"STRENGTH AND DURABILITY OF CONCRETE INCORPORATING BLAST FURNACE SLAG AGGREGATE AS REPLACEMENT OF COARSE AGGREGATES"

A thesis report submitted
In the partial fulfillment of the requirement for
the award of the degree
of
MASTERS OF ENGINEERING
IN
STRUCTURAL ENGINEERING

Submitted by:
KAVI RAJ
(ROLL NO. 851222002)

UNDER THE SUPERVISION OF

DR. SHWETA GOYAL

Associate Professor

Civil Engineering

Thapar University, Patiala

DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY, PATIALA 147004, INDIA
JULY 2017

DECLARATION

The author hereby declares that this thesis entitled "***Strength and Durability of Concrete incorporating Blast Furnace Slag Aggregate as Replacement of Coarse Aggregates***", *in whole or part has not been used to obtain any degree in this, or any other, institute, except where references have been given in text, it is entirely the authors own work. The author conforms that the library may lend or copy this upon request for academic purposes.*

(KAVI RAJ)

ROLL.NO. 851222002

CERTIFICATE

This is to certify that the work presented in thesis entitled ***"Strength and Durability of Concrete incorporating Blast Furnace Slag Aggregate as Replacement of Coarse Aggregates"*** *submitted by* ***Mr. Kavi raj*** *in partial fulfillment of the requirements for the award of degree of* ***Master of Engineering*** *in Structural Engineering at* ***Thapar University, Patiala,*** *is a bonafide work carried out by the student under our supervision and guidance. The matter embodied in this report has not been submitted anywhere for award of any other degree.*

Dr. Shweta Goyal

Associate Professor

Civil Engineering

Thapar University, Patiala

ACKNOWLEDGEMENT

Time has provided me the cherished opportunity to express my heartfelt gratitude to my guide Dr. Shweta Goyal, Associate Professor, CED, Thapar University, Patiala, who permitted me to carry out research work under their able guidance. I shall ever remain indebted to them for their meticulous guidance, constructive criticism, clear thinking, keen interest, constant encouragement and forbearance right from the beginning of this research to its completion.

I wish to express my sincere thanks to Dr. Naveen Kwatra, Professor and Head, CED, Thapar University, Patiala, who has been a constant source of inspiration for me throughout this thesis work.

The cheerful support of my friends and colleagues is sincerely appreciated. Special words of appreciation go to Sh. Ram Sumiran, Sh. Varinder Kumar and other laboratory colleague who helped me in my experimental work.

I am also thankful to all the staff members of Civil Engineering Department for their full cooperation and help.

Above all, I thank my parents, whose love and affectionate blessing have been a constant source of inspiration in making this manuscript a reality. I render my gratitude to the almighty who bestowed self confidence, ability and strength in me to complete this work.

(KAVI RAJ)

(851222002)

ABSTRACT

Lack of availability of land for waste disposal and high cost of construction material such as aggregates, we require in-expensive and low cost construction material that can be used in concrete industry.

The report presents an investigation on strength and durability properties by replacing coarse aggregate with Blast Furnace Slag aggregates (BFS). Coarse aggregates were replaced with BFS aggregate in various proportions such as 0% (control mix), 20%, 40%, 60%, 80% and 100%. Various mechanical properties of concrete were evaluated for 7 and 28 days. In case of durability properties, sorptivity, rapid chloride permeability was evaluated at the age of 28 days. Additionally, microstructural investigation was carried out on samples using scanning electron microscope to get a deeper insight in the mineralogical constitution and behavior of such mixes when used for construction purposes.

Mechanical and the durability properties of concrete get enhanced when 60 percent of coarse aggregates were replaced by BFS aggregates. Due to increased C-S-H gel a compact structure was noticed and the same was verified by SEM technique also. Thus, it leads to a growing interest in the development of new concrete type, due to its high performance, durability, better serviceability and overall economy in the long run.

CONTENTS

CONTENT			PAGE NO.
CERTIFICATE			[i]
ACKNOWLEDGEMENT			[ii]
ABSTRACT			[iii]
CONTENTS			[iv]
LIST OF TABLES			[vii]
LIST OF FIGURES			[ix]
CHAPTER – 1	**INTRODUCTION**		1-3
	1.1	General	1
	1.2	Blast furnace slag	1
	1.3	Utilization of blast furnace slag in construction industry	2
	1.4	Significance and objective of the research	2
		1.4.1 Significance in research area	2
		1.4.2 Objective of the research work	2
	1.5	Organization of the thesis	3
	1.6	Concluding remarks	3
CHAPTER – 2	**LITERATURE REVIEW**		4-18
	2.1	General	4
	2.2	Review of published literature	4
	2.3	Concluding remarks	18
CHAPTER -- 3	**MATERIAL AND DESIGN METHODOLOGY**		19-30
	3.1	General	19
	3.2	Characteristics of Material used	20

		3.2.1 Portland Cement	20
		3.2.2 Aggregate	20
		3.2.3 Water	24
	3.3	Mix proportions	24
	3.4	Casting and curing of samples	24
	3.5	Test methods	25
		3.5.1 Compressive strength of concrete	25
		3.5.2 Split tensile strength of concrete	26
		3.5.3 Scanning electron microscopy (SEM)	26
		3.5.4 Energy dispersive spectrometry (EDS)	26
		3.5.5 Rapid chloride penetration test (RCPT)	27
		3.5.6 Sorptivity	28
		3.5.7 X - Ray Diffraction	30
	3.6	Concluding remarks	30
CHAPTER -- 4		**RESULTS AND DISCUSSION**	31-52
	4.1	General	31
	4.2	Compressive strength test results	31
		4.2.1 Compressive strength	31
		4.2.2 Compressive Strength Results for 7 days	31
		4.2.3 Compressive Strength Results for 28 days	32
		4.2.4 Comparison of compressive strength at 7 days and 28 days	33
	4.3	Split tensile strength test results	34

		4.3.1 Split tensile strength	34
		4.3.2 Split tensile strength Results for 7 days	34
		4.3.3 Split tensile strength Results for 28 days	35
		4.3.4 Comparison of split tensile strength at 7 days and 28 days	36
	4.4	Scanning electron microscope (SEM) analysis	37
	4.5	Energy Dispersive Spectrometry (EDS)	41
	4.6	Rapid chloride penetration test (RCPT) RESULTS	45
		4.6.1 Rapid chloride penetration test (RCPT)	45
	4.7	Sorptivity test results	46
	4.8	X – Ray Diffracton (XRD)	50
	4.9	Concluding remarks	52
CHAPTER -- 5		**CONCLUSION**	53-54
	5.1	General	53
	5.2	Future scope of work	54
	5.3	Concluding remarks	54
REFERENCES			55-56

LIST OF TABLES

TABLE NO.	Description	PAGE NO.
2.1	Chemical and physical properties of PC, FA and GGBS	5
2.2	Mix proportion of concrete (kg/m^3)	5
2.3	Compressive strength test results	6
2.4	Compressive strength of concrete when exposed to H_2SO_4 solution	6
2.5	Chemical compositions of OPC, SF, and CS	7
2.6	Mix proportions of control mix.	7
2.7	Mix Proportions	8
2.8	Compressive strengths of the CSAF concrete specimens	8
2.9	Cement mortars specimen mix proportion	10
2.10	Concrete specimen mix proportion	10
2.11	Chemical composition and physical properties of OPC, copper slag (CS) and sand	11
2.12	Average compressive strength of cement mortars at different curing ages	12
2.13	Compressive strength of concrete mix at different curing ages	12
2.14	Mixture proportions used in the study	14
2.15	Compressive strength of concrete before heating	15
2.16	Physical and chemical properties of copper slag	16
2.17	Compressive strength tests conducted on cube specimens at 28 days	16
2.18	Split tensile strength test on cylinder at 28 days	17
3.1	Physical Properties of Cement	20
3.2	Properties of Coarse Aggregates	20
3.3	Sieve Analysis of Coarse Aggregate (20 mm)	21
3.4	Sieve Analysis of Coarse Aggregate (10 mm)	21
3.5	Sieve Analysis of Fine Aggregate	22
3.6	Physical Properties of Slag Aggregate	22
3.7	Sieve Analysis of Coarse Slag Aggregate	23

3.8	Chemical Properties of Blast Furnace Slag	23
3.9	Concrete Mix Proportion for M25 Grade	24
3.10	RCPT rating chart (ASTM 1202-97)	28
4.1	Compressive Strength of cubes at 7 Days	32
4.2	Compressive Strength of cubes at 28 Days	33
4.3	Split tensile strength of cylinders at 7 days	34
4.4	Split tensile strength of cylinders at 28 days	35
4.5	Chloride permeability of mortar mixes at 28 days	45
4.6	Sorptivity coefficients for all mixes	47

LIST OF FIGURES

FIG. NO.	Description	PAGE NO.
1.1	Blast furnace slag	1
2.1	Compressive strength development at different ages	9
2.2	Concrete strength ratio at 28 days	13
2.3	Effect of temperature on relative strength of concrete exposed to elevated temperature	15
2.4	Compressive strength of concrete and different mix ratio of copper concrete cubes	17
2.5	Relationship b/w split tensile strength and replacement of copper slag	17
3.1	Compressive strength test setup	25
3.2	RCPT test procedure setup	27
3.3	Sorptivity test procedure setup	29
4.1	Compressive strength vs. percentage of slag at 7 days	32
4.2	Compressive strength vs. percentage of slag at 28 days	33
4.3	Comparison of compressive strength at 7 days and 28 days	34
4.4	Split tensile strength vs. percentage of slag at 7 days	35
4.5	Split tensile strength vs. percentage of slag at 28 days	36
4.6	Comparison of split tensile strength at 7 days and 28 days	36
4.7	SEM results for M1 concrete mix	37
4.8	SEM results for M2 concrete mix	38
4.9	SEM results for M3 concrete mix	38
4.10	SEM results for M4 concrete mix	39

4.11	SEM results for M5 concrete mix	40
4.12	SEM results for M6 concrete mix	40
4.13	EDS for M1 specimen after 28 days curing	41
4.14	EDS for M2 specimen after 28 days curing	42
4.15	EDS for M3 specimen after 28 days curing	43
4.16	EDS for M4 specimen after 28 days curing	43
4.17	EDS for M5 specimen after 28 days curing	44
4.18	EDS for M6 specimen after 28 days curing	45
4.19	Plot of absorption v/s time at 28 days	47
4.20	Plot of absorption v/s time at 28 days for mix M1	48
4.21	Plot of absorption v/s time at 28 days for mix M2	48
4.22	Plot of absorption v/s time at 28 days for mix M3	49
4.23	Plot of absorption v/s time at 28 days for mix M4	49
4.24	Plot of absorption v/s time at 28 days for mix M5	50
4.25	Plot of absorption v/s time at 28 days for mix M6	50
4.26	XRD Spetrum of various concrete mix at 7 days	51
4.27	XRD Spetrum of various concrete mix at 28 days	52

CHAPTER - 1

INTRODUCTION

1.1 GENERAL

The most extensively utilized substance in construction industry is concrete. As construction materials cost escalates, demand has risen significantly for stronger and durable materials. It has been noticed that around 70-80 % of aggregates forms the total volume of concrete thus it requires to develop the concrete that can be economical along with the enhanced properties.

The increasing demand for construction led researchers to search for an economical and ecological substitute of natural aggregate of concrete. There is a new trend to use the recycled waste or by product available from industries like iron and steel plant, rice mill, thermal power, aluminum and copper industries etc. Many of the researchers have studied that strength and durability performance of concrete by incorporating these products. So a comprehensive literature review is presented on various slags produced from industries as a byproduct.

1.2 BLAST FURNACE SLAG (BFS)

The secondary product that is formed during the manufacture of steel in the industries is called slag. It is processed to use as construction material called as granulated BFS. It comprises of various oxides of metals along with the SiO_2. Oxides of calcium, magnesium, silicon, iron, aluminum, manganese and phosphorus are the major components of slag. Fig. 1.1 shows a typical picture of Blast furnace slag that is obtained from steel alloy making industries.

Fig. 1.1: Blast furnace slag (*www.nationalslag.org*)

Slag is further divided into two categories and these are expanded slag and granulated slag. Expanded slag is found by cooling the molten slag in controlled way in the presence of compressed air and steam while the granulated slag is formed by quenching of molten slag with the help of highly pressurized water jets due to which the slag get converted into granular pieces that can be used by grinding it into the powdered form as a construction material.

1.3 UTILIZATION OF BLAST FURNACE SLAG IN CONSTRUCTION INDUSTRY

GGBFS is used in concrete along with the OPC to form a blend that exhibits the cementitious properties along with the reduced permeability, higher strength and better durability. The slag can be use to make the slag wool that is highly insulated and can be used to create the fibres. It can also be used to form high performance concrete that exhibits high strength, low permeability, high resisitant to sulphate & chloride attacks along with the enhanced durability properties. Furthermore, the next chapter deals with the important use of various by the various worldwide scholars to investigate whether its use in manufacturing concrete is beneficial or not to the construction industries in terms of durability and strength characteristics.

1.4 SIGNIFICANCE AND OBJECTIVE OF THE RESEARCH

1.4.1 Significance in Research Area

With the increase in quantity of Industrial waste materials and the byproducts, the solid waste management has become the major issue of environmental concern for the world. Due to unavailability and high cost of land for disposal of Industrial waste, recycling/reuse of industrial secondary products has become the solution for disposal. Waste by products of industries can be used to manufacture concrete mixes that exhibits higher strength and durability properties. Thus, recycling of by products is considered to be the best alternative solution for the problem of industrial solid waste disposal. One of such waste industrial by product is Blast Furnace Slag that can be used in concrete industry by replacing the coarse aggregates but up to some extent only.

1.4.2 Objective of the Research Work

The objective of the experiment is to examine the concrete mechanical property along with its durability properties when blast furnace slag aggregates is added to concrete by replacing the coarse aggregates in the various percentages as 0% (control mix), 20%, 40%, 60%, 80% and 100%. The objectives of this study are:

- Physical and chemical characterization of blast furnace slag aggregates.
- Investigation of BFS aggregate used concrete for its strength and durability properties also.

1.5 ORGANIZATION OF THE THESIS

This thesis report is composed of various sections as follows:

CHAPTER 1: Review the utilization of Industrial waste by product i.e. BFS in concrete industry, their advantages and disadvantages, their utilization and various its properties.

CHAPTER 2: Reviews the existing literature on the utilization of BFS as construction material. The mechanical properties along with the durability properties of concrete using BFS are summarized in this section.

CHAPTER 3: Reviews the detailed methodology used in the investigation along with the various materials properties used in the study.

CHAPTER 4: Presents the results and their discussion such as mechanical properties, durability properties like Chloride ion permeability, Sorptivity and the microstructure of resultant mixes to identify the presence of various compounds is also presented here in this section.

CHAPTER 5: provides the conclusion of various research work done in the concrete laboratory. The proposal for further investigations is also explored in this chapter.

At last the References used in the thesis report are placed.

1.6 CONCLUDING REMARKS

The chapter deals with the properties, utilization and the generation of blast furnace slag. Advantages and disadvantages of using BFS are also discussed. The importance of using BFS as a substitute of coarse aggregate on the mechanical properties along with its durability properties of concrete was explored.

CHAPTER -- 2

LITERATURE REVIEW

2.1 GENERAL

This present chapter illustrate a review of literature highlighting the study by various researchers with regards to the utilization of waste by-product from industries i.e. steel slag, copper slag or blast furnace slag etc. to get the durable, eco-friendly and economical concrete.

Nowadays the most important issues of construction industry are resource efficiency and sustainability. Thus, effective use of available resources along with secondary by-products is promoted in concrete industry. The various slag i.e. steel slag, copper slag or blast furnace slag etc. are considered as the waste material of the industries manufacturing steel and this ideology of using partial or full replacement of aggregates with BFS leads to a new boom in concrete and construction industry.

2.2 REVIEW OF PUBLISHED LITERATURE

Researchers have used various slag separately and studied various properties of resultant mixes. The following section describes the various properties studied by using slag aggregates.

Li et al. (2002) experimentally studied the effect of combining fly ash (FA) and ground granulated blast-furnace slag (GGBFS) on high strength concrete properties. They studied the compressive strength characteristics and resistance against the attack of H_2SO_4. A mix was casted using ordinary Portland cememnt only and was named as PCC. In HFAC, OPC is replaced by 40 % FA while in GGFAC, OPC is replaced by a blend of 25 % FA along with 15 % GGBS. Constant w/c ratio was adopted to be 0.28. Table 2.1 shows the chemical as well as the physical properties of PC, FA and GGBS. Table 2.2 exhibits the mix proportion of concrete. Table 2.3 exhibits the compressive strength and gain in strength of concrete at different time period. An increase in strength of about 18.7% was noticed in PCC. The increase in strength of GGFAC was about 23.3% and it was found that this strength was higher than PCC. From the results it was concluded that GGFAC can achieve adequate early compressive strength as compared to PCC. Table 2.4 shows the compressive strength results of concretes immersed in H_2SO_4. Increase in submersion time leads to increase in strength of GGFAC and HFAC. PCC strength get increases up to 8th week, but after that it begins to decrease with continued exposure to H_2SO_4 environment.

Table 2.1: Chemical and physical properties of PC, FA and GGBS (*Li et al. (2002)*)

	Cement	FA	GGBS
Specific gravity	3.05	2.43	2.79
Compressive strength, 28 day, MPa	56.7	-	-
Pozzolanic activity index, 28 day, %	-	85.4	106.3
Specific surface, Blaine, m^2/kg	392	565	599
SiO_2	20.6	63.5	34.4
Al_2O_3	4.0	11.1	9.0
Fe_2O_3	3.1	5.2	2.58
CaO	62.8	14.7	44.8
MgO	2.6	1.98	4.43
SO_3	3.1	0.35	2.26
Na_2O	-	0.48	0.62
K_2O	-	0.4	0.5
LOI	1.8	2.1	1.32

Table 2.2: Mix proportion of concrete (kg/m^3) (*Li et al. (2002)*)

Binder combination	Binder				Water	Aggregate		w/b	Superplasticizer dose
	PC	FA	GGBS	Total		Fine	Coarse		
PCC	500	-	-	500	140	659	1162	0.28	1.7
HFAC	300	200	-	500	140	644	1135	0.28	1.5
GGFAC	300	125	75	500	140	647	1140	0.28	2.0

Table 2.3: Compressive strength test results (*Li et al. (2002)*)

Binder combination	Compressive strength (MPa)							Strength gain from 28 days to 1 year
	1 day	3 day	7 day	28 day	56 day	112 day	360 day	
PCC	40.5	51.2	66.8	81.1	87.9	91.2	96.3	18.7
HFAC	21.7	32.6	43	65.2	86.7	97.5	107.1	64.3
GGFAC	35.1	49.3	65.4	80.6	89.8	93.7	99.4	23.3

Table 2.4: Compressive strength of concrete when exposed to H_2SO_4 solution (*Li et al. (2002)*)

	1 week	4 week	8 week	16 week	50 week
PCC	48.6	78.5	83.2	82.7	78.1
HFAC	36.4	67.2	85.8	88.9	96.8
GGFAC	49.8	80.1	87.2	90.3	97.2

Khanzadi et al. (2009) reported the effect of using copper slag as coarse aggregates in high-strength concrete. In this study, the compressive and split tensile strength of high-strength concretes was evaluated. Type I cement along with two types of coarse aggregate i.e. limestone (LS) and copper slag (CS) aggregates were used in the study. Table 2.5 and Table 2.6 illustrate the chemical and physical properties of aggregates used in the investigation.

