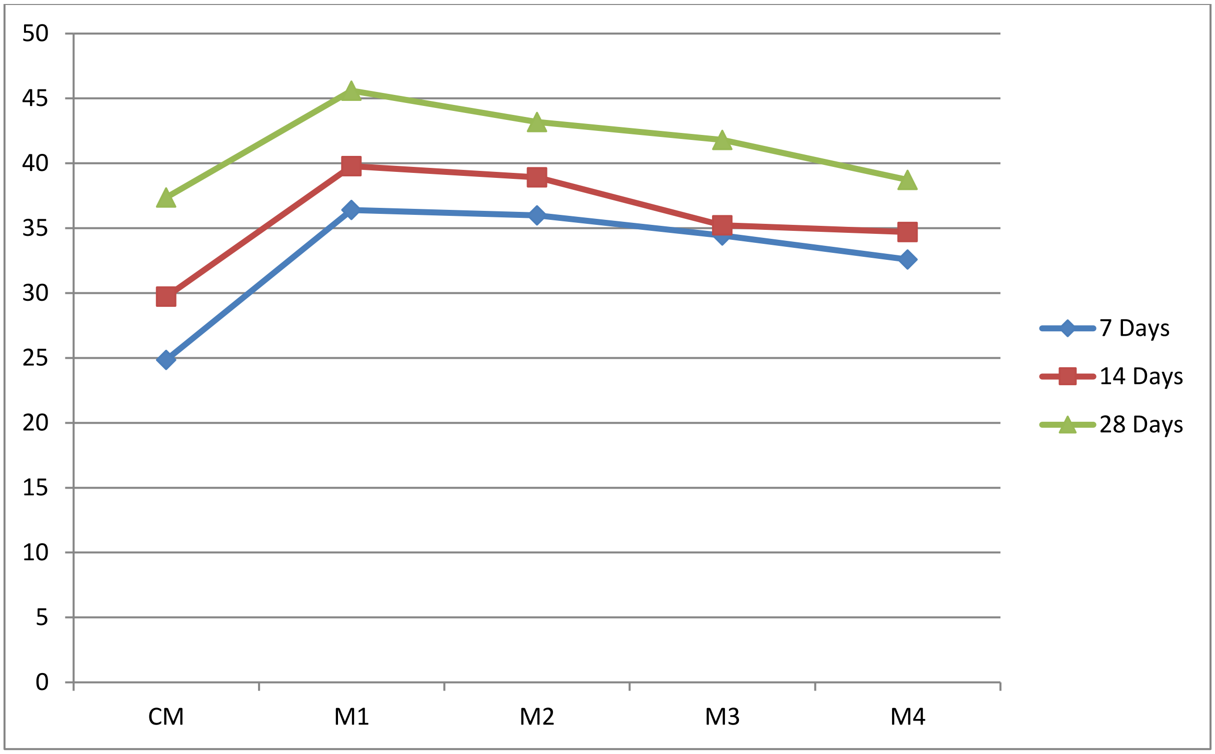

Fig 5.1 Variation in the Compressive Strength with the increase in curing age

Where CM = Control mix

M1 = 10% metakaolin and 10% foundry sand

M2 = 10% metakaolin and 15% foundry sand

M3 = 10% metakaolin and 20% foundry sand

M4 = 10% metakaolin and 25% foundry sand

The compressive strength examined for different percentages of FS with replacement of sand (by weight) i.e. for 0%, 10%, 15%, 20% and 25%. Compressive strength for 10% replacement i.e. M1 increased by 22% as compared with control mix after 28 days testing. The graph of compressive strength depicts that with the increase in percentage of foundry sand by replacing it with sand, there is an increase in the compressive strength of the concrete cubes at the water-cement ratio of 0.43. The maximum compressive strength of the cubes is found at by replacing

10 % of cement with Metakaolin and 10% replacement of sand with foundry sand. But on further replacement of sand, the compressive strength of cubes decreases.

