EXPERIMENTAL ANALYSIS ON THE EFFECTS OF MAGNETIC WATER WITH PARTIAL REPLACEMENT OF CONSTITUENT MATERIALS IN SELF COMPACTING CONCRETE

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Abstract - *Self-compacting concrete (SCC) is the concrete that flows through dense reinforcements and compacts under its own weight. A well graded SCC is highly flowable in nature which aids to its filling ability, passing ability and resistance to segregation. In recent years a variety of materials have been used to partially replace the constituent materials of SCC and have been tested so as to make the mix more economical - both in monetary and environmental aspects. In this experimental analysis we tested SCC of M30 grade made with magnetic water of 0.8 Tesla, in which sand is partially replaced with Copper Slag and Glass Powder at 0, 10, 20, 30, 40 & 50% and 0, 5, 10, 15, 20 & 25% respectively, and cement with flyash at 0, 10, 20, 30, 40 & 50%. The concrete mix was then tested in its fresh and hardened states at 7, 14 and 28 days and compared to conventional SCC. We found that magnetic water improved the workability of fresh concrete as well as compressive and split tensile strength by 11.2% and 11.44% respectively and reduced the dosage of super plasticizer by 11.5% for the same water-cement ratio. Better results were found in replacing sand with copper slag in terms of strength and economy when compared to glass powder. Flyash replacing cement at 30% gave best results while Copper slag and Glass powder gave best results at 20% replacement of sand.*

Key Words**: Concrete, Self-compacting concrete (SCC), Magnetic water, Copper slag, Glass powder, Flyash, Super plasticizer**

1 INTRODUCTION

1.1 Self-Compacting Concrete

It was around 1980's that the construction field in Japan was blooming, creating demands for new and improved methods to aid to the faster and economical production of concrete structures. It was also around this time that there were significant reductions in the number of construction laborers available. Taller, wider, heavier more complicated structures along with the durability issues in concrete and due to unskilled labor, Japan needed to improvise.

It was in 1986 that Professor Okamura [1] proposed the formulation of SCC. It was in 1988 that Professor Ozawa from University of Tokyo developed SCC successfully. He not only improved the properties of concrete but also revolutionized the placing methodologies eliminating the biggest drawback of that time-unskilled labor. All the major construction players at that time adopted SCC and developed their own testing procedures. That is when a new era in concrete production began.

Comparison between SCC and Traditional concrete:

Table: 1

SCC	Normal concrete
Concrete has high flowability to undergo compaction under its own weight.	Concrete is compacted using a vibrator.
High workability.	Low workable mix.
Workability is gained through admixtures and viscosity modifying reagents.	Workability gained through increased moisture content.
Addition of super plasticizer increases the bond between cement matrix and aggregate.	The aggregate cement matrix is weak.
Water content is low.	Water content is high.
Fines content- Cement and fine aggregate is high.	Fines content is less compared to SCC.
Lower water content decreases bleeding.	Bleeding is high.
Increased fines content gives a homogenous mix with less segregation issues.	High segregation issues.

Low viscosity due to high fines.	High viscosity.
SCC structures give good esthetic appearance.	Appearance is not satisfactory.
Good choice for thick reinforcement works.	Normal concrete is not suitable for thick reinforcement works since external compaction is difficult.

Schematic composition of SCC:

Figure: 1

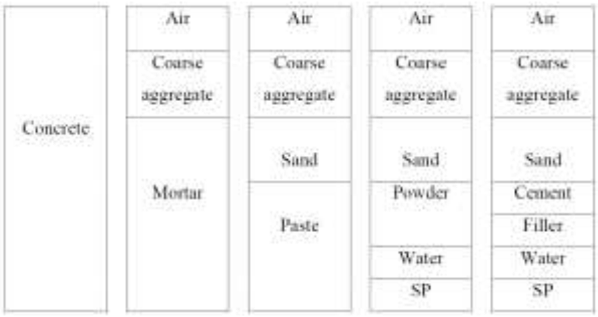

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Figure: 2

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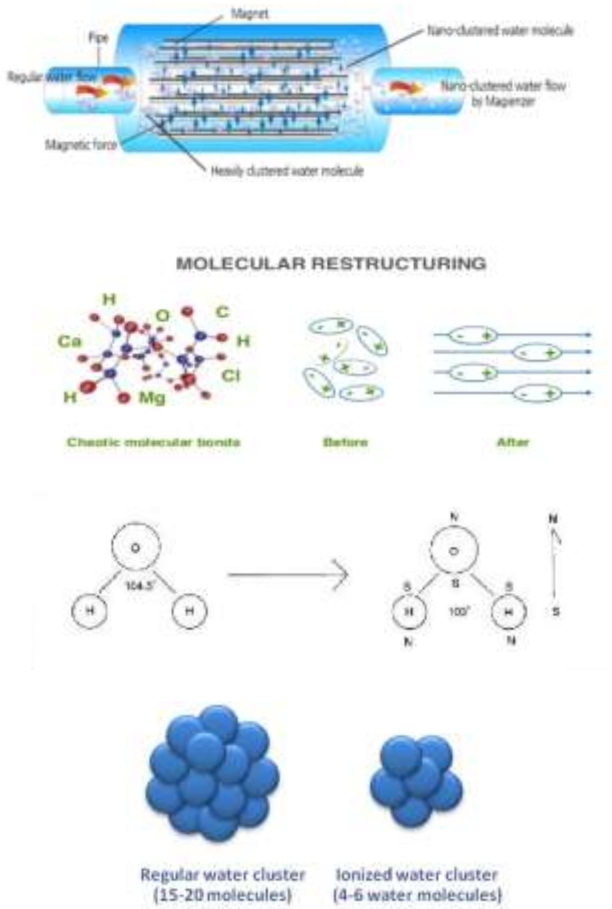
1.2 Magnetic Water

Magnetic water is the water which is passed through a magnetic field [2] [3]. The term Magnetic water does not mean that the water has gained magnetic properties [3]. It merely means that the water which is passed through a magnetic field has some of its properties altered [3] [3]. Magnetic water is used in a variety of fields- medical, domestic, Automobile, Industrial, etc [3]. Once the water is passed through the magnetic field, the scattered molecules of water tend to align in one direction [2], which changes the hydrogen-oxygen bond [3] angle from 104.5^0 to 103^0 between the molecules which leads to smaller clusters of 4-6 rather than 15-20, thereby improving the waters viscosity making it thin [2] [3]. The usage of Magnetic Water in a concrete mix would improve the durability, compressive strength, accelerate hydration, improve hardened properties and freeze and thaw resistance [2] [3]. For the same water-cement ratio higher workability can be achieved [2]. Also corrosion is said to be reduced due to the use of Magnetic Water [3].

Effect of Magnetic Field on water molecules:

Figure: 3



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Comparison between Normal Water and Magnetic Water:

Table: 2

Property	Normal Water (NW)	Magnetic Water (MW)	Standard
pH	6.98	8.17	6.5-8.5
Temporary Hardness	527 mg/l	318 mg/l	<600 mg/l
Permanent Hardness	440 mg/l	355 mg/l	<600 mg/l
Total Solids	686 mg/l	486 mg/l	<1000 mg/l
Suspended Solids	643 mg/l	413 mg/l	<2000 mg/l
Chloride Content	415 mg/l	325 mg/l	<1000 mg/l
Sulphate Content	780 mg/l	670 mg/l	<800 mg/l

2. Concrete Ingredients and Pre-experimental Investigations:

2.1 Cement:

Ordinary Portland Cement (OPC) of 53-Grade has been used throughout this experiment which was in order with IS: 12269-2013.

Figure: 4

Properties:

Table: 3

S.No	Characteristics	Values Obtained	Standard Values (IS:8112-1989)
1	Normal Consistency	31%	30-35%
2	Initial Setting Time	27 Min	< 30 Minutes
3	Final Setting Time	340 Min	< 600 Minutes
4	Fineness	3.67%	<10
5	Specific Gravity	3.12	3.10-3.15

2.2 Fine Aggregate (Sand):

Godavari river sand which passed through the 4.75 IS Sieve has been used throughout the testing procedure. The sand also confirmed to IS 383-2006 as Zone II. Fineness Modulus and Specific Gravity are determined as per IS: 2386-1963.

Figure: 5

Properties:

Table: 4

S.No	Characteristics	Value
1	Specific Gravity	2.68
2	Bulking of Sand	8% moisture content

3	Fineness Modulus	2.74
4	Zone (based on percentage passing 0.60 mm sieve)	Zone II

2.3 Coarse Aggregate:

Locally available crushed stone which retained on IS 4.75 Sieve confirming to IS: 383-1970 has been used. 20mm and 12.5 mm aggregate have been used for experimenting.

Figure: 6

Properties:

Table: 5

S.No	Characteristics	Value
1	Type	Crushed
2	Specific Gravity	2.86
3	Fineness Modulus	8.4

2.4 Super plasticizer:

DYN-M70 (which is a product of San Nopco Korea Ltd.) confirming to IS: 9103-1999, is the super plasticizer that has been used for conducting the experiments. It is an advanced polycarboxylate polymer based super plasticizer which when compared to traditional super plasticizers has more powerful dispersing effect and shows high water reduction and fluidity retention without causing retardation. It is extremely useful for producing SCC and High-performance concrete.