Table 2.5: Chemical compositions of OPC, SF, and CS (*Khanzadi et al. (2009)*)

Compound (%)	OPC	SF	CS
SiO_2	21.46	91.70	27.80
CaO	63.95	1.68	4.60
Al_2O_3	5.55	1	7.80
Fe_2O_3	3.46	0.9	52.50
MgO	1.86	1.8	1.2
CuO	–	–	1.2
SO_3	1.42	0.87	0.98
K_2O	0.54	–	1.6
TiO_2	–	–	0.49
ZnO	–	–	0.84

Table 2.6: Physical properties of the coarse aggregates (*Khanzadi et al. (2009)*)

Properties	Copper slag aggregate	Limestone aggregate
Specific gravity, g/cm^3	3.59	2.65
Aggregate crushing value, %	10–21	23
Aggregate impact value, %	8.2–16	11
Water absorption, %	0.4	0.6
Particle size, mm	75–12.5	4.75–12.5

Table 2.7 illustrates the mix proportion of concrete. The behavior of various concrete mixes with varying w/c ratio of 0.40, 0.35, and 0.30 was studied.

Table 2.7: Mix Proportions (*Khanzadi et al. (2009)*)

Mixture	LSAF	LSAS	LSAT	CSAF	CSAS	CSAT
Cement, kg/m³	430	441	450	430	441	450
Silica fume, kg/m³	–	26.5	45	–	26.5	45
Water, kg/m³	172	164	149	172	164	149
Fine aggregate, kg/m³	687	653	615	687	653	615
Limestone	1030	1115	1168	-	-	-
Coarse aggregate, kg/m³	-	-	-	-	-	-
Copper slag	–	–	–	1395	1511	1582
w/c ratio	0.40	0.35	0.30	0.40	0.35	0.30
HRWRA, L/m³	1.6	2.9	3.7	1.5	2.2	3.5
Slump, mm	110	100	100	150	130	115
Unit weight, kg/m³	2310	2385	2412	2668	2779	2791
Air content,%	2.5	2.3	2.1	2.4	2.0	1.7

OPC was used in casting of LSAF and CSAF concrete mix while 6% and 10% of cement with Silica fume was used to cast other mixes i.e. LSAS & CSAS and LSAT & CSAT. Table 2.8 shows that the compressive strengths of the CSAF concrete mix is greater than that of LSAF concrete mixes by 10.6% and 12.9% for 28 and 91 days respectively.

Table 2.8: Compressive strengths of the CSAF concrete specimens (*Khanzadi et al. (2009)*)

Concrete	Compressive strength (MPa)				Split tensile strength (MPa)		
	7 days	28 days	56 days	91 days	7 days	28 days	91 days
LSAF	48.3	61.8	65.4	66.7	3.14	4.33	4.74
CSAF	53.6	67.7	72.4	75.3	3.48	4.81	5.35
LSAS	61.5	73.9	80.6	84.2	4.24	5.54	6.15
CSAS	63.7	81.4	91.2	94.8	4.52	6.11	7.11
LSAT	74.1	84.2	96.5	102.3	5.26	6.57	7.29
CSAT	79.6	96.4	113.8	119.5	6.05	7.74	8.49

Fig. 2.1 shows the development of compressive strength at various ages of curing the concrete. Strength of CSAS concrete mix was greater than that of LSAS concrete mix by 10.2% and 12.6% for 28 and 91 days of curing, respectively. Therefore the addition of copper slag in substitution of coarse aggregates leads to 12% increase in compressive strength.

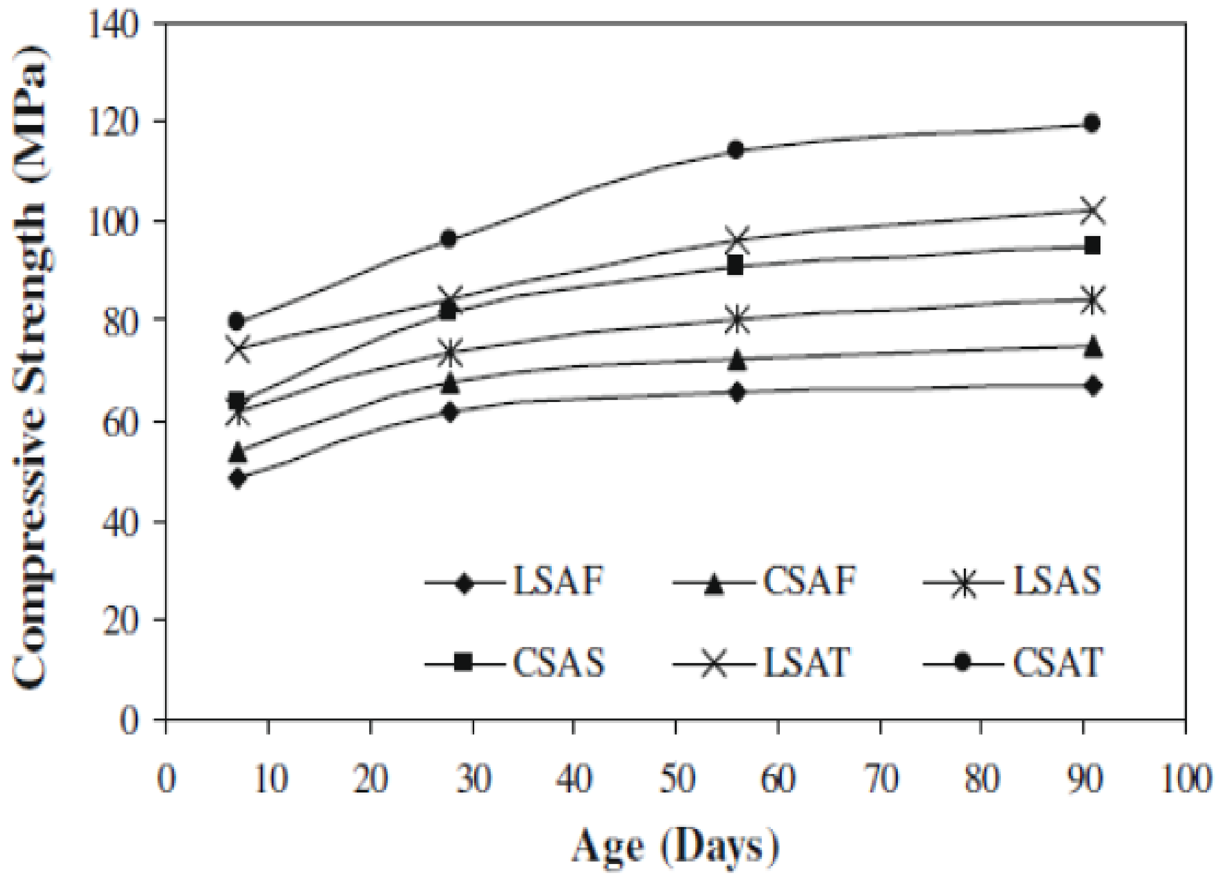


Fig. 2.1: Compressive strength development at different ages *(Khanzadi et al. (2009))*

Khalifa et al. (2011) studied the effect of copper slag as a fine aggregate on the properties of cement mortars and concrete. OPC, 20 mm & 10 mm sized aggregates and coarse sand was used in this study. In this study, they tested the various cement mortar & concrete samples with incorporation of various copper slag %age. Mix proportion of cement mortar is shown in Table 2.9. Cement mortars samples were casted by replacing the percentage copper slag by fine aggregate as 0%, 20%, 40%, 50%, 60%, 80%, and 100%. The w/c ratio was kept constant as 0.4. Table 2.10 illustrates the mix proportion of concrete mix casted in the investigation.

Table 2.9: Cement mortars specimen mix proportion (*Khalifa et al. (2011)*)

Material	Weight (g)
Cement	185
Sand	555
Water	74

Table 2.10: Concrete specimen mix proportion (*Khalifa et al. (2011)*)

Component	Weight (kg)
Water	207
Cement	416
Fine aggregate	721
10 mm aggregate	338
20 mm aggregate	790

Concrete mix were casted by replacing the percentage (weight) copper slag by fine aggregate as 0%, 20%, 40%, 50%, 60%, 80%, and 100%. The target compressive strength for 28 day was 45 N/mm^2. Table 2.11 shows the chemical composition and physical properties of OPC, copper slag (CS) and sand used in the study and the average compressive strength of cement mortars at different curing ages are illustrated in Table 2.12. From the results it was concluded that the substitution of copper slag will lead to increase in compressive strength up to 50% substitution only. After that the strength tends to decrease. Also the strength parameters were found to be satisfactory when we use copper slag in place of aggregates. Table 2.13 shows the compressive strength of concrete mix at different curing ages.

Table 2.11: Chemical composition and physical properties of OPC, copper slag (CS) and sand (*Khalifa et al. (2011)*)

Component	OPC %	CS %	Sand
SiO_2	20.85	33.05	-
Al_2O_3	4.78	2.79	-
Fe_2O_3	3.51	53.45	-
CaO	63.06	6.06	-
MgO	2.32	1.56	-
SO_3	2.48	1.89	-
K_2O	0.55	0.61	-
Na_2O	0.24	0.28	-
TiO_2	0.25	0	-
Mn_2O_3	0.05	0.06	-
CI	0.01	0.01	-
Loss on ignition	1.75	0	-
IR	0.21	0	-
CuO	0	0.46	-
$Al_2O_3 + SiO_2 + Fe_2O_3$	29.14	89.29	-
Specific gravity	3.15	3.4	2.77
Absorption (%)	-	0.17	1.36

Table 2.12 Average compressive strength of cement mortars at different curing ages (*Khalifa et al. (2011)*)

Mix No.	Mix type			Compressive strength (MPa)		
		3 days	7 days	28 days	56 days	90 days
1	Control (100% S)	22	23.3	24.6	25.3	2
2	20% CS + 80% S	22.1	29	31	34.7	36
3	40% CS + 60% S	22.1	30.6	39.8	40	42
4	50% CS + 50% S	20.3	30	42.7	44.5	50.3
5	60% CS + 40% S	23	28	39.2	42	47.8
6	80% CS + 20% S	23.1	26.8	35	40.1	44.8
7	100% CS + 0% S	20.8	23.3	26.1	32	35.5

Table 2.13: Compressive strength of concrete mix at different curing ages (*Khalifa et al. (2011)*)

Mix No.	Mix type	Density (kg/m3)	Slump (mm)	Strength (MPa)			
				$(F_{cu})^a$	$(F_{cu})^b$	$(F_t)^b$	$(F_{cr})^b$
1	Control (100% S)	2524	65.5	36.2	45.0	3	7.7
2	10% CS + 90% S	2515	80	38.8	46.0	3.5	7.2
3	20% CS + 80% S	2540	80	40.2	47.0	3.7	7.2
4	40% CS + 60% S	2550	110	38.7	47.1	3.8	6.5
5	50% CS + 50% S	2560	130	38.1	47.0	4.1	7.3
6	60% CS + 40% S	2601	165	37.7	46.0	3.6	6.3
7	80% CS + 20% S	2597	190	27.8	34.8	3.6	7.2
8	100% CS + 0% S	2653	200	29	35.1	3.4	5.9

Chunlin et al. (2011) introduced the steel slag and scrap tire particle in place of natural aggregate in usual concrete. Various concrete properties that contains electric arc furnace (EAF) slag were examined. Compressive strength, flexural strength and volume deformation of concrete were investigated. Small particles of scrap rubber for partial substitution of fine aggregate were used in some concrete specimen. Four types of concrete mixtures were prepared and were named as group A (OC), B (SC), C (OC-P) and D (SC-P). In group A, limestone in crushed was used as coarse aggregate whereas the quartz sand used as fine aggregate. Group B comprises of steel slag used as fine and coarse aggregates. In group C, limestone & quartz sand were used as aggregate. In group D, different size steel slag were used as fine and coarse aggregates and 10% volume of fine aggregate was replaced by crumb rubber powders. Fig. 2.2 shows the concrete strength ratio at 28 days. The compressive strength of 45.4 MPa, 59.6 MPa, 42.8 MPa and 51.5 MPa was found for group A, group B, group C and group D type of concrete respectively.

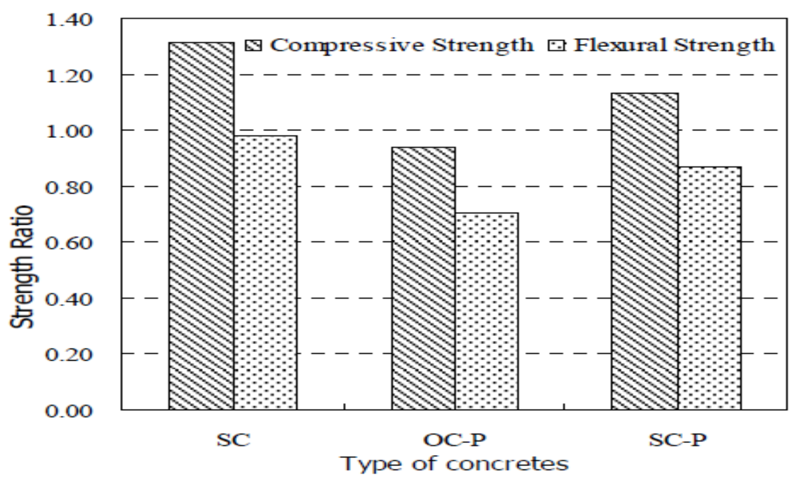


Fig. 2.2: concrete strength ratio at 28 days *(Chunlin L. et al. (2011))*

The results for flexural strength were found to be 9.5 MPa, 9.3 MPa, 6.7 MPa and 6.2 MPa for group A, group B, group C and group D type of concrete respectively. The strength characteristics illustrated by EAF slag concrete shows similarity to the conventional concrete by exhibiting the low flexural and comparatively high compressive strength characteristics. Scrap tire use in concrete lower down its flexural strength however the partial substitution of steel slag with scrap tire exhibits the higher compressive and flexural strength as compared to the conventional concrete. Thus, it was found possible to use the scrap tire as substitution of fine aggregates.

Li et al. (2012) studied the effects of elevated temperatures on strength characteristics of concrete containing ground granulated blast furnace slag (GGBFS) with substitution of ratios of 10%, 30% and 50% by cement weight. OPC (42.5 grade) and GGBFS were used effectively as the cementitious material. Fine to coarse aggregate ratio was fixed at 40%. Table 2.14 shows the mix proportion of different concrete mixes.

Table 2.14: Mixture proportions used in the study *(Li et al. (2012))*

Mix	GGBFS (%)	w/c ratio	Mixture proportion (kg/m^3)						Slump (cm)
			Water	Cement	GGBF	Fine aggregate	Coarse aggregate	Superplasticize	
M1	0	0.41	170	415	0	697	1035	2.9	19.5
M2	10	0.41	170	373	42	697	1035	2.9	19.5
M3	30	0.41	170	290	125	697	1035	2.9	19.0
M4	50	0.41	170	208	207	697	1035	2.9	20.0

The compressive strength of the concrete specimens before heating at elevated temperatures is shown in Table 2.15. The compressive strength values for unheated concrete mixes decreases with the increase in GGBFS contents of 0%, 10%, 30% and 50% and were found to be 48.3, 48.1, 47.1 and 46.4 MPa, respectively. The relative compressive strength was calculated as the percent retained strength of concrete with respect to the strength of the unheated specimens and the temperature effect on relative strength of concrete when it is exposed to elevated temperature is shown in Fig. 2.3.

Table 2.15: Compressive strength of concrete before heating *(Li et al. (2012))*

Mixture	M1	M2	M3	M4
Compressive strength (MPa)	48.3	48.1	47.1	46.4

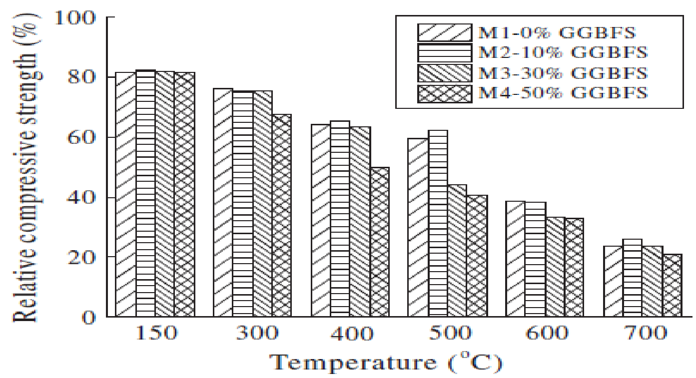


Fig. 2.3: Effect of temperature on relative strength of concrete exposed to elevated temperature *(Li et al. (2012))*

Thus, they concluded that due to release of free water and physically bound water in the concrete, the compressive strength of concrete gets reduced. When the concrte specimens are exposed to the elevated tempreture, the compressive strength is less as compared to the the lower temperature exposure.

Arivalagan et al. (2013) **e**xperimentally studied the option of use the copper slag as a alternate of sand in concrete mix. The copper slag was used in various percentages as 0%, 20%, 40%, 60%, 80% and 100%. The mechanical properties were investigated including the compressive strength, split tensile strength and flexure strength of concrete. A constant w/c ratio of 0.55 was kept throughout the investigation. Table 2.16 shows the physical and chemical properties of copper slag used in the study. Table 2.17 illustrates the compressive strength test results conducted on samples at 28 days after curing. At 40% substitution of copper slag the compressive strength was found to be maximum i.e. about 35.11 Mpa. Whereas, the mix with 60% substitution of slag leads to lower compressive strength of about 20 Mpa. Fig. 2.4 shows the compressive strength of concrete at different mix ratio of copper concrete cubes. Thus, it indicates that the strength increases as copper slag content increases till 40% replacement level only. After which the strength get lower down due to increase in free water content in concrete mixes. Table 2.18 illustrates the split tensile strength test results on cylinder at 28 days after curing. The split tensile strength is increased as copper slag quantity increases up to 40% addition, beyond that the split tensile strength value reduces but still more than 40% compared with control mix.