5.3 Split Tensile strength

The 200mm x 100 mm cylinders were used for testing the split tensile strength after 7 days, 14 days and 28 days. Specimens have been made for control mix and compared with different percentages replacement of sand with foundry sand i.e. for 0%, 10%, 15%, 20 % and 25 % and metakaolin is replaced by cement and is taken fixed i.e. 10%. Three samples have been casted for each percentage i.e. three for 7 days, three for 14 days and three for 28 days. The split tensile strength of all the mixes was determined at the age of 7 days, 14 days and 28 days for various replacement levels of FS in concrete mix.

Table 5.2 Split Tensile strength of cylinders

<table>
<tr><th colspan="11">Split Tensile Strength (MPa)</th></tr>
<tr><th>Curing age (days)</th><th colspan="2">0% MK
0% FS</th><th colspan="2">10% MK
10% FS</th><th colspan="2">10% MK
15% FS</th><th colspan="2">10% MK
20% FS</th><th colspan="2">10% MK
25% FS</th></tr>
<tr><td rowspan="3">7</td><td>2.98</td><td rowspan="3">2.99</td><td>3.75</td><td rowspan="3">3.74</td><td>3.99</td><td rowspan="3">3.30</td><td>3.55</td><td rowspan="3">3.19</td><td>2.81</td><td rowspan="3">3.09</td></tr>
<tr><td>3</td><td>3.89</td><td>3.21</td><td>2.89</td><td>3.12</td></tr>
<tr><td>2.99</td><td>3.59</td><td>2.71</td><td>3.15</td><td>3.33</td></tr>
<tr><td rowspan="3">14</td><td>3.37</td><td rowspan="3">3.39</td><td>3.97</td><td rowspan="3">4.06</td><td>4.12</td><td rowspan="3">3.85</td><td>3.45</td><td rowspan="3">3.35</td><td>2.92</td><td rowspan="3">3.14</td></tr>
<tr><td>3.39</td><td>4.45</td><td>3.8</td><td>3.32</td><td>3.12</td></tr>
<tr><td>3.41</td><td>3.78</td><td>3.62</td><td>3.27</td><td>3.39</td></tr>
</table>

28	3.81	3.86	4.24	4.26	4.2	4.09	3.36	3.59	2.9	3.24
	3.91		4.59		3.88		3.4		3.26	
	3.86		3.95		4.18		4.01		3.57	