Figure: 7

Physical properties:

Table: 6

Appearance	Clear light yellow
Odour	Characteristic
Total solids content %	50% (W/W) approx.
pH (undulated)	5.9
Specific Gravity	1.112 (25^{0}C)
Viscosity (cps)	330 5^{0}C)

2.5 Magnetic Water:

The water used throughout the experiment for preparation of concrete and for curing purposes is Tadepalligudem Municipal supply water which is found to be in accordance with IS 456:2000 and IS 3025.

Figure: 8

Preparation:

Figure: 9

The water used in making of SCC is passed through Premag N406 which has a power of 8000 Gauss. The water is made to pass through the Premag for about 60 minutes so as to induce the magnetic flux and also to maximize the exposure time of the water to the magnetic capabilities of the instrument using a submersible water pump.

Replacement Materials:

2.6 Copper Slag:

It is the bi product of smelting and refining of copper. During smelting, impurities become slag which floats on molten metal, which when quenched in water produces granules, which appear glossy black in color, and are disposed off as waste. It is has properties similar to that of natural river sand which is why it is widely used in the production of concrete as fine aggregate.

Figure: 10

Chemical Composition:

Table: 7

Component	Weight %
Silica (SiO_2)	33.85
Alumina (Al_2O_3)	2.79
Ferric oxide (Fe_2O_3)	53.45
Calcium oxide (CaO)	6.06
Magnesium oxide (MgO)	1.61
Sulfate oxide (SO_3)	1.89
Disodium oxide (Na_2O)	0.28
Titanium oxide (TiO_2)	0
Manganese oxide (Mn_2O_3)	0.06
CI	0.01
Loss on ignition	0

Physical properties:

Table: 8

S.No	Characteristics	Value
1	Specific Gravity	4.10
2	Fineness Modulus	4.132

2.7 Glass Powder:

Glass is a transparent material which is found naturally when rocks high in silicates melt due to very high temperatures and cool rapidly before they can form a crystalline structure. Alternatively, they can be produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling during which solidification occurs without crystallization. Because of its properties glass powder is used as a replacement material for sand in production of concrete to reduce the adverse environmental effects it imparts and to make use of a waste material.

Figure: 11

Chemical Composition:

Table: 9

Composition	Percentage
Silica	50 -80 %
Alumina	1 – 10%
Iron oxide	< 1%
Calcium oxide	5 -15%
Magnesium oxide	< 1.5%
Sodium oxide	1 – 15%
Potassium oxide	< 1%
Loss of ignition	-

Physical properties:

Table: 10

S.No	Characteristics	Value
1	Specific Gravity	2.6
2	Fineness Modulus	4.132

2.8 Fly ash:

Thermal plants usually generate Flyash as residue when producing electricity through combustion of ground or powdered coal. Experiments show that this bi product can partially replace the cement in the production of concrete which improves both fresh and hardened states. Due to smooth and spherical shape of Flyash particles the workability of fresh concrete increases which in turn lowers the water cement ratio, which later leads to higher compressive strength. Flyash tends to delay the setting time of concrete but aids to the strength and durability of hardened concrete. The flyash used for experimentation is obtained from Rajamahendravaram paper mill. It is found to be of Class F classification and is in accordance with IS: 3812-2003.

Figure: 12

Chemical Composition:

Table: 11

S.No	Chemical Component	Class F flyash
1	Silica (SiO_2)	55
2	Alumina (Al_2O_3)	26
3	Ferric oxide (Fe_2O_3)	7
4	Calcium oxide (Cao)	9
5	Magnesium oxide (MgO)	2
6	Sulfate oxide (SO_3)	1

Physical properties:

Table: 12

S.No	Characteristics	Value
1	Specific Gravity	2.25
2	Fineness Modulus	3.31

3. Mix Design:

Since there are no hard guidelines for SCC in Indian Standard Codes the following mixes were prepared in accordance with EFNARC guidelines (2002).

Specifications:
Coarse aggregate < 50%
Water powder ratio 0.8 – 1
Total powder content 400-600 kg/m3
Sand > 40% of mortar
Sand < 50% of paste volume
Sand > 50% by weight of aggregate
Paste > 40% of volume of mix

Table: 13

Figure: 13

3.1 Normal SCC mix (SCC):

Based on the above guidelines the following mixes were prepared for Normal SCC mix:

Cement : F.A : C.A : W.C : Ad mixture

Table: 14

Mix	Ratio					Remarks
	C	FA	CA	W/C	Admixture	
M1	1	1.9	3.7	0.8	2%	Mix Failed
M2	1	2.81	1.61	0.8	2%	Mix Failed
M3	1	2.81	1.61	0.8	4%	Mix Failed
M4	1	2.12	1.22	0.8	2%	Mix Failed
M5	1	2.12	1.22	0.8	4%	Mix Failed
M6	1	1.66	1.66	0.8	2.6%	Mix Worked

M6 is considered to be the control SCC mix throughout the experiment, which is named "SCC".