Table 2.16: Physical and chemical properties of copper slag (*Arivalagan et al. (2013)*)

Sl.No	Physical properties	Copper slag	Chemical components	% of chemical component
1	Particle shape	irregular	SiO_2	25.84
2	Appearance	Black & glassy	Fe_2O_3	68.29
3	Type	Air cooled	Al_2O_3	0.22
4	Specific gravity	3.91	CaO	0.15
5	Percentage of voids	43.20%	Na_2O	0.58
6	Bulk density	2.08g/cc	K_2O	0.23
7	Fineness modulus of copper slag	3.47	Lol	6.59
8	Angle of internal friction	51.20	Mn_2O_3	0.22
9	Hardness	6-7 mohs	Tio_2	0.41
10	Water absorption	0.3% to 0.4%	SO_3	0.11
11	Moisture content	0.1%	CuO	1.20
12	Fineness of copper slag	125 m²/kg	Sulphide sulphur	0.25

Table 2.17: Compressive strength tests conducted on cube specimens at 28 days (*Arivalagan et al. (2013)*)

Sl.No	Replacement of Copper slag (%)	Ultimate load (kN)	Average Load(kN)	Average Compressive strength at 28 days strength(N/mm2)	% of increase in compressive strength
1	CC	678 685 675	679	30.20	---
2	CS20	740 730 745	738.33	32.81	8.60
3	CS40	785 790 795	790.00	35.11	16.25
4	CS60	475 480 485	480	21.33	30.00
5	CS80	450 475 455	460	20.44	33.00
6	CSF	440 445 465	450	20	33.33

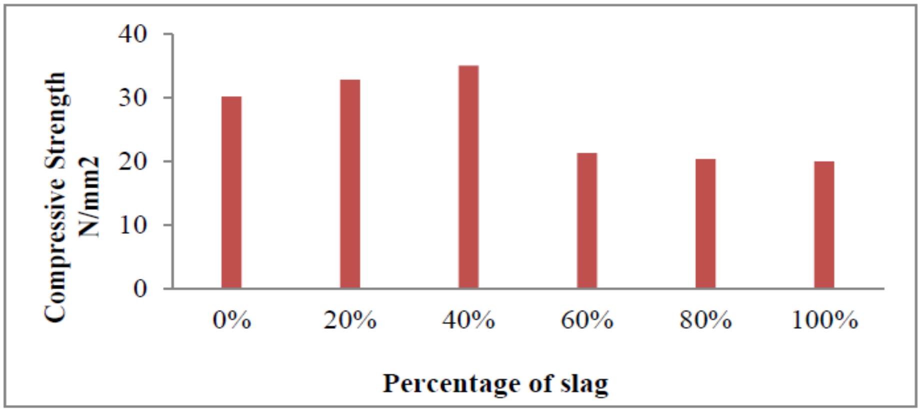


Fig. 2.4: Compressive strength of concrete and different mix ratio of copper concrete cubes (*Arivalagan et al. (2013)*)

Table 2.18: Split tensile strength test on cylinder at 28 days (*Arivalagan et al. (2013)*)

Sl.No	Replacement of Copper slag (%)	Av. Load at 28 days (kN)	Av. Split tensile strength at 28 days (N/mm²)	Increase in split tensile strength(%)
1	CC	109.56	1.55	---
2	CS20	158.34	2.24	44.52
3	CS40	202.16	2.86	84.52
4	CS60	173.18	2.45	58.06
5	CS80	141.37	2.00	12.00
6	CSF	113.09	1.60	3.22

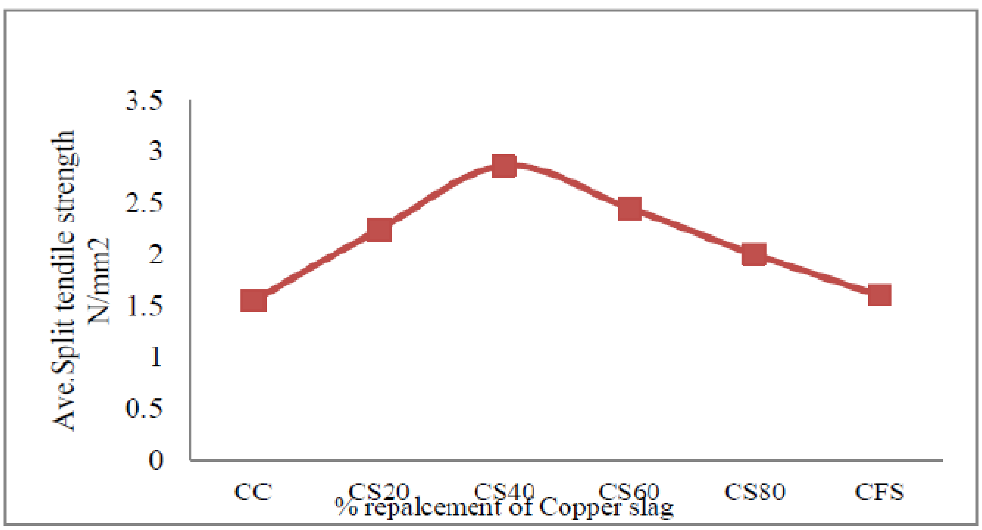


Fig. 2.5: Relationship b/w split tensile strength and replacement of copper slag (*Arivalagan et al. (2013)*)

Fig. 2.5 shows the relationship b/w split tensile strength and the substitution of copper slag The results showed that the use of copper slag in concrete increases the tensile strength of about 85% with that of control mixture.

2.3 CONCLUDING REMARKS

The work done by various researchers in reference to manufacturing of durable, economical and eco-friendly concrete using the waste industrial by-products such as various types of slag was studied thoroughly and the important conclusions given by various scholars are mentioned here in this chapter.

- GGHFAC (Grand granulated high volume fly ash concrete) can achieve adequate early-age compressive strength, while maintaining a long-term strength higher than PCC (Plain cement concrete). GGHFAC is superior to both HFAC (High volume fly ash concrete) and PCC against H_2SO_4 attack, and its weight change is about 8% after 50 weeks exposure to 2% H_2SO_4 solution. The relative strengths of GGHFC, HFAC and PCC decrease due to the decalcification and the expansive corrosion of hardened cement in H_2SO_4 solution. However, the decreasing rate of GGFAC is the lowest.
- The inclusion of copper slag in concrete leads to increase in strength properties of concrete because of strong bond acting between the cement paste and aggregate.
- It is feasible to generate aerated concrete based on geopolymers of Mk (metakaolin) of different densities using hydrogen gas generated by Al (Aluminium) powder in alkaline media. The substitution of Mk by 25% FA (fly ash) is viable to form reactive cement pastes. The substitution of the cementitious paste by BFS sand in concretes of 1200 kg/m^3 is favorable to produce concretes of good properties, lower price and environmental impact. The increment in the curing temperature from 20 to 75 ˚C accelerates the development to the compression and flexural strength during the first day.
- For cement mortars, all mixtures with diverse copper slag proportions yielded comparable or higher compressive strength than the strength of the control mixture. There was more than 70% improvement in the compressive strength of mortars with 50% copper slag substitution in comparison with the control mixture. The compressive, tensile and flexural strength of concrete were comparable to the control mix using up to 50% copper slag substitution for sand, but they decreased with a further increase in copper slag contents.

CHAPTER -- 3

MATERIAL AND DESIGN METHODOLOGY

3.1 GENERAL

The current chapter deal with the material properties and the outcome acquired from the different test performed on the material to be used in experiment. An experiment was performed to investigate the concrete strength characteristics along with its microstructure behavior.

3.2 CHARACTERISTICS OF MATERIALS USED

The various properties the materials to be used in experiment were evaluated in concrete laboratory according to IS codes of practice. The various materials that were utilized in the experiment were Ultratech make OPC 43 grade cement, 20 mm and 10 mm coarse aggregates for control mix, crushed 20 mm and 10 mm blast furnace slag aggregate, fine aggregate and water. A constant w/c ratio of 0.45 was kept throughout the experimental program. Various test were performed for the materials to be used in concrete manufacture so as to check the acceptance of materials as per IS codal provision for mix design of desired concrete strength characteristics. Various properties for the construction materials to be utilized in the study is detailed in the following sub-sections:

3.2.1 Ordinary Portland Cement (OPC)

Cement provides strength to concrete and binds the aggregates when mixed with water to form a a hard mass. About 20% of the total quantity of concrete mix is cement and has a major effect on the strength and durability characteristics of concrete. OPC 43 Grade (Ultratech Cement) was used in the experimental work conducted in lab. It was ensured that he cement to be used was free of any lumps and is fresh. Cement should not be in contact with any moisture content. If the moisture is present in the cement then it should be avoided to use. Table 3.1 illustrates the various physical characteristics of the cement. From the value observed, it has been found that all the parameters are within the specific limits and cement can be used for further study.

Table 3.1: Physical Properties of Cement

Sr. No.	Name of Test	Observed value	Standard value as per IS: 8112-1989
1.	Normal consistency (%)	29 %	-
2.	(a) Initial setting time (b) Final setting time	165 min 270 min	Not less than 30 min Not more than 600 min
3.	Soundness (mm)	2 mm	Not more than 10 mm
4.	Fineness	2 %	Not more than 10 %
5.	Compressive strength (N/mm^2) At 3 days At 7 days	 25.18 36.20	 Not less than 23 N/mm^2 Not less than 33 N/mm^2

3.2.2 Aggregates

An aggregate hold a large volume in the concrete mix and provides the dimensional stability to concrete. Coarse aggregates combines with cement and sand along with the water and forms the solid hard mass of concrete with increased crushing strength. The presence of aggregates in concrete also reduces its cost since the major volume of concrete is covered with the aggregates itself. Coarse sand used in the concrete fills the voids of coarse aggregates and reduces the cracks occurring due to shrinkage in concrete. When the water get into the voids of sand particles the cement hardening takes place. Coarse aggregates should be well graded, clean and of adequate shape as about 70 – 80 % of volume of concrete is covered by coarse aggregates only.

1. Coarse aggregates: These are the aggregates that retain on IS sieve of size 4.75 mm. The size of the aggregates used in the present study was 10 mm and 20 mm.

Table 3.2: Properties of Coarse Aggregates

Characteristics	Value	
Color	Grey	
Shape	Angular	
Maximum size	20mm	10mm
Specific Gravity	2.71	2.75
Water Absorption	0.3%	0.5%

First of all the aggregates were washed to remove any dust particles present in it and then is surface dried before using it. Table 3.2 illustrates the various physical characteristics of coarse aggregates. Table 3.3 shows the sieve analysis results for aggregates of 20 mm size and Table 3.4 for the 10 mm aggregate.

Table 3.3: Sieve Analysis of Coarse Aggregates (20 mm)

Sr. No.	IS-Sieve (mm)	Wt. Retained (gm)	% Retained	% passing	Cumulative retained (in %)
1	80	0	0	100	0
2	40	0	0	100	0
3	20	28	0.93	99.07	0.93
4	10	2876	95.87	3.20	96.8
5	4.75	75	3.20	0	99.3
6	2.36	0	0	0	100
7	1.18	0	0	0	100
8	600	0	0	0	100
9	300	0	0	0	100
10	150	0	0	0	100
11	Pan	21	0.7		
Total		**3000**		**SUM**	**697.03**
FM - 6.97					

Table 3.4: Sieve Analysis of Coarse Aggregate (10 mm)

`Sr. No.	IS-Sieve (mm)	Wt. Retained (gm)	% Retained	% passing	Cumulative retained (in %)
1	80	0	0	100	0
2	40	0	0	100	0
3	20	447	22.35	77.65	22.35
4	10	415	20.75	56.90	43.10
5	4.75	1055	52.75	4.15	95.85
6	2.36	80	4	0.15	99.85
7	1.18	0	0	0	100
8	600	0	0	0	100
9	300	0	0	0	100
10	150	0	0	0	100
11	Pan	3	0.15	**SUM**	**661**
Total		**2000**		**FM - 6.61**	

2. Fine aggregates: These are the aggregates that pass through IS sieve of 4.75 mm size. In this experimental program fine aggregates were conforming to grading zone II and were free from any dust particles. Table 3.5 exhibits the physical characteristics of aggregates used in the research work. The Specific gravity of 2.6 was evaluated in the concrete laboratory.

Table 3.5: Sieve Analysis of Fine Aggregate

Sr. No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	4.75	5	0.5	99.5	0.5
2	2.36	59	5.9	93.6	6.4
3	1.18	136	13.6	80	20
4	600 µ	243	24.30	55.7	44.3
5	300 µ	415	41.5	14.2	85.8
6	150 µ	122	12.2	2.0	98.0
7	Pan	20	2.0		
TOTAL		**1000**		**SUM**	**255**
		Zone II		**FM= 2.55**	

3. Blast Furnace Slag aggregates:

PHYSICAL TESTS

The slag is black glassy particle and in the form of boulders. First, the slag is crushed manually and then it is passed through a sieve of 20 mm and retained on sieve of 4.75 mm to get 20 mm size BFS aggregate.

Table 3.6: Physical Properties of Slag Aggregate

Physical tests	Values
Specific gravity	2.3
Maximum size of coarse aggregate	20 mm
Bulk modulus(compacted)kg/m^3	1.5
Bulk modulus(loose) kg/m^3	1.2

Then, the remaining slag is passed via sieve of 10 mm size again and retain on sieve of size 4.75 mm to get 10 mm size of BFS aggregate. The physical properties of BFS aggregate along with its sieve analysis are illustrated in Table 3.6 & Table 3.7 respectively.

Table 3.7: Sieve Analysis of Coarse Slag Aggregate

Sieve	%age of wt. passing	Remarks
20	100	
16	56.05	
12.5	27.65	slag aggregate as per IS: 383-1970
10	6.95	
4.75	0.05	

CHEMICAL TEST

The chemical properties of blast furnace slag have been found using X-ray fluorescence and shown in Table 3.8. From the chemical composition, it has been observed that the slag contains about 33% silica and 21% of calcium oxide**.** Similarly, it has been observed that it contain 23% of ferrous oxide**.** The slag content present in the slag can contribute to form silicates in the body of concrete and hence increases the strength.

Table 3.8: Chemical Composition of Blast Furnace Slag

Chemical components	%age of chemical components
MgO	0.8868
Al_2O_3	8.6925
SiO_2	33.6942
P_2O_5	0.4752
SO_3	0.9498
K_2O	0.8946
CaO	21.9869
MnO	2.4709
Fe_2O_3	23.7346
NiO	6.2144

3.2.3 Water

The water to be used in the experimental programme should be free from any harmful poisonous substance. Generally the potable water is considered suitable and good for mixing and curing purpose of concrete and the same was available in the concrete laboratory.

3.3 Mix proportions

To study the effect of BFS aggregate as the replacement of aggregate in the concrete mix, coarse aggregates were replaced with BFS aggregate in various percentages such as 0 %, 20%, 40%, 60%, 80% and 100%. The various mixes were designated as N1, N2, N3, N4, N5 and N6 respectively. M 25 was designed as a control mix as per codal provision of IS 10262: 2009 for the experimental study. OPC 43 grade Ultratech cement was used and a constant density of cement was kept in different concrete mixes to be 410 kg/m^3. . For the control concrete, the ratio of 20 mm to 10 mm coarse aggregate was maintained as 65: 35 and the w/c ratio was kept to be 0.45 to have graded aggregate according to IS 383: 1970. The fine aggregate was kept constant in all mixes. Table 3.9 shows the various mix proportion for different BFS aggregate ratio.

Table 3.9: Concrete Mix Proportion for M25 Grade

Mix proportion	Percentage variation of blast furnace slag					
	N1 (0%)	N2 (20%)	N3 (40%)	N4 (60%)	N5 (80%)	N6 (100%)
Cement	410	410	410	410	410	410
w/c ratio	0.45	0.45	0.45	0.45	0.45	0.45
Coarse aggregate	1208.47	966.87	725.08	483.39	241.6	0
Fine aggregate	596.69	596.69	596.69	596.69	596.69	596.69
Slag aggregate	0	241.6	483.39	725.08	966.78	1208.47

.

3.4 CASTING AND CURING OF SAMPLES

All the specimens were casted as per mix proportions as illustrated in Table 3.2. The required material quantities were weighed to make the mix proportions. Firstly the dry ingredients were mixed using a shovel. Then water was added to the mix gradually. The mix was filled into the moulds (cubes and cylinders) and then the compaction of filling is done by tamping rod available in the laboratory. Trowel is used to finish the top surface of concrete filled mould. The samples were kept undisturbed for 24 hours in air and then the samples were taken out of the moulds to keep in water tank for curing purpose. The samples were cured at a temperature of 25+/- 2˚C in curing water tank till any further testing.

3.5 TEST METHODS

The concrete mixes obtained were tested for various properties and the procedure for all properties is reviewed in the following sections.

3.5.1 Compressive Strength of Concrete

The cubes were casted under standard laboratory conditions were tested after a curing age of 7 and 28 days. The specimens were tested on 500 tons capacity Automatic Compression Testing Machine (ACTM). The sample was taken out from curing tank and clean with dry cloth to remove any surface water present on it.

Fig. 3.1 Compressive strength test setup

The cubes were placed in the position in CTM and a continuous load was applied on sample at the rate of 15 N/mm^2/minute till the specimen failure takes place. Fig. 3.1 shows the cube testing under CTM.

3.5.2 Split Tensile Strength of Concrete

Split tensile strength was determined for the concrete as per IS Code 5816-1970. In this test, 300 mm long and 150 mm dia cylindrical specimen was kept in CTM for testing. Load was applied till the failure of cylindrical sample took place along its dia in vertical direction.

The magnitude of split tensile strength (in MPa) is as follows:

$T = 0.637\ p/dl$

Where,

T= tensile strength of concrete (in MPa)

p = load applied on the sample

d = Dia. of specimen (in mm)

l = length of specimen (in mm)

3.5.3 SEM - Scanning electron microscopy

Concrete sample morphology was analyzed with SEM technique. SEM is a instrument that shows the detailed internal structure of heterogeneous concrete particles. In order to study the morphological behavior of concrete JSM 651OLV SE microscope was used. Broken pieces obtained after the compression test at 28 days were used for studying SEM of all the mixes.

3.5.4 Energy Dispersive Spectrometry (EDS)

Scanning Electron Microscopic & Energy Dispersive Spectrometry (6510-LV,JOEL, Japan) is conducted to study the micro- structure properties of the samples. The samples were cured for 28 days period before testing is done. Any internal change that can occur in the micro structure of concrete can be analysed by the EDS technique. The morphology of the samples was analyzed with SEM. The chemical characterization or elemental analysis of a sample can be done by EDS technique. In this test a spectrum was selected and analysis was done on it, which shows peak of different elements that represents the chemical composition of material as shown in chapter 4.

3.5.5 RCPT - Rapid Chloride Penetration Test

It is the common and important environmental effect that causes the steel reinforcement corrosion that is present in concrete due to propagation of chloride ions into the concrete. Ingression of chloride leads to damage to the concrete surface and also effects the reinforcing steel thus the structures require annual repairs and maintenance. Chloride can penetrate into the concrete structure by various methods like hydrostatic pressure, capillary absorption and the most predominant is diffusion.

Diffusion occurs when chloride concentration on outer surface of concrete is greater as compared to the chloride concentration present on inner side of concrete. The setup that was used during the RCPT test in lab is shown in Fig. 3.2.

Fig. 3.2 RCPT test procedure setup

As a result the chloride ion concentration propagates through the concrete and reaches the reinforcement level that leads to the corrosion in the presence of oxygen available from atmosphere. The rate of penetration of chloride ions in the surface of concrete depends on the various factors like mix proportion, type of curing and time of curing, use of supplementary cementitious materials, degree of hydration and type of construction practices done at site.

Chloride permeability testing procedure:

The ingress of chloride ion concentration into the concrete can be tested by a method developed by Whiting in 1981 and is named as RCPT (rapid chloride penetration test). This method is simple and quick to perform. The RCPT is implemented by observing the amount of electrical current passing through the sample for 6 hours. Specimen was obtained by cutting it as a cylindrical slice of concrete. Table 3.10 shows the rating chart for RCPT. While doing the test a 60V DC voltage was maintained beyond both the sample ends. One lead is submerged in a 3.0% salt (NaCl) solution while the other lead is immersed into 0.3 M sodium hydroxide (NaOH) solution.