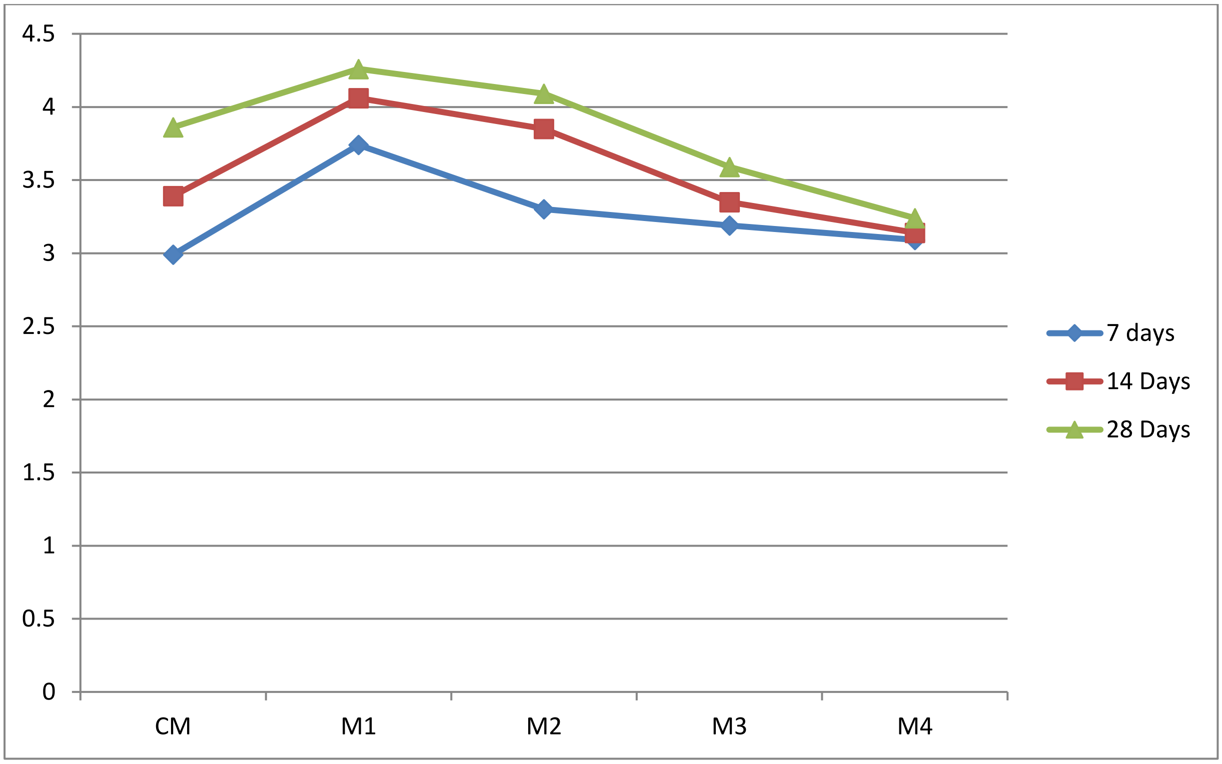

Fig 5.2 Variation in the Split Tensile Strength with the increase in curing age

Where CM = Control mix

M1 = 10% metakaolin and 10% foundry sand

M2 = 10% metakaolin and 15% foundry sand

M3 = 10% metakaolin and 20% foundry sand

M4 = 10% metakaolin and 25% foundry sand

The split tensile strength results of individual concrete mix are shown graphically. Split tensile strength also increases after 10% replacement of sand by foundry sand. Split tensile Strength of

M1 is increased by 10.36% as compared with control mix after 28 days testing. The maximum values of split tensile strength of concrete with replacement of sand with foundry sand were at 10% which is higher than control mix. After 20 % addition of foundry sand, the specimen decrease in strength. For strength purpose 10% is acceptable for split tensile strength but for cost reduction 20% is also acceptable due to less decrease in strength after 28 days.

5.4 Flexural Strength

The most common concrete structure subjected to flexure is a highway or airway pavement and strength of concrete for pavements is commonly evaluated by means of bending tests. When concrete is subjected to bending, then tensile and compressive stresses and in many cases direct shear stresses are developed. The 100 mm x 100mm x 550 mm beams were used for testing the compressive strength after 7 days, 14 days and 28 days. Specimens has been made for control mix and compared with different percentages replacement of sand with FS i.e. for 0%, 10%, 15%, 20 % and 25 %and fixed percentage replacement of cement with MK i.e. 10%. Three samples have been casted for each percentage i.e. three for 7 days, three for 14 days and three for 28 days testing.

Table 5.3 Flexural strength of beams

Flexural strength (MPa)										
Curing age (days)	0% MK 0% FS		10% MK 10% FS		10% MK 15% FS		10% MK 20% FS		10% MK 25% FS	
7	6.38	6.39	7.61	7.51	7.2	7	6.48	6.49	6.43	5.92
	6.42		7.89		6.93		5.9		5.77	

	6.37		7.32		6.89		7.09		5.58	
14	7.44	7.47	8.22	8.62	7.99	7.5	6.75	6.98	6.97	6.61
	7.49		9.14		7.13		7.2		6.53	
	7.48		8.5		7.38		7		6.34	
28	8.76	8.78	9.45	9.44	9	8.96	8.23	8.45	7.15	7.49
	8.78		9.1		9.09		8.51		7.9	
	8.8		9.77		8.8		8.6		7.43	