3.2 Magnetic SCC mix (M SCC):

We found the Magnetic SCC mix on the basis of successful normal SCC mix.

Cement : F.A : C.A : W.C : Ad mixture

Table: 15

Mix	Ratio					Remarks
	C	FA	CA	W/C	Admixture	
M1	1	1.66	1.66	0.8	2%	Mix Failed
M2	1	1.66	1.66	0.8	2.1%	Mix Failed
M3	1	1.66	1.66	0.8	2.2%	Mix Failed
M4	1	1.66	1.66	0.8	2.3%	Mix Worked

Note: The dosage of Super plasticizer was reduced by 11.57% because of the useage of Magnetic Water.

M4 is considered to be the magnetic SCC mix throughout the experiment, which is named "M SCC".

Replacement quantities in various M SCC mixes:

Table: 16

Material	%	Replacing Material	Mix	Ratio				
				Cement	FA	CA	Admixture	Replacement quantity
Sand	10	Copper slag	CS 10	1	1.494	1.66	2.3	0.166
Sand	20	Copper slag	CS 20	1	1.328	1.66	2.3	0.332
Sand	30	Copper slag	CS 30	1	1.162	1.66	2.3	0.498
Sand	40	Copper slag	CS 40	1	0.996	1.66	2.3	0.664
Sand	50	Copper slag	CS 50	1	0.83	1.66	2.3	0.83
Sand	5	Glass Powder	GP 5	1	1.577	1.66	2.3	0.083
Sand	10	Glass Powder	GP 10	1	1.494	1.66	2.3	0.166
Sand	15	Glass Powder	GP 15	1	1.411	1.66	2.3	0.249
Sand	20	Glass Powder	GP 20	1	1.328	1.66	2.3	0.332
Sand	25	Glass Powder	GP 25	1	1.245	1.66	2.3	0.415
Cement	10	Flyash	FA 10	0.834	1.66	1.66	2.3	0.166
Cement	20	Flyash	FA 20	0.668	1.66	1.66	2.3	0.332
Cement	30	Flyash	FA 30	0.502	1.66	1.66	2.3	0.498
Cement	40	Flyash	FA 40	0.336	1.66	1.66	2.3	0.664
Cement	50	Flyash	FA 50	0.83	1.66	1.66	2.3	0.83

4. Tests and Results:

4.1 Fresh Concrete tests:

As per EFNARC guidelines the following are the preferred testing methods for various characteristics of SCC:

Table: 17

Characteristic	Preferred test
Flowability	Slump-flow test
Viscosity	T_{50cm} Slump flow test
Passing ability	L – Box test

Acceptance criteria for Self-compacting Concrete on the basis of EFNARC guidelines:

Table: 18

Mix	Slump Flow (mm)		T_{50cm} Slump flow (sec)		L – Box (mm)		U – Box (mm)	
	Max	Min	Max	Min	Max	Min	Max	Min
	800	650	5	2	1	0.8	30	0
SCC	673		4.98		0.82		25	
M SCC	740		3.99		0.91		14	
CS 10	733		4.13		0.92		16.5	
CS 20	726		4.28		0.92		16	
CS 30	718		4.32		0.95		17.5	
CS 40	705		4.55		0.93		16.5	
GP 5	726		4.18		0.9		13	
GP 10	709		4.23		0.89		12	
GP 15	694		4.26		0.92		14	
GP 20	618		4.29		0.86		15	
FA 10	737		4.12		0.93		15	
FA 20	729		4.19		0.92		17	
FA 30	715		4.26		0.88		16	
FA 40	706		4.53		0.86		19	