Table 3.10: RCPT rating chart (ASTM 1202-97)

Chloride permeability	Charge passing (coulombs)
High	Greater than 4000
Moderate	2000 - 4000
Low	1000 - 2000
Very low	100 - 1000
Negligible	Less than 100

RCPT – Advantages and Disadvantages

Advantages

- Test is quick and simple.
- It can be used for quality control.
- The interpretation of the results obtained is easy.

Disadvantages

- Sometimes during the RCPT test the physical and chemical changes get evolve into the concrete samples that leads to inaccurate values.
- Concrete samples containing steel or carbon fibers in it do not provide the satisfactory results.

Chloride ion concentration can penetrate into the concrete surface by means of a mechanism known as diffusion. Chloride ion concentration moves through the concrete surface and reach the level of reinforcement which leads to the corrosion of reinforcing steel.

3.5.6 Sorptivity

Sorptivity is the ingression of water into the sample with the passage of time. Sorptivity test procedure is shown in Fig. 3.3.

Fig. 3.3: Sorptivity test procedure setup

Factors affecting the sorptivity test

There are various factors on which the absorption of water depends. Some important factors are listed below:

- Mix proportion of concrete specimens.
- The physical characteristics along with its chemical composition of the cementitious component and aggregates that are used in the concrete.
- Duration and the type of curing done on concrete in order to achieve the desired strength.

CALCULATIONS

The absorption is designated by I and is given by the formula as:

$I = M_t/(AxD)$

Where;

I = absorption (mm)

M_t = change in mass of sample (in grams)

A = Exposed area of sample (in mm^2)

D = water density (g/mm^2)

3.5.7 X - Ray Difraction

In order to perform XRD of the samples, the 28 days cured sample is taken and crushed & pulverized into an average size of 10 microns. Then mount the crushed sample particles on glass fibre filter with the help of tubular aerosol suspension chamber (TASC).

3.6 CONCLUDING REMARKS

In this chapter various materials (cement, sand and blast furnace slag) that are used in present work have been defined and the methods of the tests that have been performed have also been described. Also, the estimation of all the quantities to be used in the mix has been specified in accordance with Indian Standard code. After this specimens were made and tested for various strength and durability properties of various concrete mixes.

CHAPTER -- 4

RESULTS AND DISCUSSION

4.1 GENERAL

This section reviews the results that were acquired by a variety of tests performed on the samples of concrete obtained when coarse aggregate was replaced from BFS aggregate in the range of 0%, 20%, 40%, 60%, 80% and at last 100%. In order to achieve the objective of study the strength characteristics of the concrete manufactured from Blast furnace slag, the coarse aggregate is replaced from BFS in various percentages and the results are obtained. The various mixes were cast using the proportions as laid down in Tables 3.9 in the previous chapter. This experimental program includes:

1. Materials properties determination that is to be used for making concrete.
2. Mix proportion for BFS concrete.
3. Casting of samples
4. Curing of samples.
5. Test to determine mechanical properties of concrete.
6. SEM analysis
7. EDS - Energy dispersive x-ray spectroscopy
8. Rapid chloride penetration test (RCPT) for durability test of concrete
9. Sorptivity test
10. X-ray diffraction (XRD) analysis

4.2 COMPRESSIVE STRENGTH TEST RESULTS

4.2.1 Compressive strength

The main function of concrete in structure is mainly to resist the compressive forces that induces into the structure. The test results for the 7 and 28 days for various mix and the control mix are shown in the Table 4.1 and Table 4.2.

4.2.2 Compressive Strength Results for 7 Days

Table 4.1 illustrates the average compressive strength of concrete mix for different mix proportion for 7 days and its graphical representation is shown in Fig. 4.1.

Table 4.1: Compressive Strength of Cubes at 7 Days

Sr. No.	Replacement of slag (%)	Avg. compressive strength(MPa)	% increase/decrease in compressive strength
1	0	20.88	-
2	20	22.64	+ 8.42
3	40	22.21	+ 6.36
4	60	23.83	+ 14.12
5	80	19.68	- 5.74
6	100	19.45	- 6.85

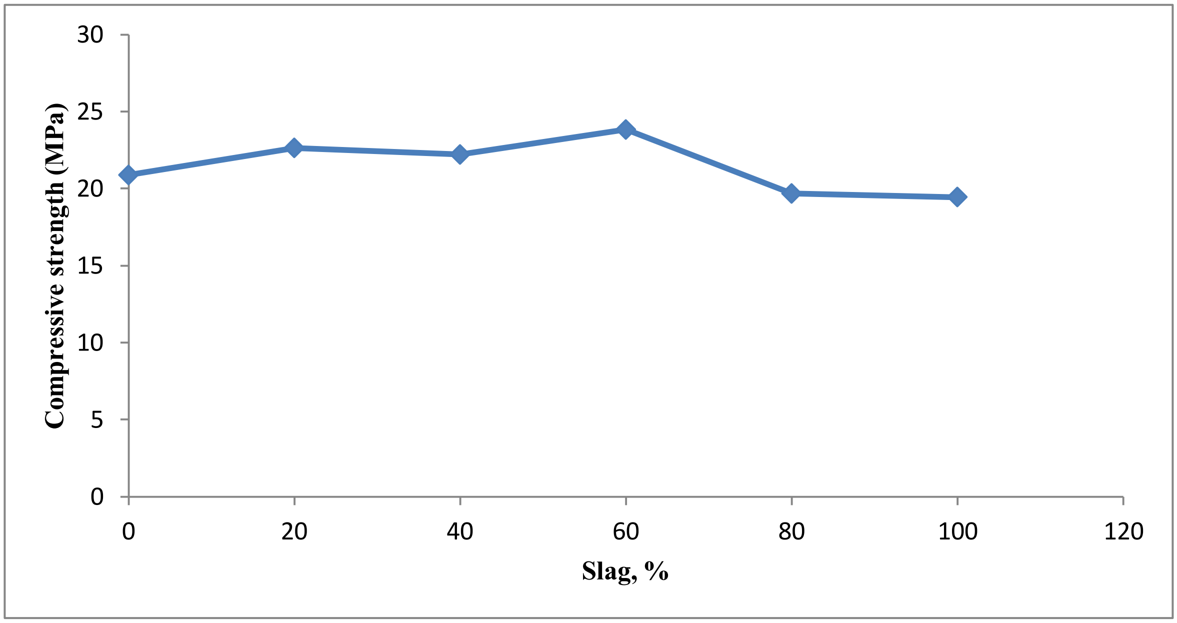


Fig. 4.1: Compressive strength vs. percentage of slag at 7 days

The result exhibits that the compressive strength get increased when the coarse aggregate is substituted by Blast furnace slag up to 60% replacement level only and shows the maximum compressive strength value of 23.83 MPa. But, when the substitution level is further increased from 60% to 80% and 100% then the compressive strength shows the lower values of 19.68 MPa and 19.45 MPa respectively.

4.2.3 Compressive Strength Results for 28 Day

The compressive strength test results of concrete mix for 28 days for different mix proportion shown in Table 4.2 and its graphical representation is shown in Fig. 4.2. The result illustrates that the compressive strength get increases when coarse aggregate is replaced by BFS aggregate up to 60% replacement level only and shows the maximum compressive strength value of 36.11 MPa. But, when the substitution level is further increased from 60% to 80% and 100% then the compressive strength shows the lower values of 31.73 MPa and 30.40 MPa respectively.

Table 4.2: 28 days Compressive Strength of Cubes

Sr. No.	Replacement of slag (%)	Avg. compressive strength (MPa)	% increase/decrease in compressive strength
1	0	32.44	-
2	20	33.80	4.19
3	40	35.25	8.66
4	60	36.11	11.31
5	80	31.73	- 2.18
6	100	30.40	- 6.28

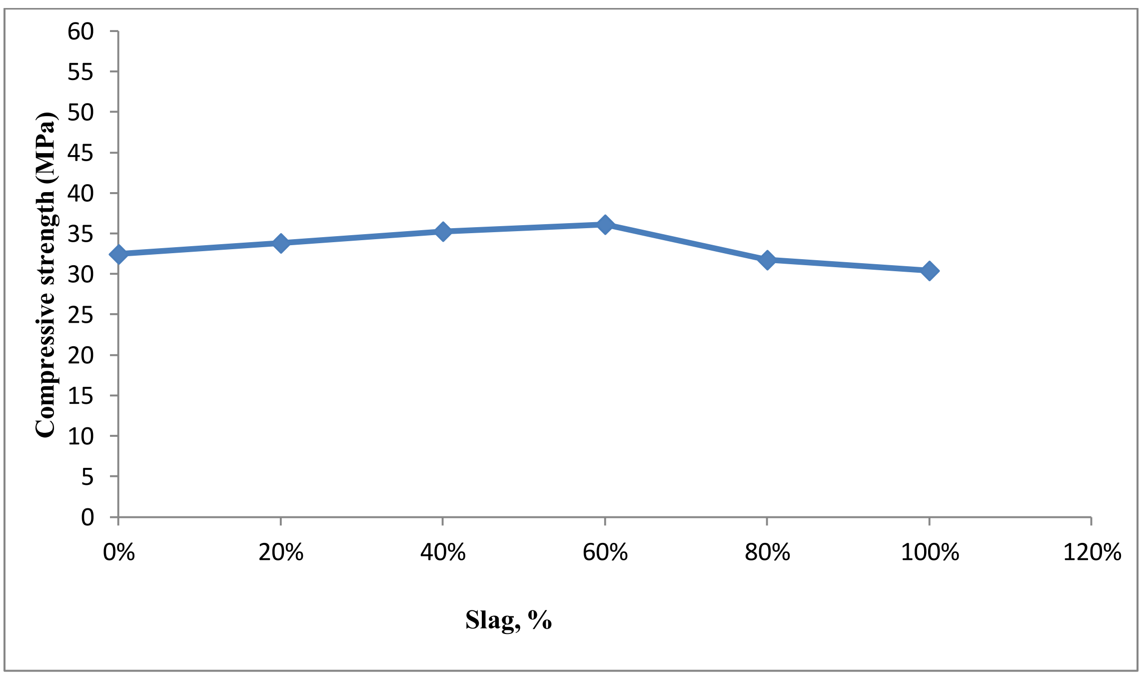


Fig. 4.2: Compressive strength vs. percentage of slag at 28 days

4.2.4 Comparison of compressive strength at 7 days and 28 days

The comparison of compressive strength is shown in Fig. 4.3. From the fig., it is clear that both at 7 days and 28 days the compressive strength of mixes get increase with increase in BFS aggregate proportion till 60%, thereafter it starts decreasing.

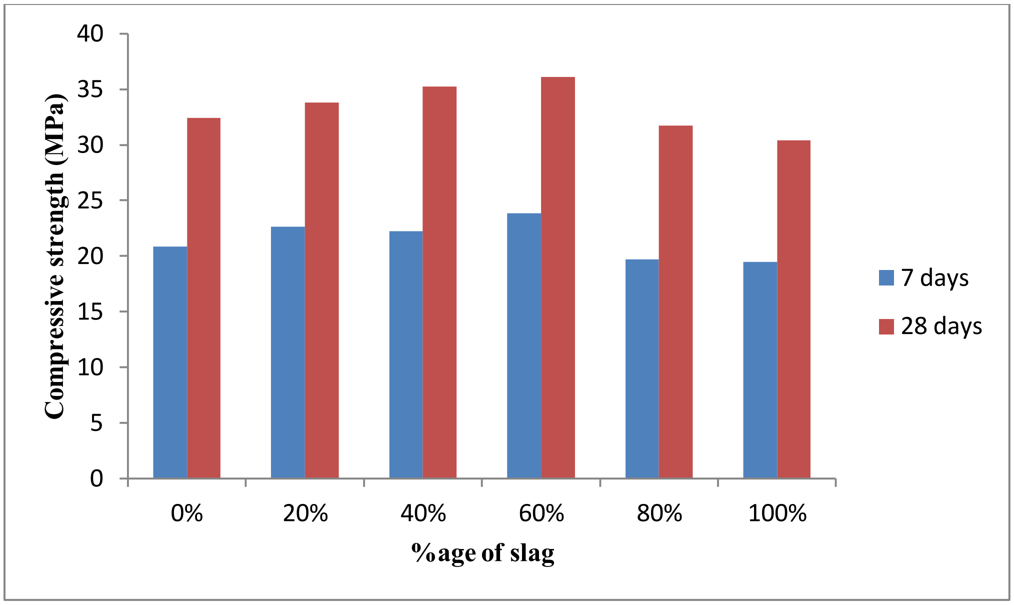


Fig. 4.3: Comparison of compressive strength at 7 days and 28 days

4.3 SPLIT TENSILE STRENGTH TEST RESULTS

4.3.1 Split tensile strength

The minimum tensile stress needed to split the material apart is termed as split tensile strength. The results are reviewed in the Table 4.3 and Table 4.4.

4.3.2 Split tensile strength Results for 7 days

Table 4.3 shows the average 7 days split tensile strength of concrete mix for various mix proportion and its graphical representation is shown in Fig. 4.4.

Table 4.3 Split tensile strength of cylinders at 7 days

	Replacement of slag (%)	Avg. Split tensile strength (M Pa)	%age of increase in strength
1	0%	2.4	-
2	20%	2.5	4.16
3	40%	2.7	12.5
4	60%	3.0	25
5	80%	2.6	8.33
6	100%	2.5	4.16

The result shows that the split tensile of concrete cylinders get increased when the coarse aggregate is replaced by BFS aggregates upto 60% replacement level only and shows the maximum split tensile strength value of 3.0 MPa. But, when the replacement level is further increased from 60% to 80% and 100% then the split tensile strength shows the lower values of 2.6 MPa and 2.5 MPa respectively.

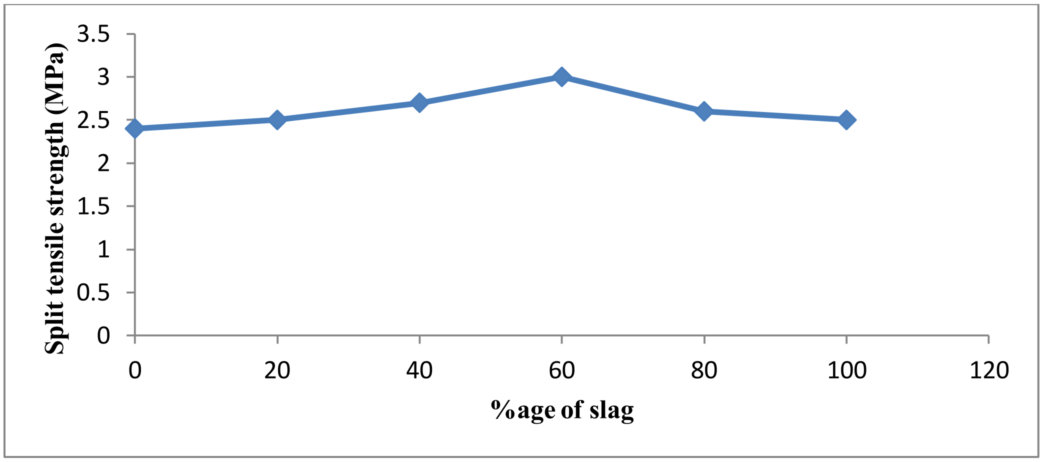


Fig. 4.4 Split tensile strength vs. percentage of slag at 7 days

4.3.3 Split tensile strength Results for 28 days

Average tensile strength of concrete for 28 days for different mix proportion shown in Table 4.4. Fig. 4.5 shows its graphical representation.

Table 4.4 Split tensile strength of cylinders at 28 days

Sr. No.	Replacement of slag (%)	Avg. Split tensile strength (MPa)	%age of increase in strength
1	0%	3.1	-
2	20%	3.2	3.22
3	40%	3.3	6.45
4	60%	3.9	25.80
5	80%	3.6	16.12
6	100%	3.5	12.90

The result shows that the split tensile strength get increased when coarse aggregate was replaced by BFS aggregates upto 60% replacement level only and shows the maximum split tensile strength value of 3.9 MPa. But, when substitution level is increased further from 60% to 80%

and 100% then the split tensile strength shows the lower values of 3.6 MPa and 3.5 MPa respectively.

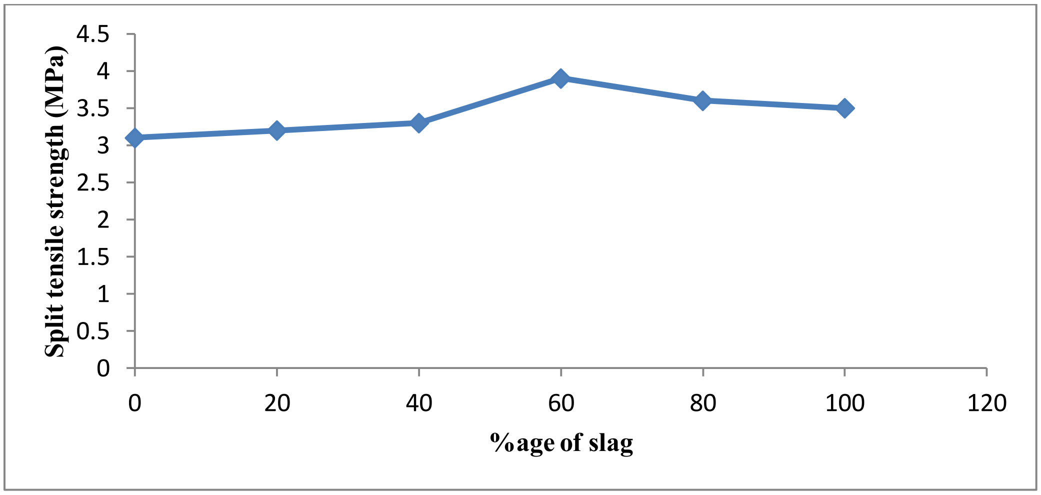


Fig. 4.5 Split tensile strength vs. percentage of slag at 28 days

4.3.4 Comparison of tensile strength at 7 days and 28 days

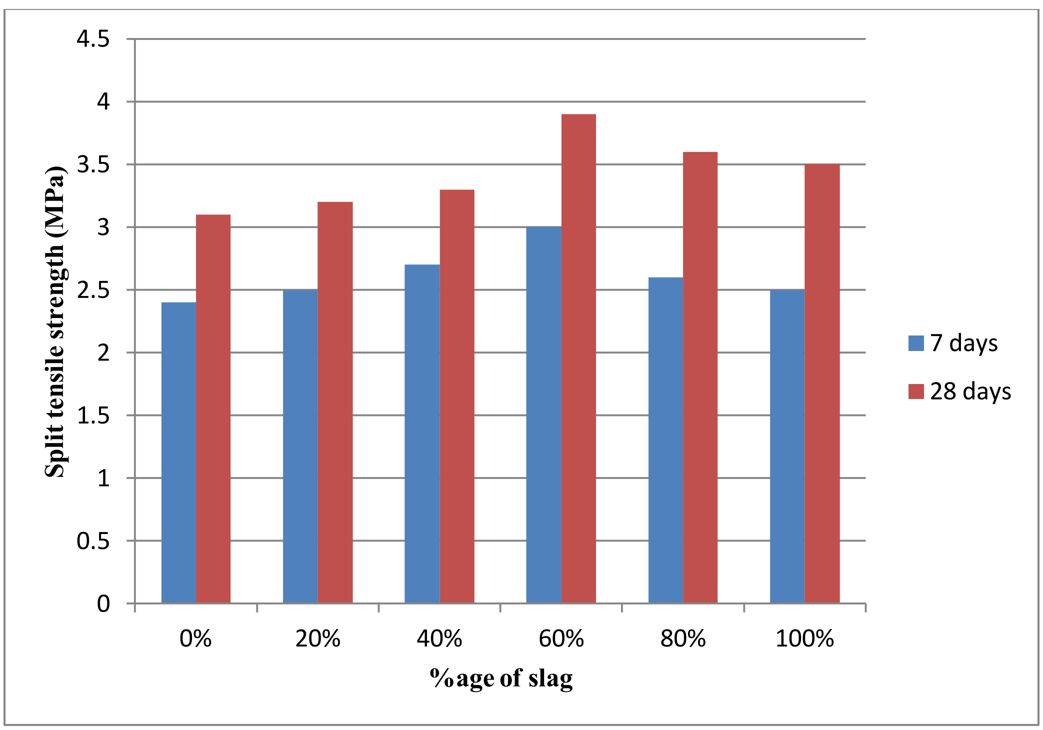


Fig. 4.6 Comparison of split tensile strength at 7 days and 28 days

Fig. 4.6 shows the split tensile strength comparison. From the fig., it can be seen that split tensile strength for mixes at 7 days and 28 days increased with the increase in BFS aggregate proportion till 60%, thereafter it starts decreasing.