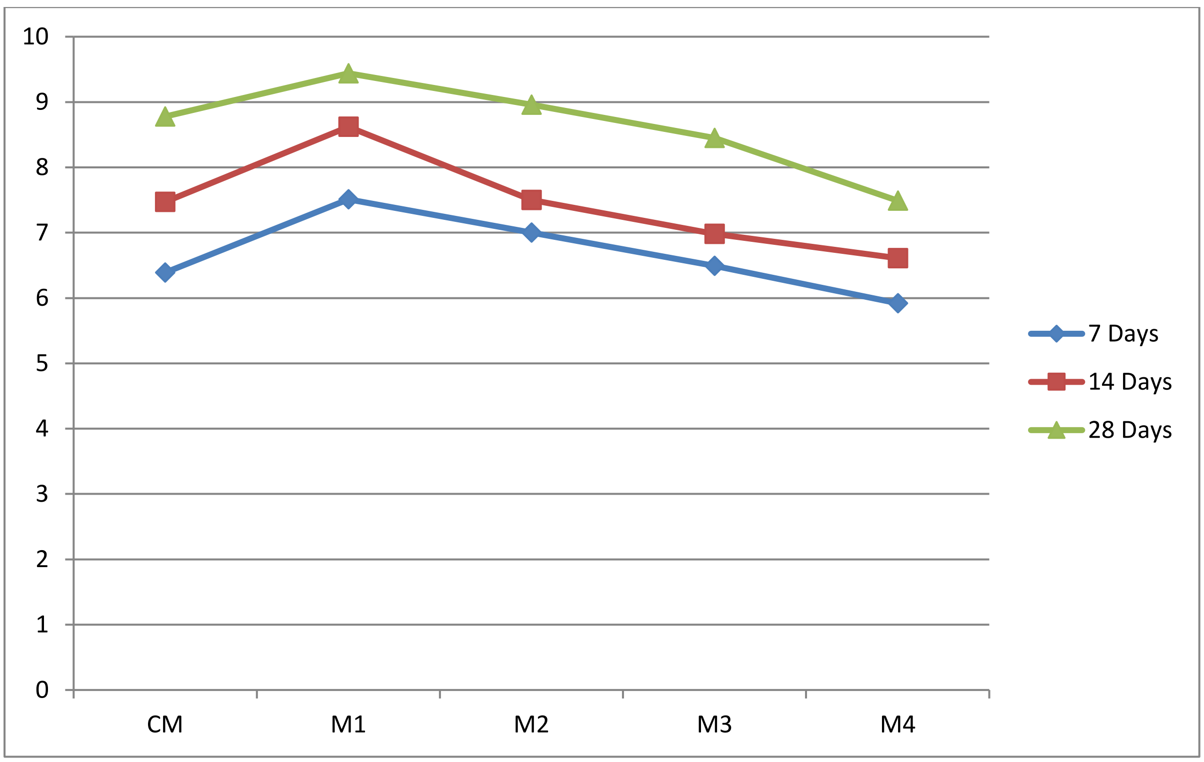

Fig 5.3 Variation in the Flexural Strength with the increase in curing age

The Flexural strength results of individual concrete mix are shown graphically. Flexural strength also increases after 10% replacement of sand by foundry sand. Flexural Strength of M1 is increased by 7.5% as compared with control mix after 28 days testing. The maximum values of Flexural strength of concrete with replacement of sand with foundry sand were at 10% which is higher than control mix. After 20 % addition of foundry sand, the specimen decrease in strength. For strength purpose 10% is acceptable for Flexural strength.

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CHAPTER 6

CONCLUSION

6.1 Analyzing compressive strength

The graph of compressive strength depicts that with the increase in percentage of Foundry sand by replacing it with sand while taking metakaolin constant i.e. 10% with cement, there is a increase in the compressive strength of the concrete cubes at the water- cement ratio of 0.43. The maximum compressive strength of the cubes is found at by replacing 10 % of sand with foundry sand. But on further replacement of sand with foundry sand, the compressive strength of cubes decreases.

6.2 Analyzing split tensile strength

The graph of split tensile strength test shows that the split tensile strength of the concrete varies in the same fashion as the compressive strength. The maximum split tensile strength is observed by replacing 10 % of sand with foundry sand at the water cement ratio of 0.43 but for cost reduction 20% is also acceptable due to less decrease in strength after 28 days.

6.3 Analyzing flexural strength

The graph of flexural strength of concrete portrays that by replacing sand with foundry sand by different percentage and keeping metakaolin constant i.e. 10% by cement, the flexural strength of the concrete varies in the same manner as that of compressive strength and tensile strength. The maximum flexural strength of concrete is observed when foundry sand replaces sand by 10%. But on further replacement of sand with foundry sand, the flexural strength decreases.

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