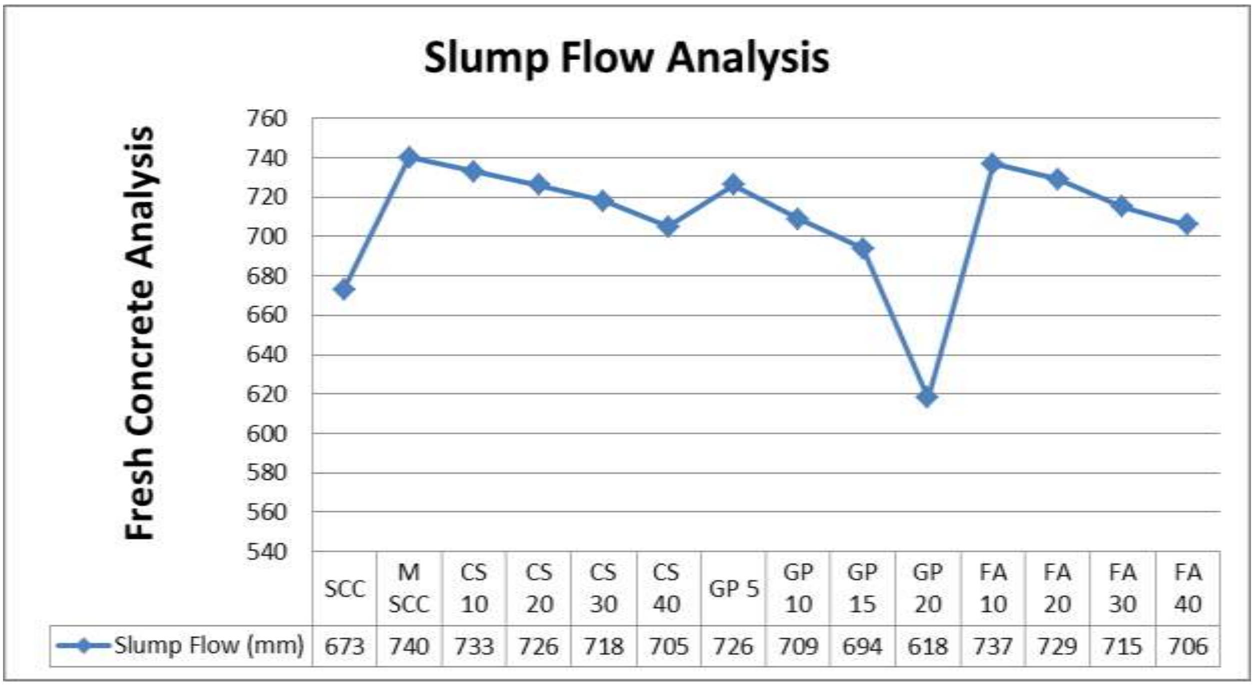
Note: CS 50% mix failed.

GP 25% mix failed.

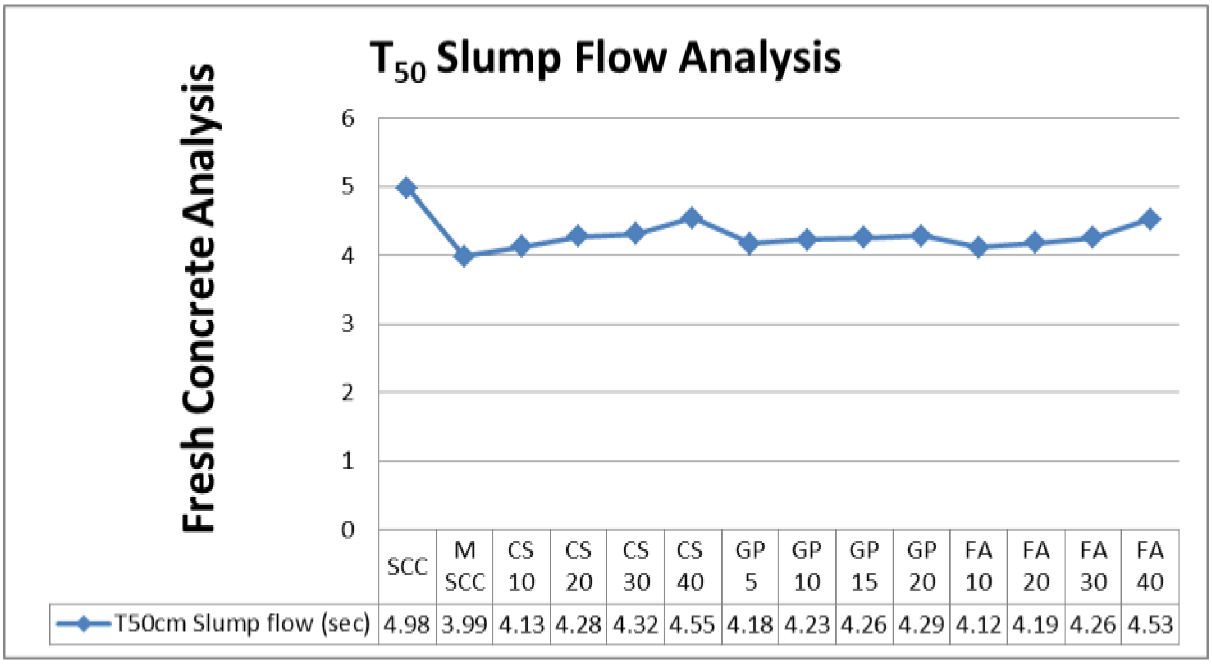
FA 50% mix failed.