4.4 SEM - Scanning electron microscope analysis

SEM analysis conducted to analyze the microstructure of all six concrete specimens. Broken pieces obtained after the compression test at 28 days were used for studying SEM. The results are illustrated in Fig. 4.7 - Fig. 4.12. The morphology of the mixes are observed in SEM is found to be consistent with the observations made during compressive strength results.

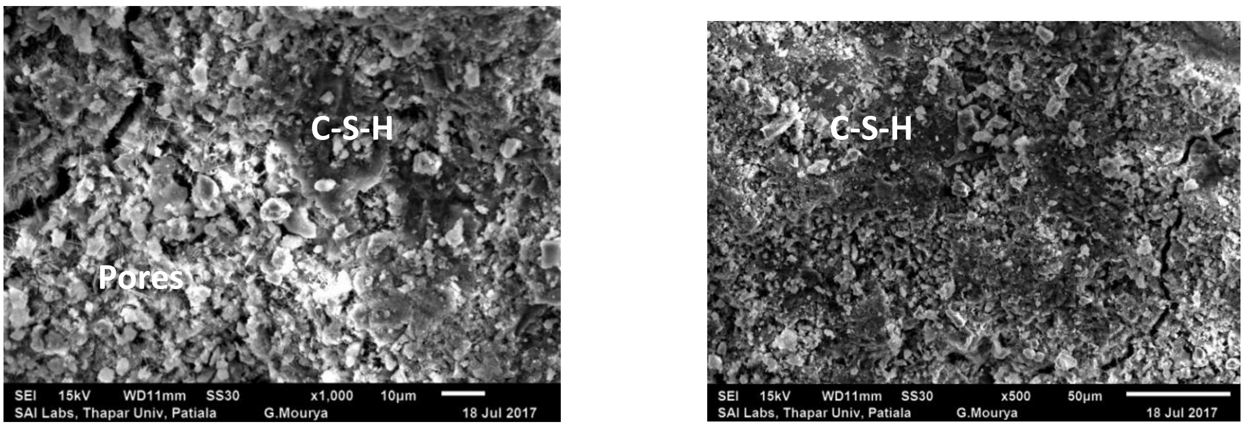


Fig. 4.7: SEM results for M1 concrete mix

In M1 concrete mix (Fig. 4.7), SEM results show a dense arrangement of calcium silicate and hydrate gel which that is found to be responsible for increase in compressive strength of concrete.

In concrete mix M2 (Fig. 4.8), more compact structure can be observed due to increased C-S-H gel which is formed may be due to proper grading obtained by replacing coarse aggregate with Blast Furnace Slag aggregates. However, the pores were also observed in the results given by SEM technique.

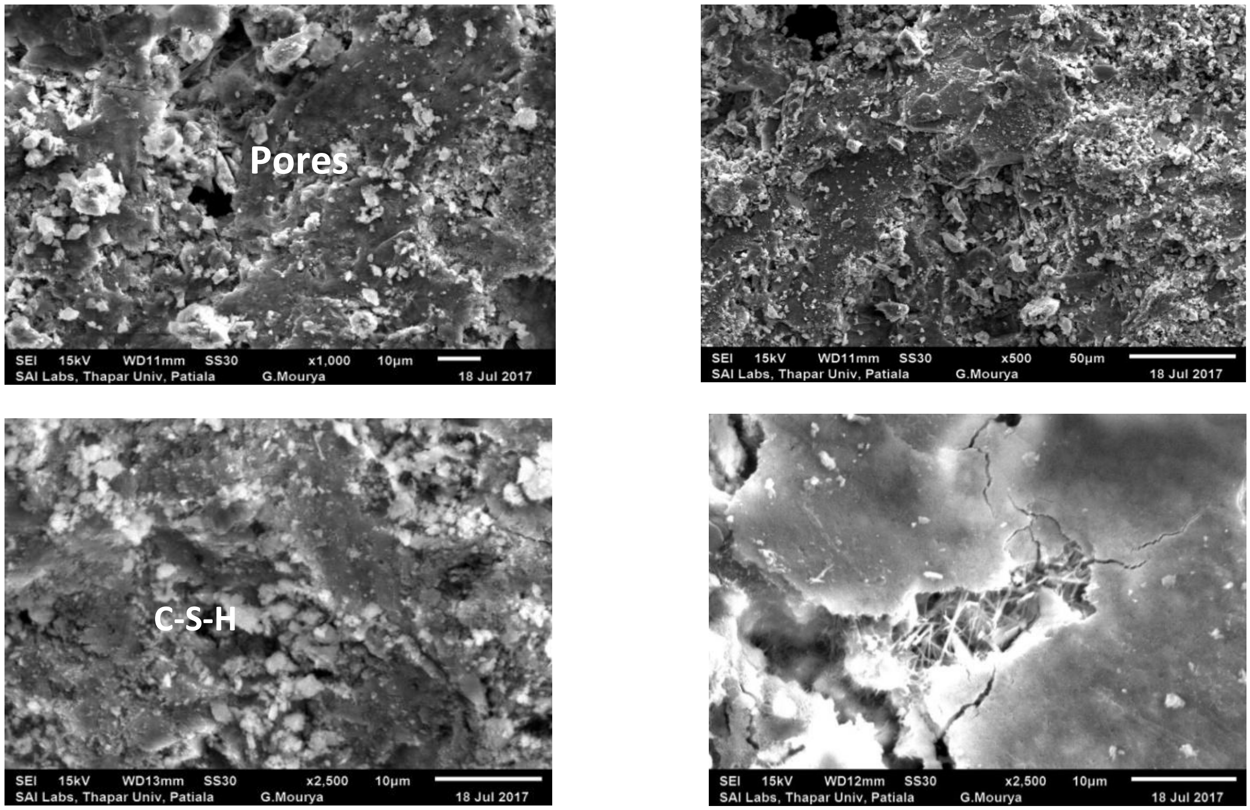
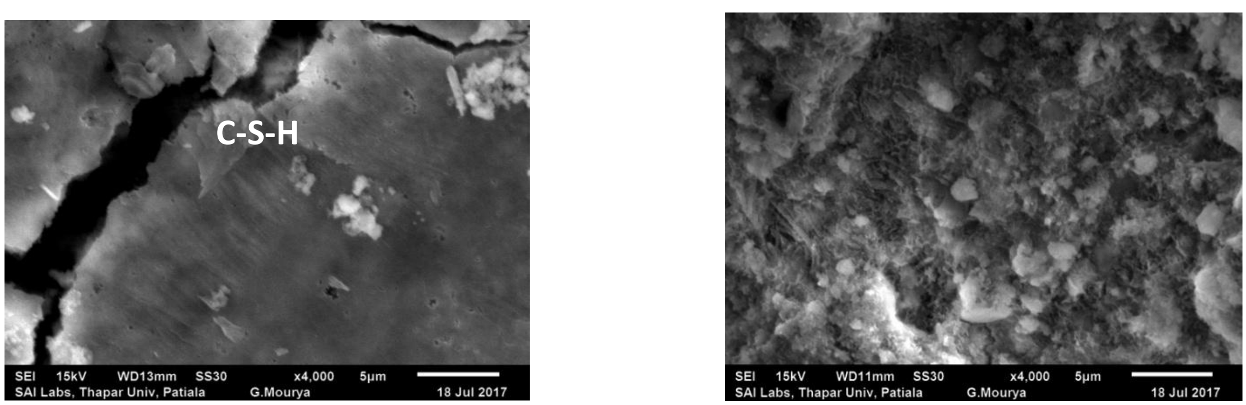


Fig. 4.8: SEM results for M2 concrete mix

This type of compacted structure can be seen for concrete mixes M3 and M4 also due to increased C-S-H gel that provides the strength to the concrete as illustrated in Fig. 4.9 and Fig. 4.10.



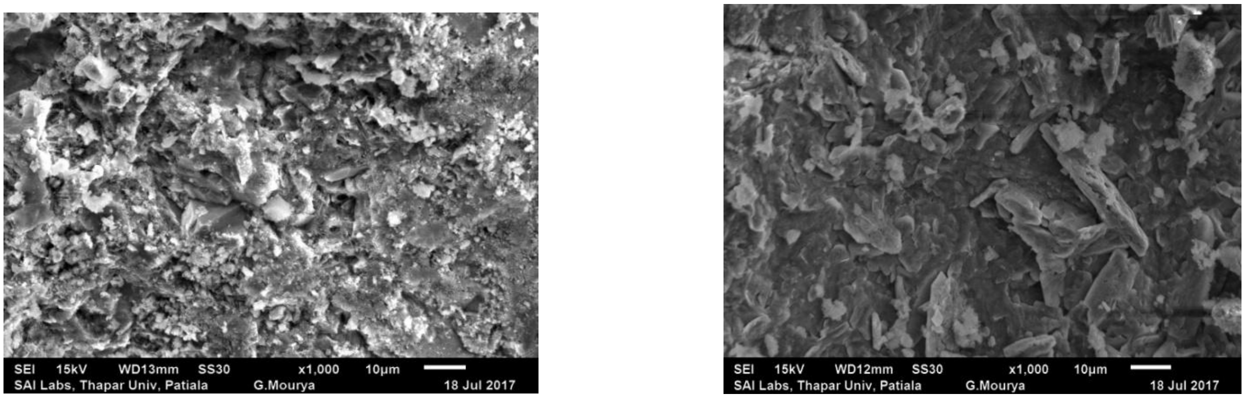


Fig. 4.9: SEM results for M3 concrete mix

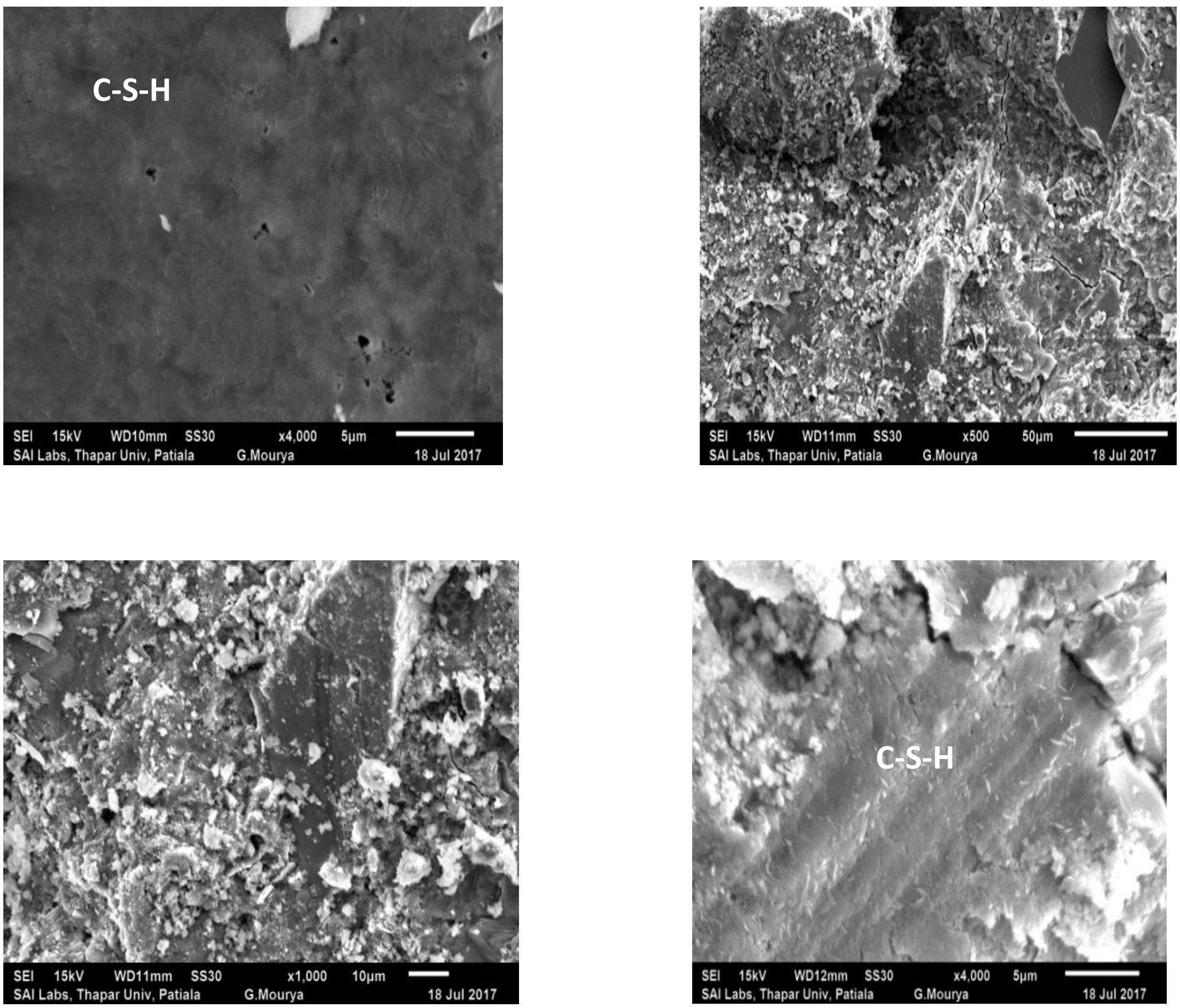


Fig. 4.10: SEM results for M4 concrete mix

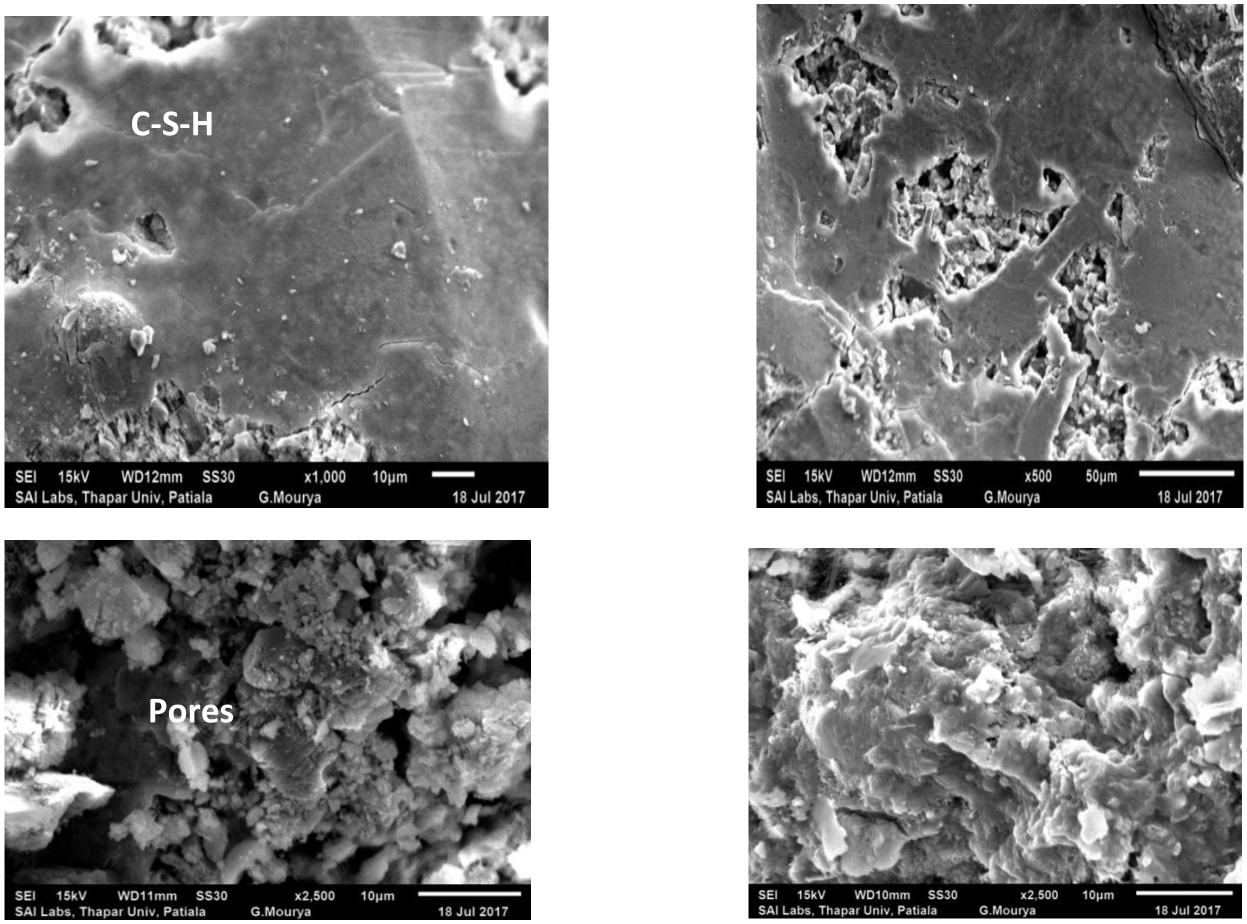
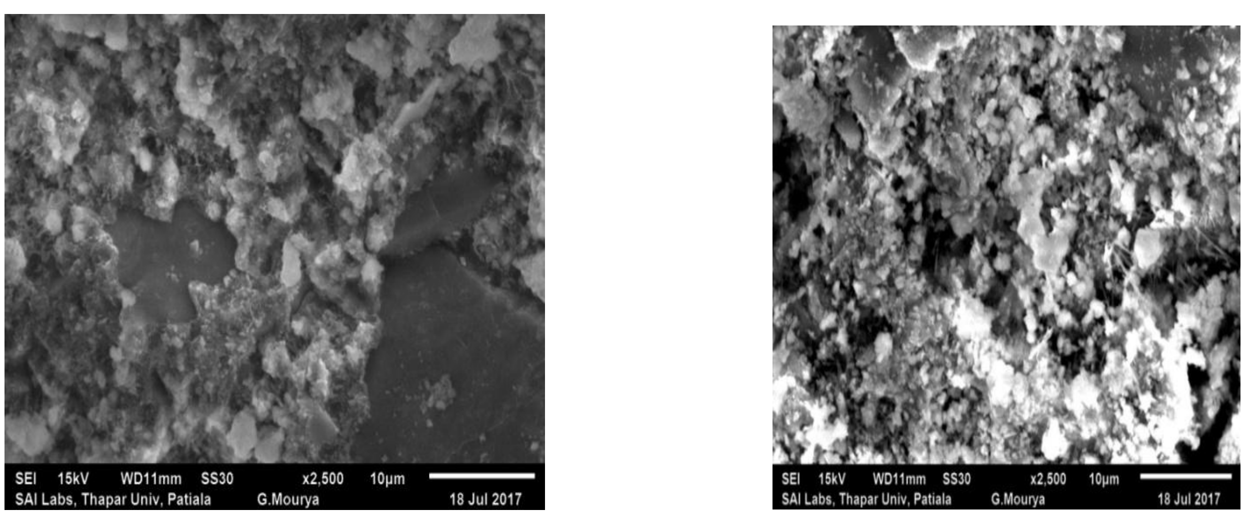


Fig. 4.11: SEM results for M5 concrete mix

Same kind of trend was observed in case of concrete mix M6 as shown in Fig. 4.12. Voids and ettringites were observed in mix M6 also thus the strength got reduced.