Figure: 14 **Figure: 15** **Figure: 16**

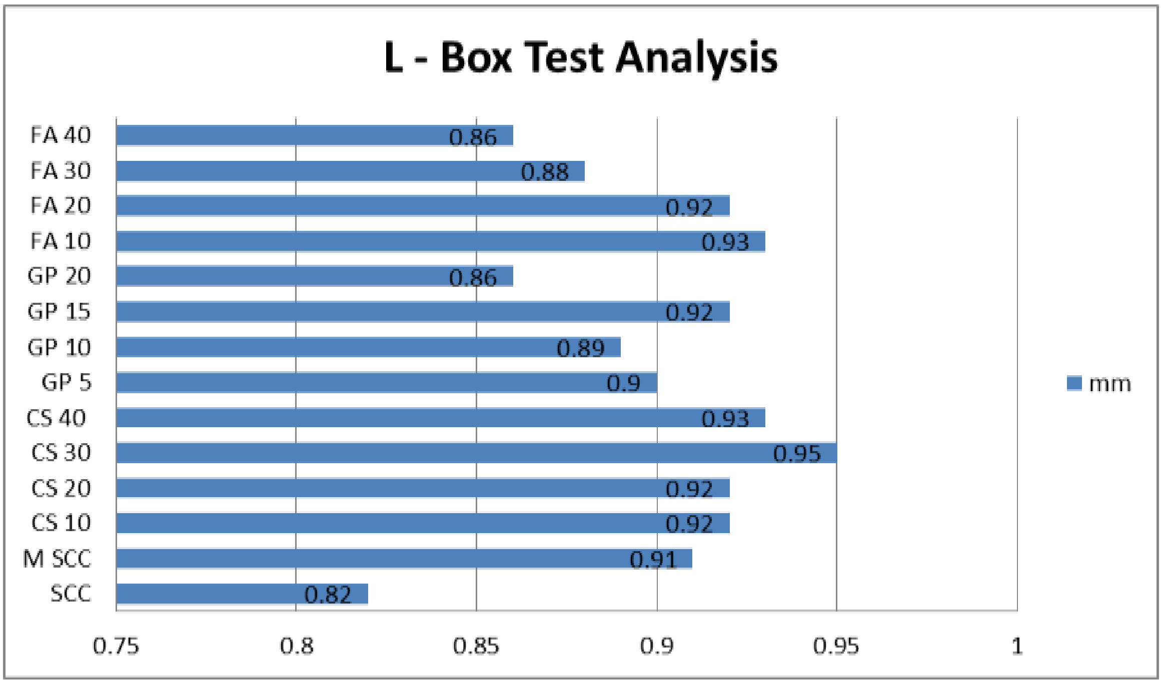
Graph: 1



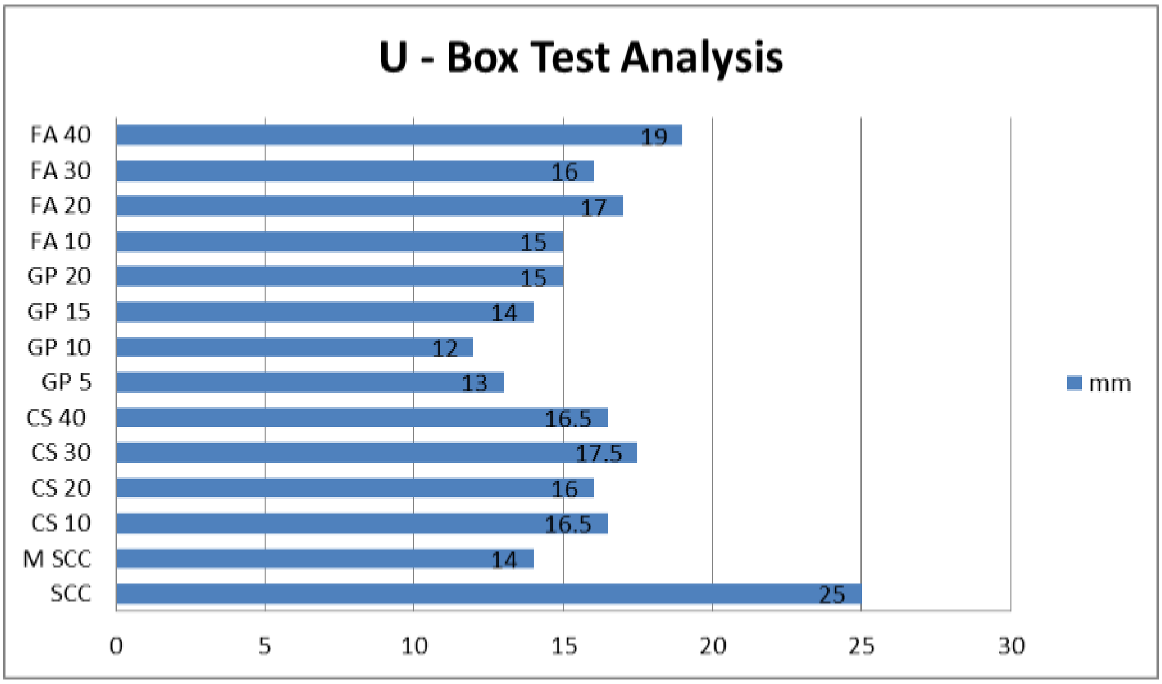
Graph: 2



Graph: 3



Graph: 4



4.2 Hardened Concrete Tests:

All the concrete samples were tested for Compressive and Split Tensile Strength on 7, 14 and 28 Days.

Note: The cubes and cylinders casted were demoulded after 48 hours of placing them in their respective moulds.

Figure: 17 **Figure: 18**

Note: CS 50% mix failed.

CS 40% mix failed in curing.

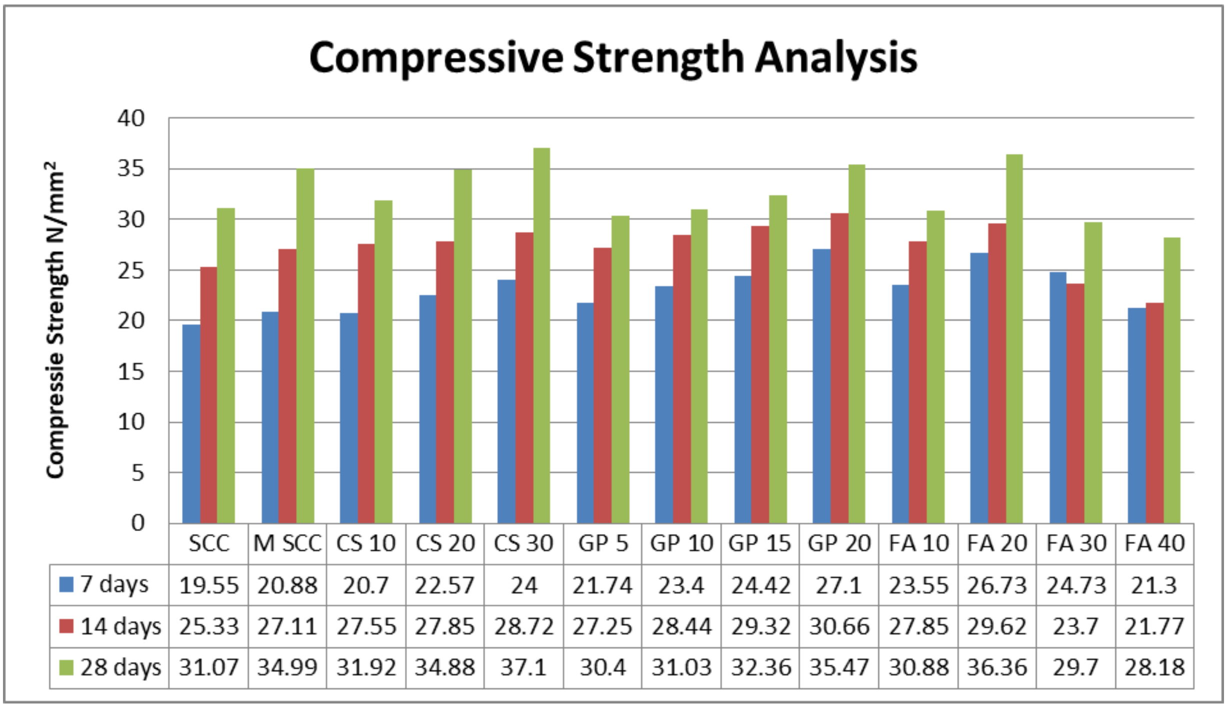
GP 25% mix failed.

FA 50% mix failed.