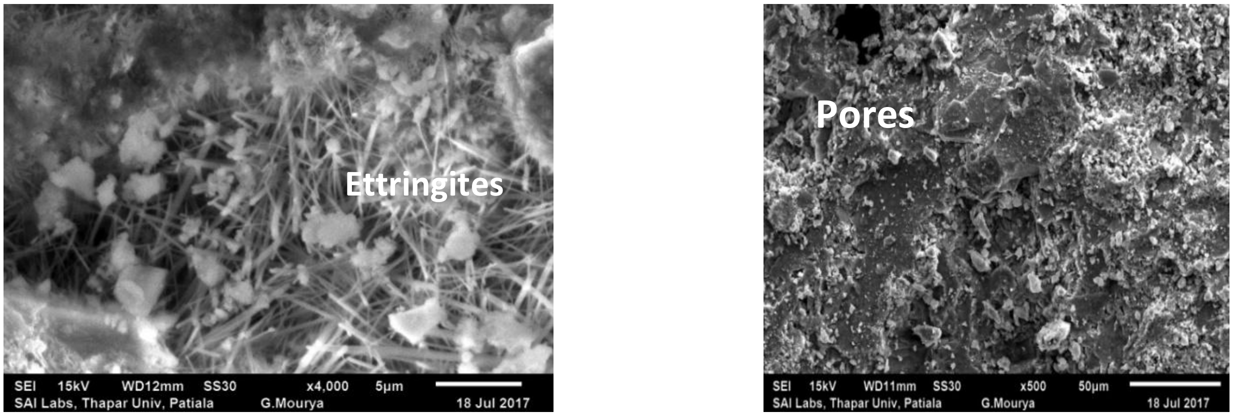


Fig. 4.12: SEM results for M6 concrete mix

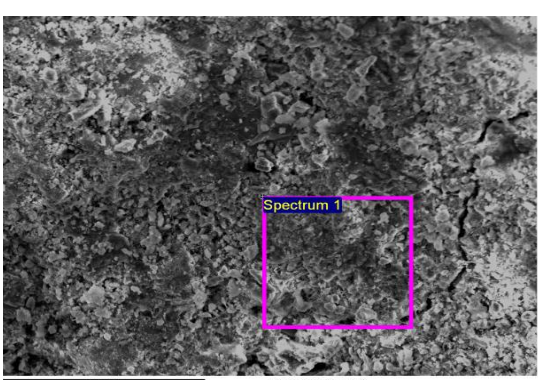
Hence the difference in strength of all concrete mixes was reflected in there micro structure also. The observed microstructure as revealed by SEM suggests that a dense microstructure is associated with higher strength.

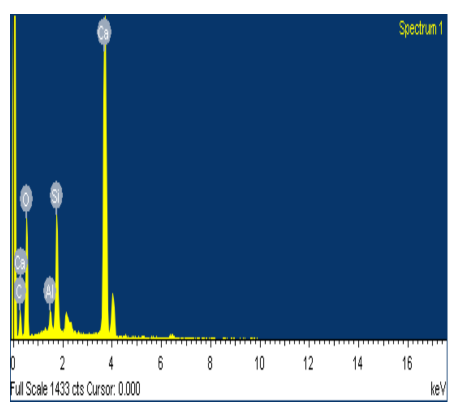
4.5 Energy Dispersive Spectrometry (EDS)

EDS RESULTS

EDS is used to analyze the chemical characterization and elemental analysis of sample. All the samples were kept in curing tank for 28 days before EDS analysis was done. The EDS results are shown in Fig. 4.13 to Fig. 4.18. The weight % and atomic % of various elements are shown in the Figures attached. From all the figures it can be seen that the major elements in the mixes are Si and Ca. The ratio of Si/Ca varied from 0.1 - 0.33 in all the mixes. It indicates that the use of BFS aggregates do not change the major chemical composition of the resultant mixture.

M1 SPECIMEN:

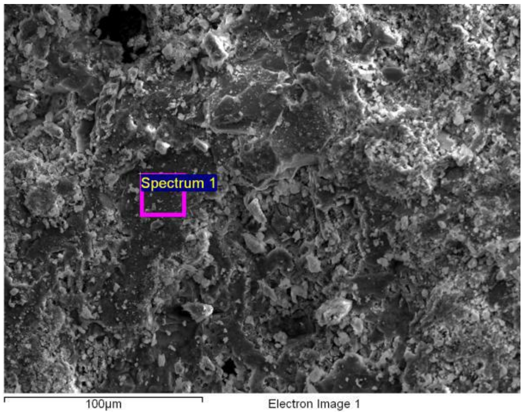


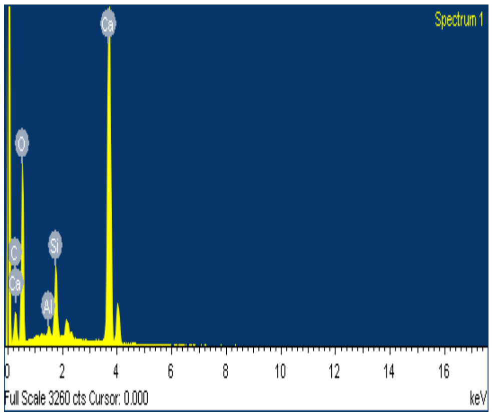


Element	Weight (%)	Atomic (%)
CK	6.11	10.95
OK	45.54	61.25
AlK	1.02	0.82
SiK	6.88	5.27
CaK	40.44	21.71
Total	100	

Fig. 4.13: EDS for M1 specimen after 28 days curing

M2 SPECIMEN:

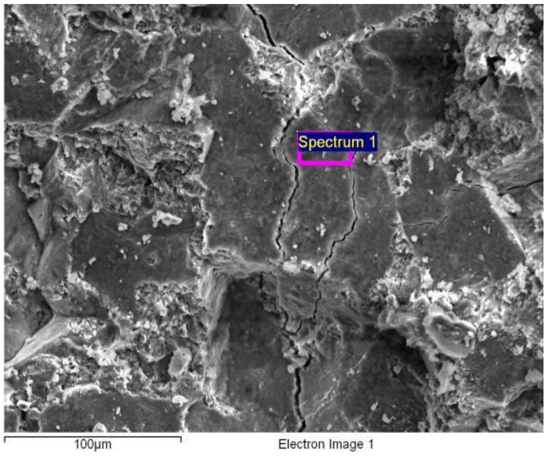


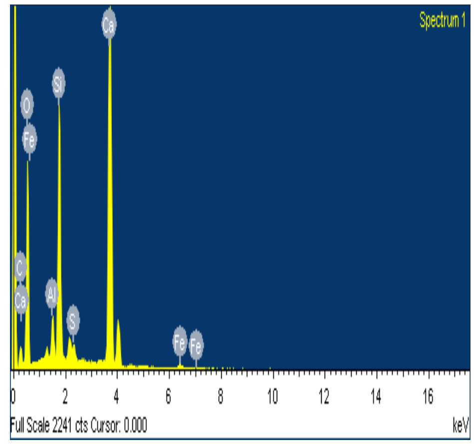


Element	Weight (%)	Atomic (%)
CK	5.14	8.82
OK	53.60	69.04
AlK	0.44	0.34
SiK	3.72	2.73
CaK	37.10	19.08
Total	100	

Fig. 4.14: EDS for M2 specimen after 28 days curing

M3 SPECIMEN:

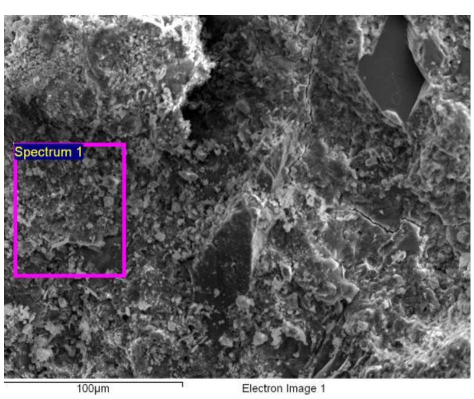


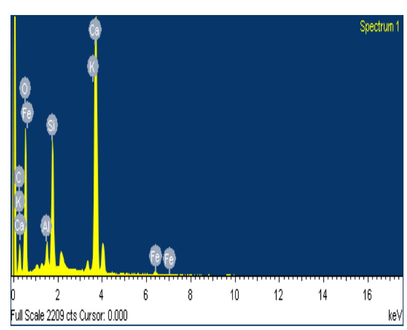


Element	Weight (%)	Atomic (%)
CK	4.02	7.16
OK	48.25	64.51
AlK	1.72	1.37
SiK	11.03	8.40
SK	0.57	0.38
CaK	33.28	17.76
FeK	1.12	0.43
Total	100	

Fig. 4.15: EDS for M3 specimen after 28 days curing

M4 SPECIMEN :

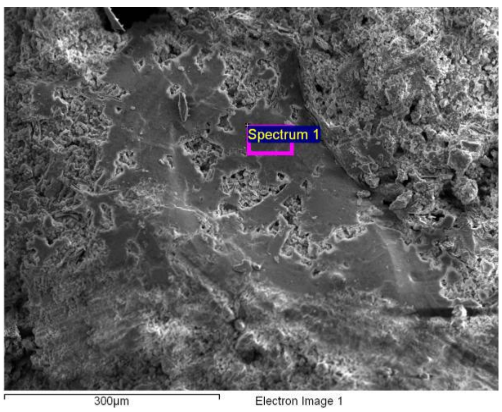


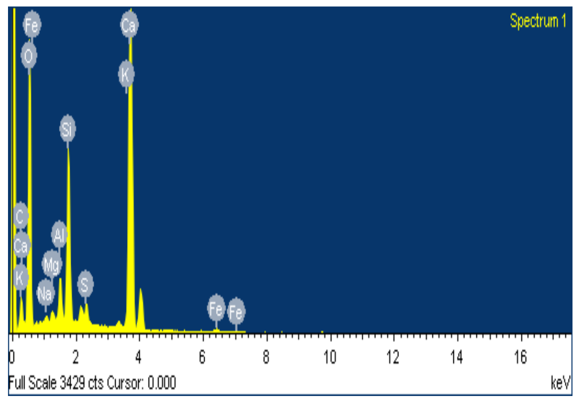


Element	Weight (%)	Atomic (%)
CK	1.87	3.37
OK	50.79	68.86
AlK	1.52	1.22
SiK	8.41	6.49
KK	1.13	0.62
CaK	34.97	18.92
FeK	1.32	0.51
Total	100	

Fig. 4.16: EDS for M4 specimen after 28 days curing

M5 SPECIMEN

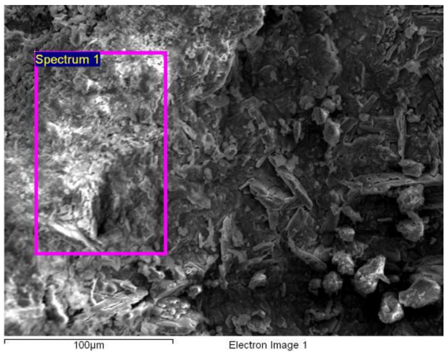


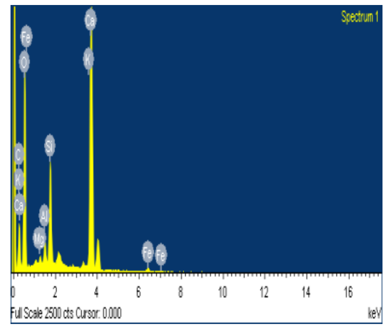


Element	Weight (%)	Atomic (%)
CK	1.64	2.82
OK	56.94	73.49
NaK	0.39	0.35
MgK	0.35	0.30
AlK	1.76	1.35
SiK	7.60	5.59
SK	0.90	0.58
KK	0.42	0.22
CaK	28.98	14.93
FeK	1.02	0.38
Total	100	

Fig. 4.17 EDS for M5 specimen after 28 days curing

M6 SPECIMEN:





Element	Weight (%)	Atomic (%)
CK	5.27	8.83
OK	55.69	70.11
MgK	0.44	0.37
AlK	1.19	0.89
SiK	5.50	3.94
KK	0.54	0.28
CaK	30.11	15.13
FeK	1.26	0.45
Total	100	

Fig. 4.18: EDS for M6 specimen after 28 days curing

4.6 RAPID CHLORIDE PENETRATION TEST (RCPT) RESULTS

4.6.1 Rapid chloride penetration test (RCPT)

The test was done for all the six concrete mixes replacing coarse aggregates with BFS aggregate at a period of 28 days.

Table 4.5: Chloride permeability of mortar mixes at 28 days

Mix Designation	Charge passed at 28 days	Permeability according to ASTM C1202
M1	2290	Medium
M2	2216	Medium
M3	2117	Medium
M4	2008	Medium
M5	2382	Medium
M6	2468	Medium

All the mixes have moderate permeability (coulombs between 2000 and 4000) as per ASTM C1202 as shown in Table 4.5. A decrease in coulombs value was observed in concrete mix M2, M3 and M4 as compared to mix M1 (control mix). In concrete mix M4, the coulomb value decreased by 12% at 28 days as compared to mix M1 which indicates that the microstructure of mix M4 is more denser in comparison to M1 control mix and the formation of CSH gel that fills the empty capillary voids within the hardened cement paste and thus refines the pore size distribution of the mix. Hence, it increases the strength as well as the durability performance also. The same trend has also been shown by the compressive strength results. Mix M6 shows the maximum value for the coulombs passed through the sample. There was increase in RCPT value at 28 days when compared to control mix. Since, the concrete mix M6 exhibits the maximum charge passed through it thus it can be concluded that M6 shows the lowest resistance to chloride ion penetration may be due to presence of voids and pores present in its microstructure as shown by SEM results also.

4.7 SORPTIVITY TEST RESULTS

In order to check the capillary suction, all the mixes were subjected to sorptivity test at 28 days of curing. The absorption is plotted as function of square root of time for the six concrete mixes and is shown in Fig. 4.19. The slope of the straight line that represents the relationship between the absorption and square root of time is defined as sorptivity. It is clearly indicated by this Fig. that M4 mix has the lowest sorptivity, followed by control specimens. M6 mix has the highest sorptivity. The difference in sorptivity values may be attributed to the difference in their pores characteristics. This may indicate that M4 and M1 concrete mix possess smaller capillary pores than M5 and M6. It was clearly visible in SEM pictures that M5 and M6 concrete mix has maximum number of pores. Sorptivity of control specimen (M1) cured for the age of 28 days was 0.030 mm/sec$^{1/2}$. Further to calculate the sorptivity coefficient, the best fit lines for data obtained at 350 minute of test were used. The best fit line and the corresponding slope of all the mixes is presented in Figures 4.19 to 4.24. The value of slope is taken as sorptivity coefficient and is presented in Table 4.6. In M4 sample, decrease in sorptivity value was observed while in M5 and M6, sorptivity get increased at 28 days.

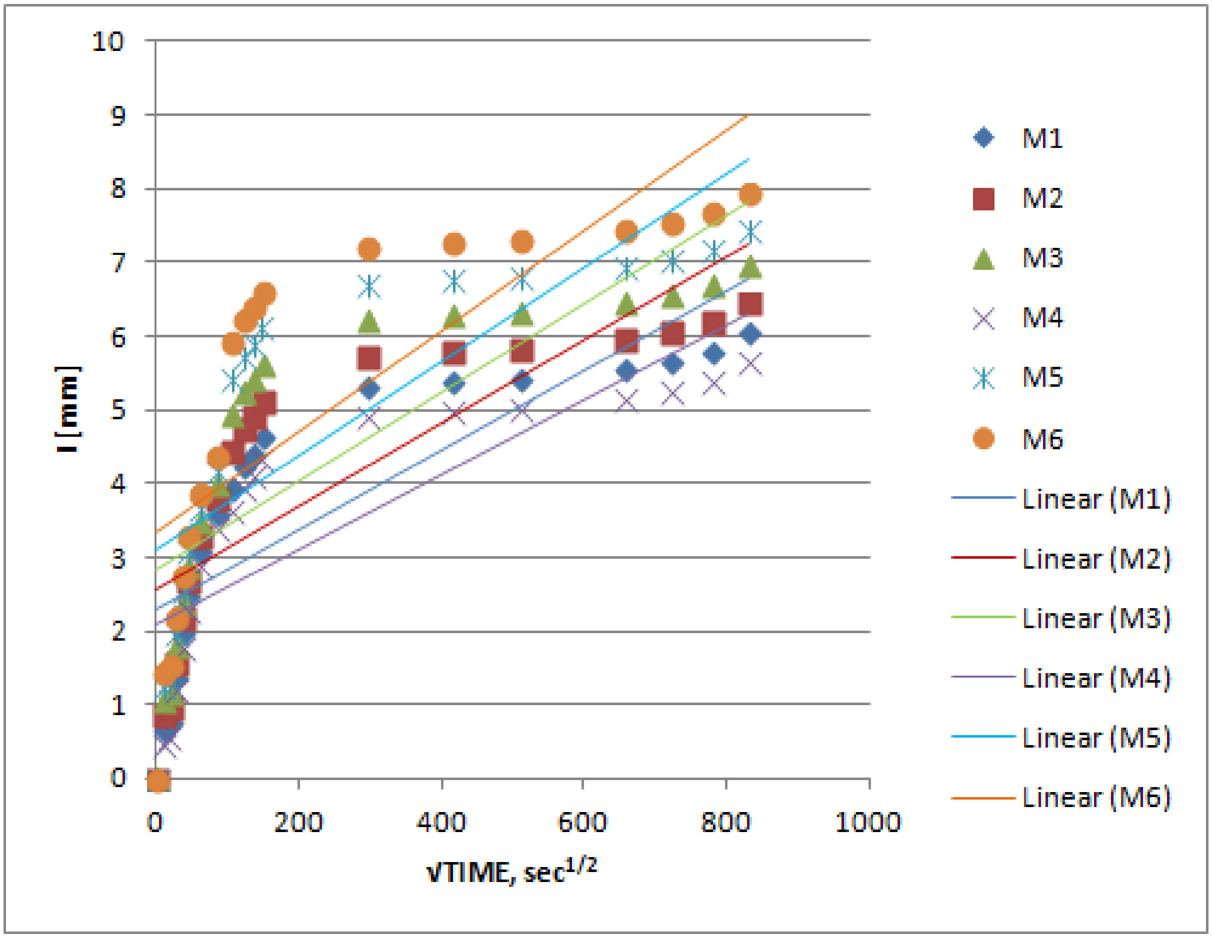


Fig. 4.19: Plot of absorption v/s time at 28 days

Table 4.6: Sorptivity coefficients for all mixes

Sr. No.	Sample	Sorptivity coefficients (mm/√s)
1	M1	0.030
2	M2	0.033
3	M3	0.036
4	M4	0.029
5	M5	0.039
6	M6	0.042

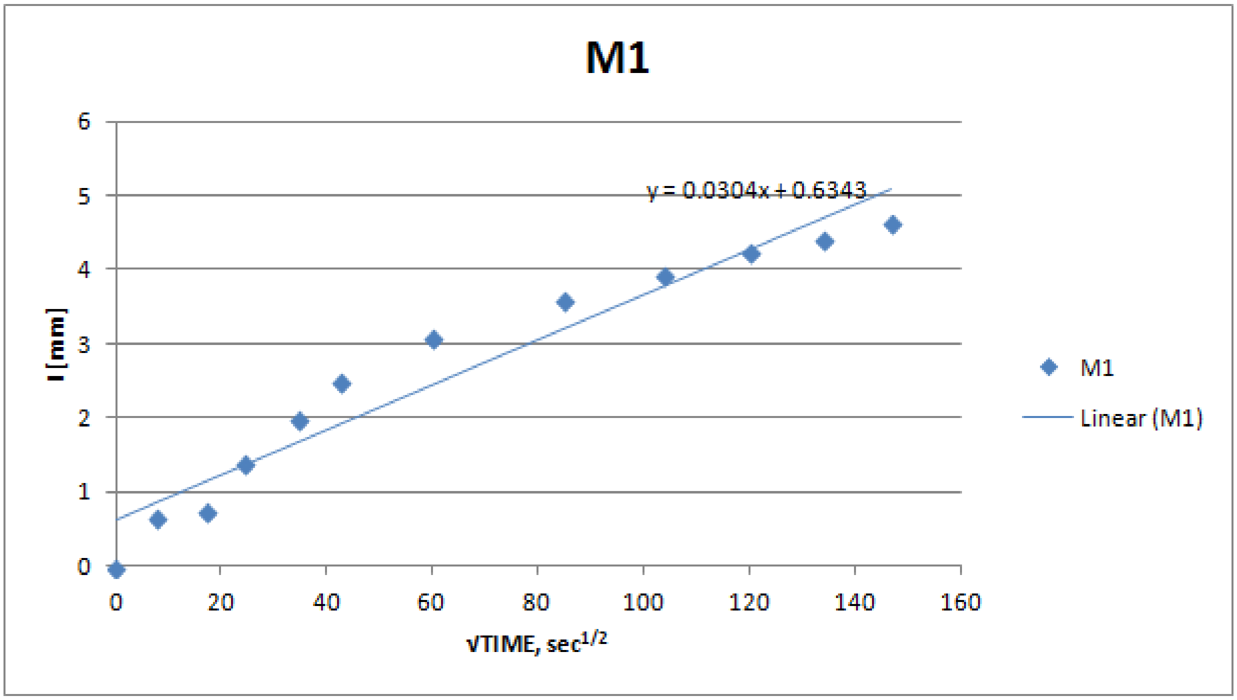


Fig. 4.20: Plot of absorption v/s time at 28 days for mix M1

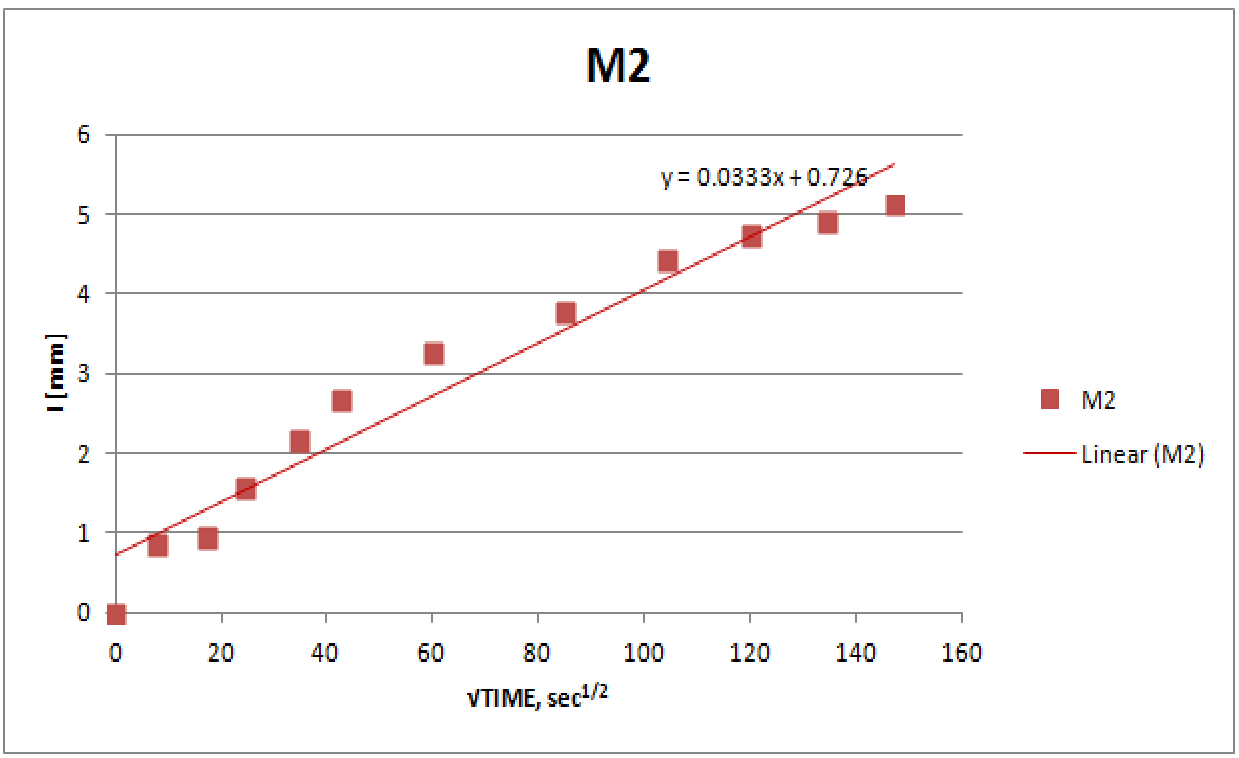


Fig. 4.21: Plot of absorption v/s time at 28 days for mix M2

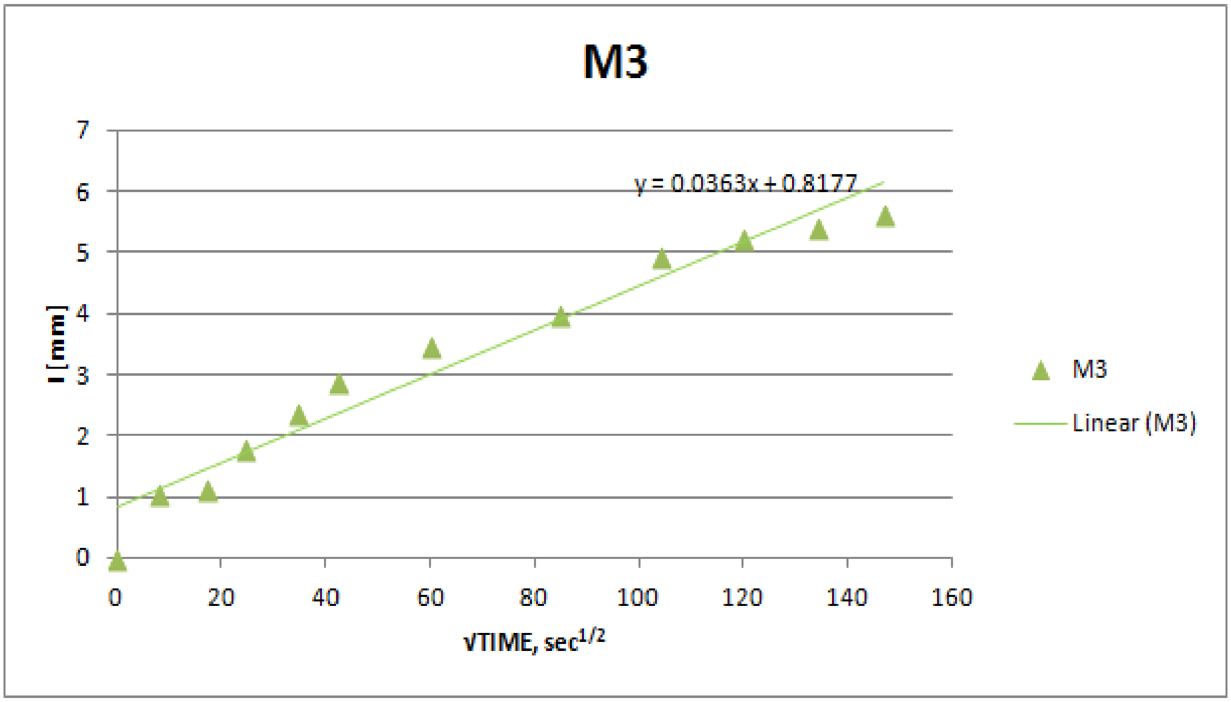


Fig. 4.22: Plot of absorption v/s time at 28 days for mix M3

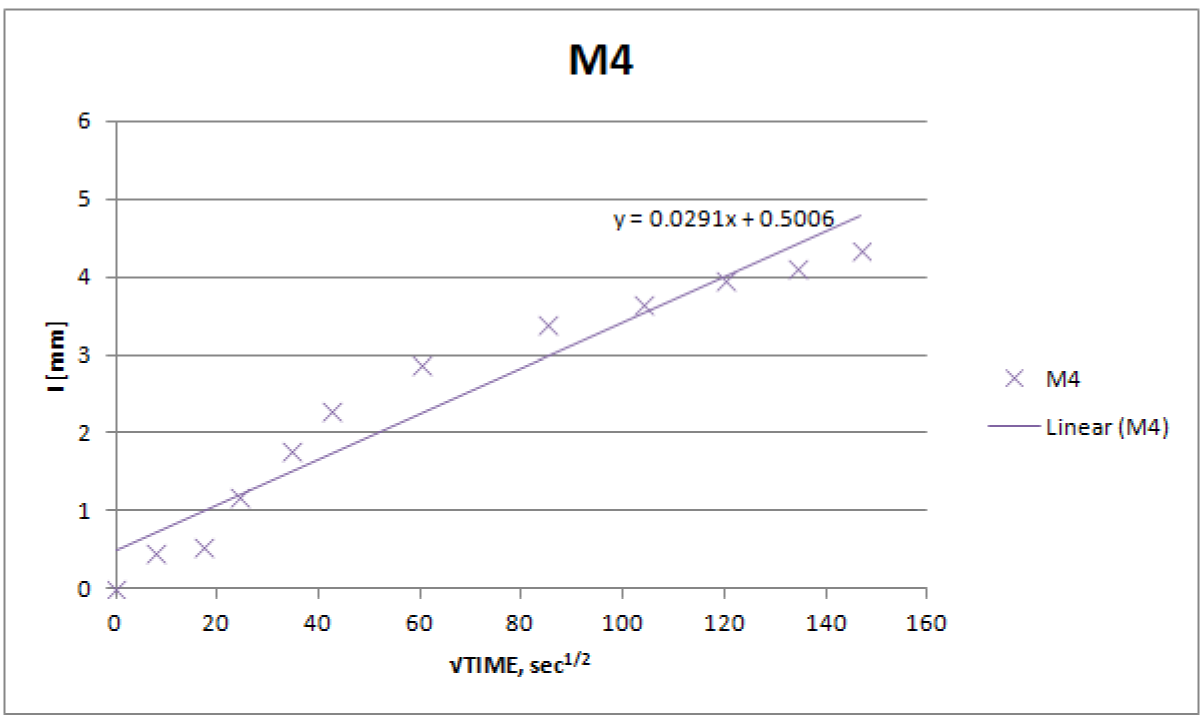


Fig. 4.23: Plot of absorption v/s time at 28 days for mix M4

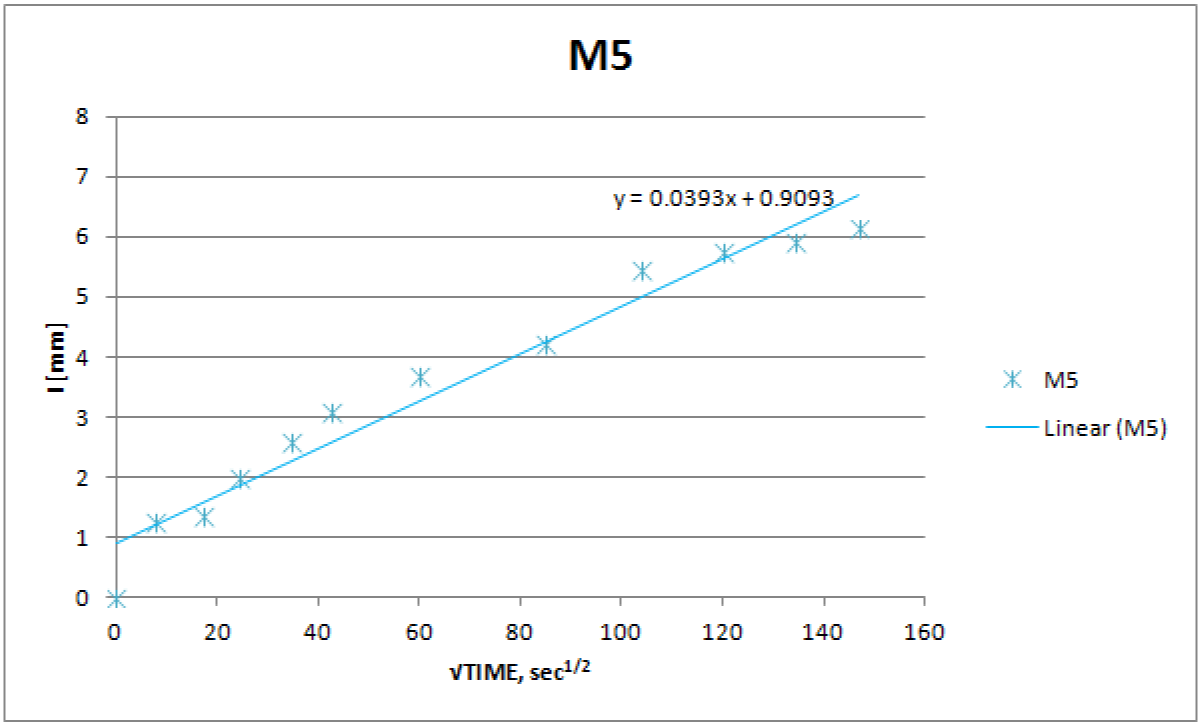


Fig. 4.24: Plot of absorption v/s time at 28 days for mix M5

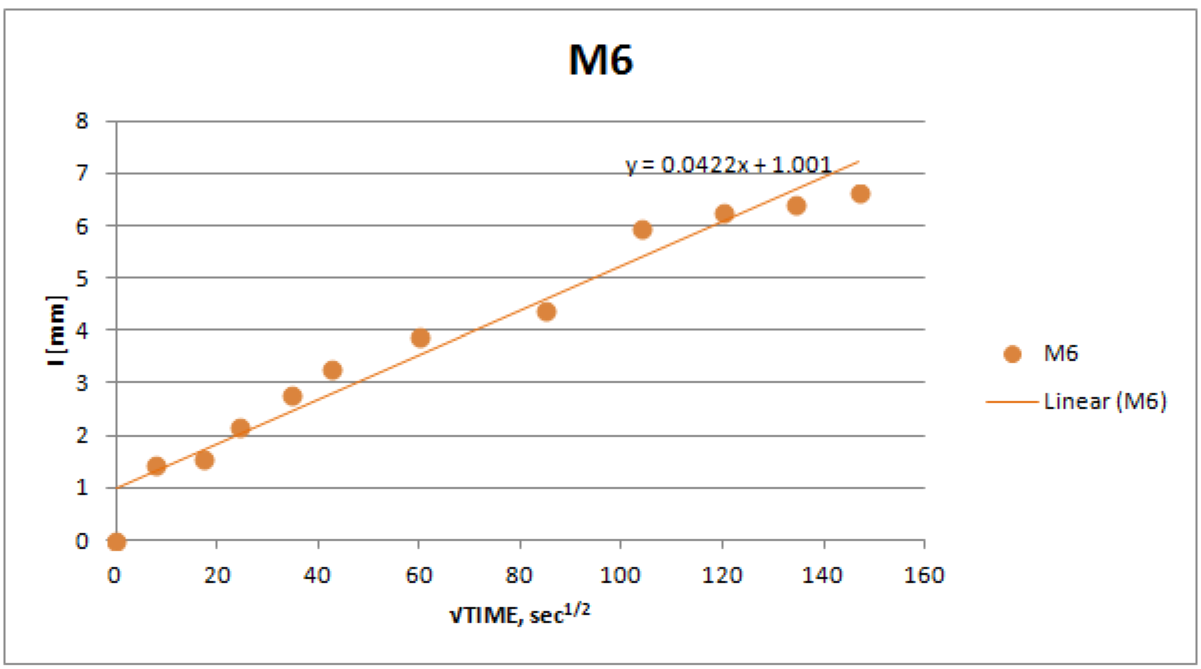


Fig. 4.25: Plot of absorption v/s time at 28 days for mix M6

4.8 X – RAY DIFFRACTION (XRD)

By using XRD technique we can examine the various crystalline phases of concrete such as ettringite & Calcium silicate, calcium alumina silicate hydrate, calcium hydroxide and calcite. The diffractogram is made up of succession of diffraction maximum points in which intensity of the diffracted radiation is plotted on the ordinate and angle 2 theta on abscissa. The diffraction image depends upon the material structure and every crystalline phase of concrete has its own diffraction image. The diffraction methods allows the study of the texture and shape of crystals, crystalline structures and the internal stresses acting the sample, phase quantitative & qualitative analysis, phase transformations etc.