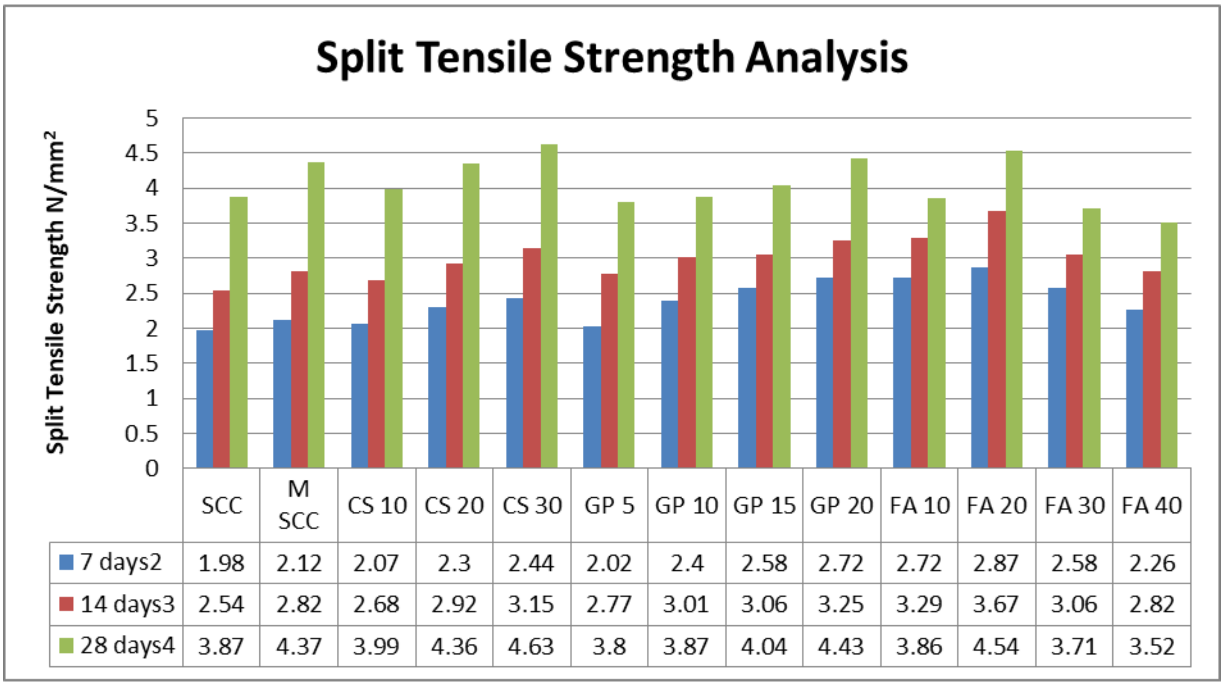
Figure: 19

Figure: 20

Graph: 5



Graph: 6



Hardened concrete test analysis summary:

Table: 19

Mix	Compressive Strength			Split Tensile Strength		
	7 days	14 days	28 days	7 days	14 days	28 days
SCC	19.55	25.33	31.07	1.98	2.54	3.87
M SCC	20.88	27.11	34.99	2.12	2.82	4.37
CS 10	20.7	27.55	31.92	2.07	2.68	3.99
CS 20	22.57	27.85	34.88	2.3	2.92	4.36
CS 30	24	28.72	37.1	2.44	3.15	4.63
GP 5	21.74	27.25	30.4	2.02	2.77	3.8
GP 10	23.4	28.44	31.03	2.4	3.01	3.87
GP 15	24.42	29.32	32.36	2.58	3.06	4.04
GP 20	27.1	30.66	35.47	2.72	3.25	4.43
FA 10	23.55	27.85	30.88	2.72	3.29	3.86
FA 20	26.73	29.62	36.36	2.87	3.67	4.54
FA 30	24.73	23.7	29.7	2.58	3.06	3.71
FA 40	21.3	21.77	28.18	2.26	2.82	3.52

5. Conclusion:

1. Due to the use of Magnetic water of 0.8 Tesla in preparation of self-compacting concrete (SCC) of M30 grade, the workability of concrete increased significantly for the same water-cement ratio when compared to control mix, because of which 9.05% increase in slump flow was obtained.
2. Using magnetic water in SCC of M30 grade increased compressive strength by 11.2% and split tensile strength by 11.44% when compared to conventional SCC.
3. It was found that 11.5% of super plasticizer dosage was reduced by the employment of magnetic water in SCC.
4. Partial replacement of sand at 10, 20, 30, 40 and 50 % with copper slag resulted in steady improvement of Compressive and Split tensile strength upto 30% but at 40 and 50% the SCC mix failed.
5. The compressive strength and split tensile strength effectively increased by 16.25% and 16.41% at 30% replacement for 28 days when compared to conventional SCC, therefore it is recommended.

6. When fine aggregate was partially replaced with Glass Powder at 5, 10, 15, 20 and 25 % the Compressive strength and Split tensile strength improved upto 20% replacement but at 25 % the SCC mix failed.
7. The compressive strength and split tensile strength effectively increased by 12.4% and 12.64% at 20% replacement for 28 days when compared to conventional SCC and it is the recommended replacement percentage.
8. From the results it is evident that better results were obtained in replacing sand with copper slag in terms of strength and economy when compared to glass powder.
9. When Cement was replaced with Flyash there was an increase in compressive and split tensile strength for 10% and 20% replacements but did not attain target strengths at 30% and 40%. 20% replacement gave best results of 14.54% and 14.75% increase in compressive and split tensile strengths when compared to conventional SCC at 28 days and therefore it is recommended.

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