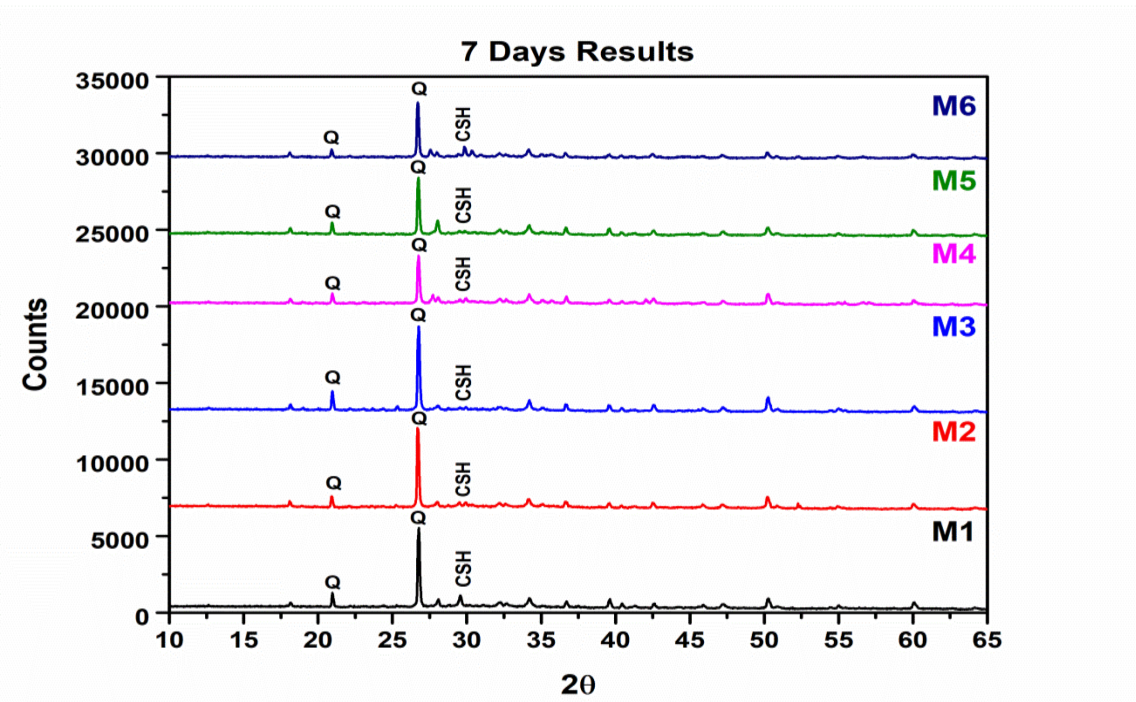


Fig. 4.26 XRD Spetrum of various concrete mix at 7 days

The various minerals are present in the concrete samples due to which the diffraction peaks of various minerals that are present in aggregate make interference with the peaks of poorly crystalline hydration phases of the concrete. The diffraction peaks of poorly crystalline CSH phase of concrete are weak. Fig. 4.26 and Fig. 4.27 represent the XRD spectrum for various mix at 7 days and 28 days respectively. The major phases observed in the concrete mixtures were Quartz, calcium silicate and calcium hydroxide. XRD analysis reveals that there is not any qualitative change in phases present in concrete on replacement of coarse aggregate with blast furnace slag aggregates.

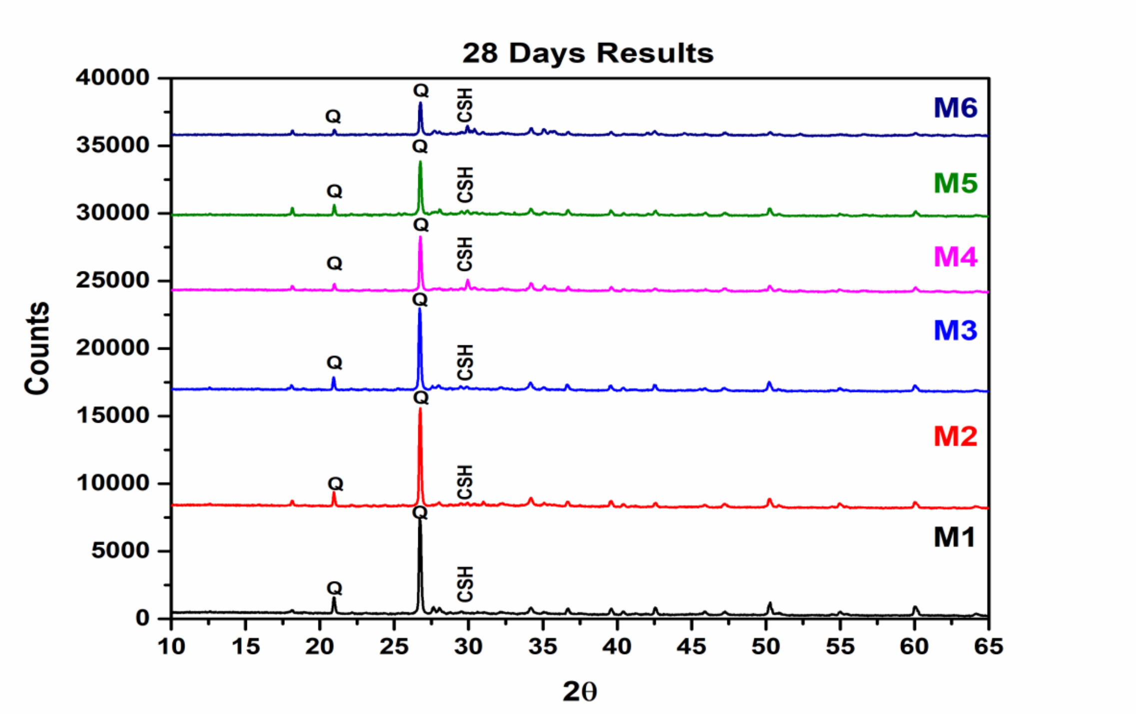


Fig. 4.27 XRD Spetrum of various concrete mix at 28 days

4.9 CONCLUDING REMARKS

In this chapter the findings of the experimental investigations were discussed. Different tests were performed to determine the blast furnace slag effect on strength and durability properties. SEM was also conducted for all the six mixes to analyze the microstructure of the mixes. In this investigation it was found that mortar mix showed considerable improvement on mechanical and durability properties in M4 mix when coarse aggregate was replaced with 60% of blast furnace slag aggregates.

CHAPTER - 5

CONCLUSION

5.1 CONCLUSION

Concrete is an age old material. Mainly it is constituted of cement , sand and aggregate made up of natural stone. In the present study, natural stone coarse aggregate was substituted with BFS aggregates in proportion of 0%, 20%, 40%, 60%, 80% and 100% in concrete. The various structural characteristics e.g. split tensile strength, compressive strength and durability properties of concrete were determined in the study. The following conclusion has been made from the present study.

- The maximum 28 days compressive strength of concrete was noticed to be 36.11 MPa when the coarse aggregate is replaced by Blast furnace slag upto 60% replacement level. only and shows the maximum compressive strength value of 36.11 MPa. However, when the BFS aggregate is further replace with coarse aggregates in various proportions such as 60% to 80% and 100% then the compressive strength shows the lower values of 31.73 MPa and 30.40 MPa respectively.
- The same trend was found to be followed by concrete mix M6 when split tensile strength test was done on it. The maximum value for tensile strength was found to be 3.9 MPa upto 60% replacement level only. However, the strength trend goes down when we increase the replacement level.
- The compact structure of M4 mix was further confirmed by SEM analysis also. Increased C-S-H was observed in this mix. While in other mixes, ettringites were observed which got deposited in pores resulting in increased porosity and reduced strength.
- All the mixes had medium permeability against chloride penetration. However, M4 mix has least chloride permeability, which indicates a dense matrix while M6 mix exhibits the highest value of RCPT (i.e. 2468 coulombs) at 28 days.
- M6 mix has the highest sorptivity while M4 has the lowest sorptivity. It indicates that M4 and M1 concrete mix possess smaller capillary pores than M5 and M6. It was clearly visible in SEM pictures also that M5 and M6 concrete mix has maximum number of pores.

5.2 FUTURE SCOPE OF WORK

- By using various combinations of concrete ingredients including supplementary cementitious materials and waste by-products of industries such as blast furnace slag, steel slag and copper slag as the partial or full replacement of usual aggregates, the eco-friendly and economical concrete of higher mechanical and durability properties can be manufactured.
- The work can also be extended to include the incorporation of different fibers into the GGBS concrete and see their effect on the strength development and durability characteristics.
- Other durability aspects like alkali aggregate reaction, acid attack and sulphate attack can be further studied by the use of combination of various slag as replacement of coarse aggregates.

5.3 CONCLUDING REMARKS

This chapter deals with the conclusions that were achieved by the results of strength and properties regarding concrete durability. Most important objective of the investigation was to reveal that the use of BFS aggregate as the replacement of coarse aggregate was beneficial. Inclusion of BFS aggregate as 60% replacement of coarse aggregates improved both the strength and durability properties. It was verified by SEM technique also.

REFERENCES

[1] Arivavalagan S. (2013) “Experimental study on the flexural behavior of reinforced concrete beams as replacement of copper slag as fine aggregate.” Civil Engineering and Urbanism; vol. 3; PP 176-182.

[2] ASTM 33 C, “Standard Specifications for concrete aggregates.” American Society for Testing and Materials International, West Conshohocken.

[3] ASTM 1202 C-97, “Standard test method for electrical induction of concrete, ability to resist chloride ion penetration.” American Society for Testing and Materials International, West Conshohocken.

[4] ASTM 1585 C-13, “Standard test method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes.” American Society for Testing and Materials International, West Conshohocken.

[5] Chunlin L., Kunpeng Z., Depeng D. and Chen C. (2011) “Possibility of concrete prepared with steel slag as fine and aggregates: A preliminary study.” Procedia Engineering; vol. 24; PP 412-416.

[6] IS: 383-1970: Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standard, New Delhi-1970.

[7] IS: 2386 (Part III)-1963: Method of Test for Aggregates for Concrete, Bureau of Indian Standard, New Delhi-1963.

[8] IS: 4031 (Part 6)-1988: Method of Physical Tests for Hydraulic Cement, Bureau of Indian Standard, New Delhi-1988.

[9] IS: 5816 –1970: Methods of Tests for splitting tensile strength of concrete cylinders, Bureau of Indian Standard, New Delhi-1988.

[10] IS: 8112–1989 (Reaffirmed 2005): Specification for 43 Grade Ordinary Portland Cement, Bureau of Indian Standard, New Delhi-2005.

[11] Khalifa S., Jabri Al., Abdullah H., Saidy Al., and Ramzi T. (2011) “Effect of copper slag as a fine aggregate on the properties of cement mortar and concrete.” Construction and Building Materials; vol. 25; PP 933-938.

[12] Khanzadi M. and Behnood Ali. (2009) “Mechanical properties of high strength concrete

incorporating copper slag as coarse aggregate." Construction and Building Materials; vol. 23; PP 2183-2188.

[13] Li G. and Zhao X. (2002) "Properties of concrete incorporating fly ash and ground granulated blast- furnance slag." Cement and Concrete Composites; vol. 25; PP 293-299.

[14] Li Q., Li Z. and Yuan G. (2012) "Effects of elevated temperature on properties of concrete containing ground granulated blast furnace slag as cementitious material." Construction and Building Materials; vol. 35; PP 687-692.

[15] http://www.wikipedia.org

[16] http://www.theconstructor.org

[17] http://www.sciencedirect.com

[18] http://www.elsevier.com

STRENGTH AND DURABILITY PROPERTIES OF CONCRETE INCORPORATING BLAST FURNACE SLAG AGGREGATE AS REPLACEMENT OF COARSE AGGREGATES

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

PAGE 43

PAGE 44

PAGE 45

PAGE 46

PAGE 47

PAGE 48

PAGE 49

PAGE 50

PAGE 51

PAGE 52

PAGE 53

PAGE 54

PAGE 55

PAGE 56

PAGE 57

PAGE 58

PAGE 59

PAGE 60

STRENGTH AND DURABILITY PROPERTIES OF CONCRETE INCORPORATING BLAST FURNACE SLAG AGGREGATE AS REPLACEMENT OF COARSE AGGREGATES

ORIGINALITY REPORT

16%	10%	11%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.nbmcw.com Internet Source	1%
2	Li, Qingtao, Zhuguo Li, and Guanglin Yuan. "Effects of elevated temperatures on properties of concrete containing ground granulated blast furnace slag as cementitious material", Construction and Building Materials, 2012. Publication	1%
3	Elsharief, A.. "Influence of lightweight aggregate on the microstructure and durability of mortar", Cement and Concrete Research, 200507 Publication	1%
4	www.europment.org Internet Source	1%
5	Chunlin, Liu, Zha Kunpeng, and Chen Depeng. "Possibility of Concrete Prepared with Steel	1%

Slag as Fine and Coarse Aggregates: A Preliminary Study", Procedia Engineering, 2011.
Publication

dspace.thapar.edu:8080 — 1%
Internet Source

Green Energy and Technology, 2013. — 1%
Publication

Al-Jabri, K.S.. "Effect of copper slag as a fine aggregate on the properties of cement mortars and concrete", Construction and Building Materials, 201102 — 1%
Publication

Submitted to University of Brighton — <1%
Student Paper

Submitted to Institute of Technology, Nirma University — <1%
Student Paper

www.i-scholar.in — <1%
Internet Source

Submitted to National Institute Of Technical Teachers' Training & Research — <1%
Student Paper

Li, G.. "Properties of concrete incorporating fly ash and ground granulated blast-furnace slag", Cement and Concrete Composites, 200304 — <1%

Publication

www.rjpbcs.com
Internet Source
<1%

Submitted to Higher Education Commission Pakistan
Student Paper
<1%

Submitted to Jaypee University of Information Technology
Student Paper
<1%

Khanzadi, M.. "Mechanical properties of high-strength concrete incorporating copper slag as coarse aggregate", Construction and Building Materials, 200906
Publication
<1%

Submitted to Guru Nanak Dev Engineering College
Student Paper
<1%

www.ijirem.org
Internet Source
<1%

Nasir, Muhammad Amoudi, Omar S. Baghabra. "Effect of casting temperature on strength and density of plain and blended cement concretes prepared", Construction and Building Materials, June 1 2016 Issue
Publication
<1%

Almusallam, A.A.. "Effect of silica fume on the mechanical properties of low quality coarse aggregate concrete", Cement and Concrete Composites, 200410 <1%

Publication

Submitted to University of East London <1%

Student Paper

Submitted to Institute of Graduate Studies, UiTM <1%

Student Paper

Submitted to Visvesvaraya Technological University <1%

Student Paper

www4.uwm.edu <1%

Internet Source

ljs.academicdirect.org <1%

Internet Source

Ramezanianpour, A.A., M. Esmaeili, S.A. Ghahari, and M.H. Najafi. "Laboratory study on the effect of polypropylene fiber on durability, and physical and mechanical characteristic of concrete for application in sleepers", Construction and Building Materials, 2013. <1%

Publication

www.ipublishing.co.in <1%

Internet Source

www.veoliatrust.org

Internet Source

<1%

www.deepdyve.com
Internet Source

<1%

espace.library.curtin.edu.au
Internet Source

<1%

Tiwari, Anshuman, Sarbjeet Singh, and Ravindra Nagar. "Feasibility assessment for partial replacement of fine aggregate to attain cleaner production perspective in concrete: A review", Journal of Cleaner Production, 2016.
Publication

<1%

Submitted to Indian Institute of Technology Roorkee
Student Paper

<1%

Submitted to University of Sheffield
Student Paper

<1%

lrd.yahooapis.com
Internet Source

<1%

scholarcommons.usf.edu
Internet Source

<1%

Submitted to Curtin University of Technology
Student Paper

<1%

Submitted to Universiti Malaysia Pahang
Student Paper

<1%

Submitted to Universiti Tunku Abdul Rahman — <1%

Student Paper

Devi, V. Subathra, and B.K. Gnanavel. "Properties of Concrete Manufactured Using Steel Slag", Procedia Engineering, 2014. — <1%

Publication

Shafiq, Nasir Nuruddin, Mudh. Fadhil Kha. "Calcined kaolin as cement replacing material and its use in high strength concrete. (Abstract)", Construction and Building Materials, April 15 2015 Issue — <1%

Publication

asiyan.ksu.edu.tr — <1%

Internet Source

Submitted to Nanyang Technological University, Singapore — <1%

Student Paper

Springer Atmospheric Sciences, 2016. — <1%

Publication

Submitted to Jawaharlal Nehru Technological University — <1%

Student Paper

Dave, Niragi Misra, Anil Kumar Srivastav. "Experimental analysis of strength and durability properties ((j) crossmark of quaternary cement bind", Construction and — <1%

Building Materials, March 15 2016 Issue
Publication

www.irjet.net
Internet Source

<1%

Aguilar, R. Arellano Diaz, O. Burciaga G. "Lightweight concretes of activated metakaolin-fly ash binders, with blast furnace slag aggregates.(R", Construction and Building Materials, July 2010 Issue
Publication

<1%

Chithra, S. Kumar, S.R.R. Senthil Chinna. "The effect of Colloidal Nano-silica on workability, mechanical and durability properties of High Per", Construction and Building Materials, June 15 2016 Issue
Publication

<1%

Salih, Moslih Amer Farzadnia, Nima Ali, . "Development of high strength alkali activated binder using palm oil fuel ash and GGBS at ambient tem", Construction and Building Materials, Sept 15 2015 Issue
Publication

<1%

Submitted to B.S. Abdur Rahman University
Student Paper

<1%

data.epo.org
Internet Source

<1%

Submitted to Napier University
Student Paper

<1%

Ravinder Kaur Sandhu, Rafat Siddique. "Influence of rice husk ash (RHA) on the properties of self-compacting concrete: A review", Construction and Building Materials, 2017
Publication

<1%

Murari, Krishna, Rafat Siddique, and K. K. Jain. "Use of waste copper slag, a sustainable material", Journal of Material Cycles and Waste Management, 2015.
Publication

<1%

etd.lib.metu.edu.tr
Internet Source

<1%

www.scribd.com
Internet Source

<1%

www.ijrat.org
Internet Source

<1%

www.geopolymer.org
Internet Source

<1%

Siddique, Rafat Kaur, Gurwinder Kunal. "Strength and permeation properties of self-compacting concrete containing fly ash and hooked steel f", Construction and Building

<1%

Materials, Jan 30 2016 Issue
Publication

www.researchtrend.net
Internet Source
<1%

docs.oracle.com
Internet Source
<1%

www.iosrjournals.org
Internet Source
<1%

ijartet.com
Internet Source
<1%

Pathak, Neelam Siddique, Rafat. "Effects of elevated temperatures on properties of self-compacting-concrete containing fly ash and sp", Construction and Building Materials, Sept 2012 Issue
Publication
<1%

Ma, Qianmin Guo, Rongxin Zhao, Zhiman Li. "Mechanical properties of concrete at high temperature--a review.(Abstract)", Construction and Building Materials, Sept 15 2015 Issue
Publication
<1%

www.irbnet.de
Internet Source
<1%

wlv.openrepository.com
Internet Source
<1%

file.scirp.org
Internet Source
<1%

www.concretesociety.org.nz
Internet Source
<1%

espace.curtin.edu.au
Internet Source
<1%

mie-u.repo.nii.ac.jp
Internet Source
<1%

www.rroij.com
Internet Source
<1%

prr.hec.gov.pk
Internet Source
<1%

Siddique, R.. "Properties of concrete incorporating high volumes of class F fly ash and san fibers", Cement and Concrete Research, 200401
Publication
<1%

Paratibha Aggarwal, Rahul Pratap Singh, Yogesh Aggarwal. "Use of nano-silica in cement based materials—A review", Cogent Engineering, 2015
Publication
<1%

Wafa, M. A., and K. Fukuzawa. "Simultaneous effect of alkali activator and water/slag cement ratios on composites properties by full
<1%

replacement of Portland cement", Journal of Composite Materials, 2014.
Publication

digital.library.unt.edu
Internet Source

<1%

Exclude quotes On

Exclude bibliography On

Exclude matches < 8 words